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Introducing Fly Ash into LSI's Recipe

Andrew Mathias Beckrich
Minnesota State University - Mankato

Introducing Fly Ash into Landscape Structures' Precast Recipe

By

Andrew Beckrich

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<u>Chapter 1: Introduction and Problem Statement</u>

Chapter 1.1: Problem Statement

There has been published data that states that concrete producers can use Fly Ash as an alternative to Portland cement and still generate similar or better strength properties. By applying these principles to our industry and products, what new processes will need to be put in place and followed? What is the correct combination/portion of Fly Ash that will produce similar and better results as well as the adjusted new recipes? What type of cost is associated with the introduction of this new ingredient? Lastly, how does this affect the quality and reputation of Landscape Structure's product?

Chapter 1.2: Background

Landscape Structures Inc. (LSI) is a park and playground equipment manufacturer based out of Delano, MN. The mission statement states, "Landscape Structures is the premier provider of innovative playground equipment and is committed to creating inspiring play experiences for children while honoring the environment. From personalized playground design to custom-designed play structures, they offer commercial playground equipment that is artful, safe, and most of all, made for years of fun." (Playlsi.com)

Steve and Barb King founded this company in 1971 in their garage. Since then, they have grown to over 300 employees and have sold more than 50,000 playground structures with the same motto: "Our highest purpose is to make a difference in the world – create a better place for children and families." (Barb King)

The Glass Fiber Reinforced Concrete (GFRC) production plant has been redesigned and built this last year (2011) to overcome barriers with their previous methods. LSI has substantially improved the layout and overall process to the concrete division by reducing cycle times, inventory levels, and labor required for successful completion. GFRC has had technological breakthroughs within the industry which has made the products creative, fun, and competitive within the market. The increase of interest and demand accompanied by these breakthroughs has provided the initiative to design and produce the plant and to look over all the processes involved.

The company has experienced growth and is producing "continuous play" themed equipment globally. Landscape Structures has adopted the "Toyota Production System" and has incorporated the Lean Manufacturing principles within all of its plants. The company has implemented a variety of methods to continuously improve itself with the goal of reducing waste and cost to manufacture, while increasing quality and delivery expectations. It has improved its production style from a batch plant system to a more flexible "pull" type system. The batch system is where the plant produces X number of type A products on day one, Y number of type

B products on day two, and so on; while “pull” increases the flexibility of the variety of products it can produce.

The pictures below show some of the variation GFRC is capable of.



Figures 1-3 - (Left to Right: The Pinnacle, Tree Climb, Mushroom Steppers)

Chapter 1.3: Importance

The owner of the company, Steve King, has expressed that he believes GFRC and the pre-cast division is going to highly increase in demand over time. We have shown an increase in demand in the GFRC division and have been continually expanding our product variety. Mr. King wants to continue children’s learning by allowing them the ability to play on natural looking equipment where they can learn about the environment through play. Mr. King has decided to fund the expansion of GFRC so that the company can facilitate growth.

Steve King and Pat Faust (President) have expressed their views that Landscape Structures should always be on the lookout for any opportunity available to help give them a competitive edge. They realize that material costs are increasing with today’s market and that they should analyze the supply chain of our operation. One of our biggest costs that go into our mix is the Portland cement. Studies have shown that a concrete producer can replace a portion of their Portland cement with Fly Ash and still receive similar strength ratios.

Since our corporate goal, like any other company, is to reduce operating costs, this is a strong initiative that I would like to investigate further. Studies have shown that not only does Fly Ash keep strength properties while mixed with Portland cement, but can be manufactured and bought at a fraction of the cost compared to Portland cement alone.

In addition to cost reduction in materials, LSI has a corporate goal for continuing to show the incentive to stay green. Since they are a recreational playground manufacturer, the community expects to see environmentally friendly products being produced from us that are non-hazardous to the community. This would allow us to stay friendly with our output while allowing us to be friendlier with our input.

The big question now, is how can we incorporate this into our processes? Bringing in another material will cost the company money in two ways. First, we need to study the background of Fly Ash and understand what new chemicals we are going to be introducing. We will need to verify that these materials are safe for us to use and that the product will have no ramifications to the community including the kids playing on them. We will need to quote out what additional equipment, storage, and delivery patterns we will need to ensure we have a supply. Also, we will need to analyze cost associated with figuring out the "right" combination to our recipe. These costs include: research and development, validation testing, process development, documentation, and rollout. We will then weigh the pros and cons and determine if this environmentally friendly substitute is worth pursuing.

Chapter 1.4: Deliverables

Deliverables are important to benchmark improvement of the proposed alternative to current conditions. With the deliverables, we can not only compare current standards and costs in the future, but also provide a new documented benchmark on where to start continuous improvement principles and programs going forward.

This project is worth investigating because the costs and benefits of going green are too substantial to overlook. This will be ground breaking to the industry because Landscape will be leading the innovation. While other concrete manufacturers in separate industries like architecture and landscaping have been known to use this technique, no company in recreational playground parks has made this step.

Our recipe has been specifically designed to sustain safe strength levels for kids to play on. GFRC has been able to track performance that shows their processes are within control. This means that they will have a strong benchmark to compare to going fourth.

The categories are subject to change as the case study progresses, but what this study hopes to create and produce is:

- Design of experiments that compares the current process of mixing to alternative ways to maximize potential.
    - This will include a step by step process that can be followed to produce replicable results of the desired process.
- A new validated recipe involving the addition of Fly Ash into the concrete mix if the outcome is successful.

- Cost justification so that management can make an educated business decision which will include:
  - Tensile and compression strengths compared to current standards at different percentages
  - The investment of capital, materials, and time to bring in-house
  - Cost comparison between Fly Ash and Portland cement including ROI
  - Defect, obsolescence, and long term wear
  - Analysis of the green initiative to the industry
  - Product time to market improvement
- This study’s recommendation and analysis of the data presented will be submitted to management so they will have engineering support.

Chapter 2: Literature Review

Chapter 2.1: Steam Cure and Hydration Process

Curing concrete and finding the adequate environment is a huge focus to ensuring product life-cycle. "Curing has a strong influence on the properties of hardened concrete; proper curing will increase durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing and de-icers" (Hanson). When Portland cement is mixed with water, a chemical reaction called hydration begins. A moist, warm environment is necessary to successfully cure concrete products. Accelerated curing hastens the hydration process so that concrete strengths can be reached more quickly, rather than waiting the entire 28 days. Autoclaves tend to have a high cost associated with them, so steam and dry heat have been the method of choice.

Improvement is rapid at the early stages but continues indefinitely slower after the initial cure. The strength of the concrete depends on the amount of crystal growth within the concrete matrix. When hydration occurs, crystals begin to grow because of the chemical reaction between the Portland cement and the water. If the water is not adequate, the crystals cannot grow and strength will not be achieved. The crystals are important because they serve as the bond within the exothermic reaction that "weaves" the ingredients together and provides it strength. It is important to maintain proper curing temperatures; otherwise the hydration reaction will be affected. If the concrete is too hot, the reaction will become too rapid not giving the crystals the chance to properly grow. The high temperature differentials will end up causing small cracks (hairline fractures) within the concrete, leaving it brittle. Inversely, if the cure is too wet, a porous concrete structure can be formed. This will cause the structure to become weak and give it soft spots. The affects of humidity, circulation, insulation, and time control all have direct influence to the overall strength and integrity of the concrete (Brighthub).

According to Mel Marshall P.E., the owner of Mel C. Marshall Industrial Consultants Inc., "18F in curing temperature doubles the rate of hydration. The higher the curing temperature, the more accelerated the hydration process and the more rapid the strength gain." He tells us that dry heat can be effective during the curing process as long as the environment is humid enough to ensure moisture doesn't evaporate from the product while curing.

According to Calvin McCall, manager of technical services for Blue Circle Cement in Charlotte, N.C., "If adequate moisture isn't maintained in the curing environment, the concrete won't develop maximum compressive strength, and cracking may occur." Three methods are typically used to accelerate cure times:

1. Discharging steam of hot air directly into the curing environment.

2. Enclosing steam of hot water pipes, which heats the concrete by convection and radiation.
3. Attaching electrical resistance wires to the forms and covering them with insulation, which heats the product by heating the forms.

Generating steam and introducing it into the environment is generally the most widely used method to decrease cure times. It's an efficient method that raised the temperature and maintains 100% humidity around the product. Boilers that are run off diesel are the preferred cost-effective way to accomplish this.

One last important factor that needs to be understood is the effects of a preset. "Research shows that strength losses can occur if concrete is heated excessively prior to attaining initial set" (Calvin McCall). Initial set can be detected by monitoring the internal temperature of the concrete. An increase in temperature indicates that initial set has occurred and hydration has begun.

Chapter 2.2: Fly Ash Introduction

Concrete, which is typically comprised of Portland cement, pea rock, sand, and water, has had a long history building the most important and influential structures. The addition of Fly Ash has been utilized as early as the 1930's to increase physical and aesthetic properties. The earliest significant use of Fly Ash to the construction industry was the Hungry Horse Dam in 1948 (U.S. DOT), utilizing 120,000 metric tons of Fly Ash. This opened the door and paved the way for using Fly Ash as an admixture in concrete construction. However, the last 20 years has peaked the interest of studying the effects of Fly Ash.

Fly ash is a residue that is generated during the combustion of ground or powdered coal. Fly Ash is a by-product of coal fired electric generating plants. The ash that settles to the bottom of the chamber, called bottom ash, is mixed with the fine particles that rise with the flue gases and caught by particle filtration units. Mixed together, the two ashes combined is called coal ash. Coal ash, consisting mostly of silica, alumina, and iron, forms a compound similar to Portland cement when mixed with lime and water. The combination between the two is what is used in the industry.

Companies now sell concrete mixtures with and without Fly-Ash, typically at the same cost. The consumer can choose to utilize the beneficial characteristics of the admixture or choose to bypass. Consumers can also purchase raw Fly Ash to be used in their own mixture at a fraction of the cost. Most distributors, however, are located on the west coast, so transportation costs could negate the price break.

Chapter 2.3: Classifications of Fly Ash

There are two major classes of Fly Ash that are studied and used. The first is Class C and the second is Class F. The two major classes are based off of their chemical composition resulting from the type of coal burned.

Class C is relatively young in the industry as an alternative to Portland but is beginning to gain interest. It is produced by burning younger lignite or subbituminous coal giving it a light tan color. Class C Fly Ash has cementitious properties and has shown the ability to harden and gain strength over time. The content for this type shows a high lime concentration at over 20%. Alkali and sulfate (SO_4) contents are generally higher in Class C Fly Ashes.

Class F, grey in color, has a long record of use in the industry and has withstood the test of time. It is produced by burning anthracite or bituminous coal and has little cementitious properties. Class F has higher pozzolanic properties which will allow the concrete to continue gaining strength even after the 28 day cure cycle; studies have shown higher compression strengths over time. Due to the properties, Class F increases the ability to resist attack from sulfates in the soil or ground water. Class F Fly Ash is particularly beneficial in high performance concrete applications where high compressive strengths are required or where severe exposure conditions demand highly durable concrete.

Chapter 2.4: Environmental Concerns for Fly Ash

Worldwide, the manufacture of Portland cement accounts for 6-7% of the total carbon dioxide (CO_2) produced by humans. This is the equivalent of 330 million cars driving 12,500 miles per year (Build It Green). The cement is fired in a rotary kiln at approximately 2700$^{o\ F,}$ which consumes a huge amount of fossil fuels and produces high amounts of CO_2. The chemical reaction that occurs also creates CO_2 as a by-product. Since Fly Ash adds beneficial long-term strength properties to the product, the product can last longer reducing the demand for replacement and the natural resources needed to extract and process them.

In the past, the particles that rose with the gases were vented into the atmosphere. Due to regulations in the last couple decades, these particles have been labeled hazardous and capturing is required. There has been concern regarding the use of Fly Ash due to the hazardous content. The fine particles that rise with the gases have been determined to contain more hazardous material than the ash settled to the bottom. However, adding the two sources and mixing them together bring the proportion levels of contaminates to a qualifying range of non-hazardous thus allowing the U.S. EPA to indicate that there is not a health threat.

Typically, coal burning plants would recycle the coal ash to a landfill. Experts have raised concerns regarding the presence of heavy metals in the mixture. Others argue that the heavy metals are locked effectively within the cementitious matrix, preventing release. Furthermore, since the recycled ash is used in the concrete mixture, the possibility of hazardous materials leached into the environment is lower.

Additional research will need to be done to ensure safety for the audience our products are intended for. With the introduction of Fly Ash, there also comes introduction of heavy metals, that by itself would be hazardous to people.

Chapter 2.5: Fly Ash Characteristics

Since the high interest in using Fly Ash is to improve properties, we have discovered a number of benefits. Fly ash has a composition of tiny spherical shaped particles that allow the small voids in cement to be filled, requiring less water. Since the voids are replaced with material that has cementitious properties, the overall product becomes denser. Its density allows it to be less permeable to water and protects it from erosion, leaving an overall smoothness improvement to its finished surface.

Fly ash, as an additive, makes the hydration reaction temperature lower, resulting in reducing shrinkages and thermal cracking. As discussed before, the additional properties help the overall resistance to sulfate attack and alkali-aggregate reactivity as well. Fly ash also has a higher ultimate strength than conventional Portland which can allow the manufacturer to use less material to achieve similar strength properties.

Long term, the lower water content needed for mixture advocates less stress cracks due to environmental shifting. Overall this makes the final product significantly more durable.

Chapter 2.6: Compression and Tensile Strength Testing

Compression strength is the capacity of a material to withstand an axial inward force. When the limit of the material is reached, the material is crushed and the peak "resistance" force is captured. This test is typically done in a compression testing machine designed for tensile and compression testing. The compression test procedure typically utilizes a cylinder-like shape as shown on Figure 4 below. The bottom holder is stationary as the top compresses down on the material. Machines generally bring the load to the surface before applying force. The equation $\sigma = F / A$ is then used to calculate the strength.

Figure 4 – (Typical test apparatus for compression testing provided by http://www.asdu.ait.ac.th/NewsAndEvents/newsletterData/HTMLFormat/iss4no6/development.htm)

The flexural strength test is similar to the compression test. The flexural test determines the ability of the material to resist failure in bending. This test is also called the "Modulus of Rupture". The accepted dimensions for this test are for the span to be three times the depth. So if you have a 2-inch deep sample, you will want a 6 inch by 6 inch sample. With any good mix design, the flexural strength should be 12-20% of the overall compression strength. This test can utilize the same machine used in the compression test but with a different orientation as shown below.

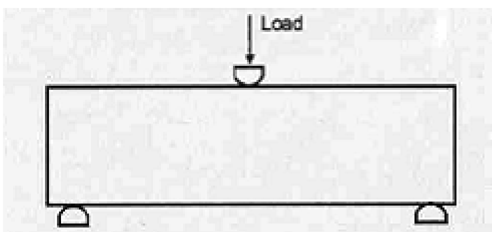


Figure 5 – (Typical test apparatus for flexural testing provided by http://www.cadman.com/section.asp?pageid=3148)

Chapter 2.7: Slump Testing

The concrete slump test is used to measure the consistency of fresh concrete. It tests the workability against the stiffness. The test is used to measure the effects of added plasticizers (Rheobuild). It is also used to control the amount of variability between individual batches. The test itself is rather easy. There are many different varieties of the test, so the one used in this study will be consistent across every test.

To properly measure the amount of "slump" in the concrete, a batch of concrete must be made first. The fixture used is a flat piece of Plexiglas with rings evenly spaced apart at 3/8" between them. The center ring, labeled "0", is the width of the cylinder that you fill with the current batch of concrete (it is important to note that the mixer is still in rotation as to not allow the concrete to set up. After the cylinder is full, one carefully lifts/removes the cylinder to allow the concrete to take shape, or slump. The width of the final diameter of the concrete determines the consistency and how liquid the concrete is.

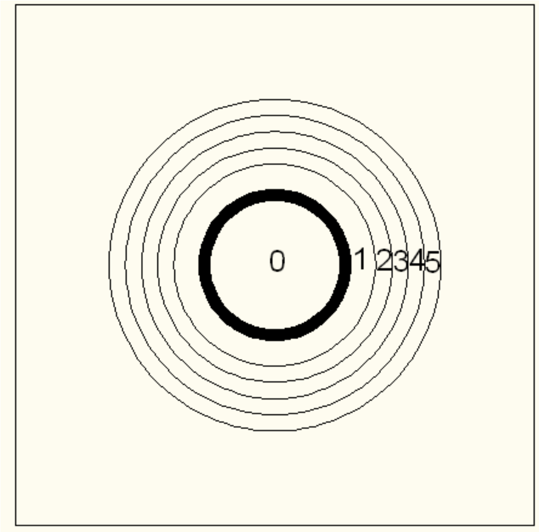


Figure 6 – (Slump test board used during slump test.)

If the concrete does not spread out to the 2-3 range, then the operator must add more Rheobuild. If the concrete goes past the 2-3 range, then the concrete should not be used because it is too liquefied. This means that the operator must try to stay on the low side and build their way up.

Chapter 2.8: Introduction to Design of Experiments

Design of Experiments (DOE) "is defined as the systematic procedure carried out under controlled conditions in order to discover an unknown effect, to test or establish a hypothesis, or to illustrate a known effect[1]" (Moresteam.com). To analyze an unknown process, experiments are used to evaluate the significant impact a process input has to it. DOE is utilized to reduce costs by speeding up the design process. Typical uses in manufacturing include reducing product material, labor complexity, minimizing process variation, reducing scrap rates and rework, and the need for inspection.

There are multiple components to the DOE process that should be clearly defined. Factors, levels, and responses are the three major components to any experimental design. Factors, often referred to as the inputs into the process are the controllable variables that the user intends to study. Take for instance the study of tool life in a machine shop. Let's say that the operator wants to find the best bit for the longest life while machining. The factors that could contribute to a longer life cycle could be material of the bit, being tungsten, diamond, or stainless steel. Additional factors could be the speed at which he drills into a known, consistent material, the angle at which he drills into material, and the waiting period between drilling operations. There could be many more factors in determining tool life, but for this example we are just going to focus on these. There are other factors that the operator cannot control called uncontrollable variables. These uncontrollable factors are also called noise factors. These could be the material properties of each bit and how they might have close, but different material proportions that could skew the data. Other noise factors could include temperature and humidity in the atmosphere that cannot be controlled. When doing these experiments, to offset the variability of unknown factors, the operator would want to try to eliminate all discrepancies by keeping every aspect consistent. By running the tool life test, to offset the noise factors the operator would want to run all tests on the same day, in the same shop, using the same tools, and take samples from the same batches.

Levels are the settings for each factor under study. As discussed before, the type of bit used, being diamond, tungsten, or stainless steel are all different levels. Additional levels could be 30º, 45º, and 60º cutting angles and speeds could be 1200rpm, 1400rpm, and 1600rpm. These levels being tested must be run at the same conditions as to expect unbiased results.

Lastly, the response is the output of the experiment that you are trying to optimize. This would be the life of the tool in minutes, days, or any length of time. The length of time is the measurable outcome potentially influenced by the factors at the given levels.

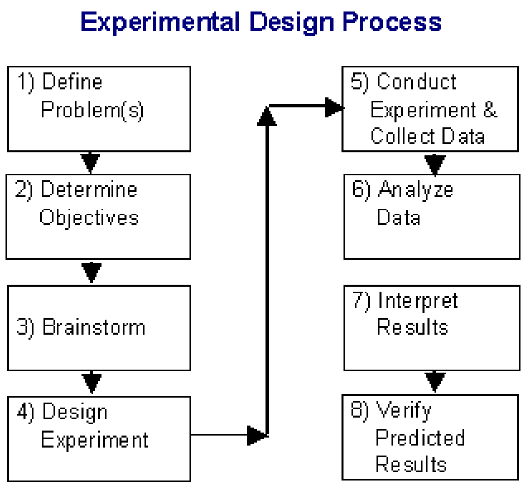


Figure 7 – (The experimental design process provided by Moresteam.com)

Chapter 2.9: Potential Traps of DOE

There are four potential traps that the operator running the tests needs to be aware of. These include measurement error, uncontrollable factors that induce variation, correlation without causation, and combined effects or interactions.

Measurement error can provoke unexplained error and could potentially obscure the results. Note that error is not another term for mistake, mistakes in testing procedures should negate the test being done and automatically qualify the user to redo the test. These measurement errors could be bad calibration in testing equipment. Even though the user may be using the same procedure, running the test multiple times will allow the user to see if the results are consistent.

Uncontrollable factors, or noise factors, should be accounted for such as multiple machines, multiple operators, multiple shifts, raw materials and so on. These should be accounted for before running the tests so that results are consistent with all the uncontrollable factors at that time. This is why it is imperative to keep outside factors the same. If one runs all the tests with the same humidity, assuming humidity plays the same role on each test, each outcome will have the same noise factor level and variation will be offset.

Next, correlation without causation is a trap many new operators fall into. As Dr. Chang used in his DOE class spring of 2011, a study was shown that ice cream sales were correlated to burglary rates in a given town. These two examples might show corresponding data but if one looks at the larger picture, there might be other factors involved. By keeping in mind relevance to the subject, the tester might realize that burglaries happen when it's not raining, or when it's warmer outside. This example highlights the importance of factoring in operational knowledge when designing an experiment.

Lastly, interactions between factors require more in depth thought before running experiments. Let's look at how many drinks it takes for a typical person to get drunk. For simplicity, let's take the number of drinks and correlate it to the percent blood-alcohol level. Even though it might take eight "shots" of alcohol to get a person legally drunk, if you look at the type alcohol consumed this might skew the data. If that person took eight shots of whiskey to get drunk one night, eight shots of vodka a separate night, it might only take six shots of the two combined to reach the same results. The mixing of the two alcohols might interact with the percentage making the response variable lower.

Chapter 3: Methodology

Chapter 3.1: Gathering Raw Materials for Testing

It is important to gather all "ingredients" or raw materials before beginning the test for the best ratio of Fly Ash. The current design recipe for Landscape Structures' concrete uses: Portland cement, fine silica sand grade 4075, ¾" rock, pea rock, softened city water at 60º, Rheobuild, and liquefied air. All of these ingredients must be from the same lot to ensure as little deviation as possible. This is important because LSI receives Portland cement in the most expensive form: 92lb bags. Brad Hotchkiss, a former Manufacturing Engineer at LSI, noticed that the slump test varied from lot to lot for the Portland cement but stayed consistent within the lot that was received. To eliminate this variable, it is important to make sure that all Portland cement used is from the same lot. This methodology will be used to gather all other ingredients. Since most of the ingredients are already on site, it will be ensured that there are adequate amounts for all testing without replacement.

For the Fly Ash received, this thesis will be studying Class F's effects on compression and flexural strengths because it has more material properties that we desire long term for our products as explained in the Literature Review Section (Chapter 2). Work with our purchasing manager to quote out and bring in Fly Ash will have to be done.

Chapter 3.2: Testing Levels and Sampling

For this test procedure, it can be read online and heard from concrete experts that a manufacturer can replace up to 50% of the Portland content with Fly Ash. The test will include Fly Ash concentrations at 0%, 10%, 15%, 20%, 25%, 30%, 40%, and 50%. Each level will require repetition to ensure accurate results; therefore, three cylinder samples will be produced of each.

Since LSI processes the concrete the day after its initial cure cycle with additional value added processes, it is important to make sure that the strength ratings of the cured concrete is strong enough to transport and work on during the entire life cycle of curing. This is why compression strengths will be taken at day one, day seven, day fourteen, and day twenty-eight. Concrete is said to be fully cured at ambient conditions after the 28^{th} day, therefore no further testing will be done afterwards. The 28^{th} day is when it is acceptable to ship the completed product to the customer.

To reiterate, the test will have eight different levels of concentration of Fly Ash from 0% to 50%, on four different time periods from one day to twenty-eight days, with three samples of each for a total of 96 samples.

Therefore, the amount of Fly Ash that will be needed for testing is shown in the table below. It is intended to proportionally replace total weight of Portland with Fly Ash. If the batch mixer takes 94 pounds of cement per batch, the following can be concluded:

Fly Ash %	Cement (lbs.)	Fly Ash (lb.)	Total
0%	94	0	94
10%	85	9	94
15%	80	14	94
20%	75.2	18.8	94
25%	70.4	23.6	94
30%	65.8	28.2	94
40%	56.4	37.6	94
50%	47	47	94

The summation of the third column, Fly Ash, is 178.2 pounds. Just as a safety stock number for possible testing in the future and learning curve for the proper mixing methods, 300 pounds will be brought in for testing. It may be more or less based on the quantities available.

The cylinder testing will look like this:

Day 1	Sample A	Sample B	Sample C	Average
0% (1)				
10% (2)				
15% (3)				
20% (4)				
25% (5)				
30% (6)				
40% (7)				
50% (8)				
Day 7	Sample D	Sample E	Sample F	Average
0% (1)				
10% (2)				
15% (3)				
20% (4)				
25% (5)				
30% (6)				
40% (7)				
50% (8)				
Day 14	Sample G	Sample H	Sample I	Average
0% (1)				
10% (2)				
15% (3)				
20% (4)				
25% (5)				
30% (6)				
40% (7)				
50% (8)				

Day 28	Sample J	Sample K	Sample L	Average
0% (1)				
10% (2)				
15% (3)				
20% (4)				
25% (5)				
30% (6)				
40% (7)				
50% (8)				

Next, after the best percentage of Fly Ash is found, based off of compression testing, the design of experiment will begin. This is where optimization of the Fly Ash will be done. This test will look at two different tests with three factors in each. This is where the mixing itself get taken into account to try and verify the best mixing method. The DOE will look this:

		+	-
A	Rotation Orientation	CW	CCW
B	Liquid Air	High	Low
C	Rotation RPM	High	Low

n =	3	K =	3

	A	B	C	Treatment Combination	I	II	III	Total	Average
1	-	-	-	-1				0	#DIV/0!
2	+	-	-	a				0	#DIV/0!
3	-	+	-	b				0	#DIV/0!
4	+	+	-	ab				0	#DIV/0!
5	-	-	+	c				0	#DIV/0!
6	+	-	+	ac				0	#DIV/0!
7	-	+	+	bc				0	#DIV/0!
8	+	+	+	abc				0	#DIV/0!
								0	#DIV/0!

After mixing parameters are met, the optimal recipe will be found by using a similar DOE.

		+	-
A	Water (lbs)	92	Low
B	Temp of Water (°F)	High	62
C	Rheobuild (oz)	10	Low

	n =	3	K =	3					
	A	B	C	Treatment Combination	I	II	III	Total	Average
1	-	-	-	-1				0	#DIV/0!
2	+	-	-	a				0	#DIV/0!
3	-	+	-	b				0	#DIV/0!
4	+	+	-	ab				0	#DIV/0!
5	-	-	+	c				0	#DIV/0!
6	+	-	+	ac				0	#DIV/0!
7	-	+	+	bc				0	#DIV/0!
8	+	+	+	abc				0	#DIV/0!
								0	#DIV/0!

After these tables are filled out, Mega Stat software in Excel will be used to analyze the results. The analysis will include variation and explanation of statistical analysis, effects estimate by percentage, regression model, and the optimal solution.

After a regression model for futuristic conditions is determined, it will be important for the test to be re-run for validity. This will be done by picking a random treatment combination and comparing expected to actual results. To make sure this is accurate and consistent; it will be made sure to set aside the ingredients from the same batch as to not allow any variation in the test.

Chapter 3.3: Mix Design

Since the introduction of Fly Ash allows less water concentration, it will be important to carefully ensure that all batches are as consistent as possible for the air entrainment and slump test. This is how control of the experiment's responses for the uncontrollable factors will be ensured. A meeting with LSI's mix designer, Mike Dorvel from BASF, will be needed to help with the adjustment of other ingredients to make sure a consistent batch is created each time.

As far as the mixing itself, the concrete production team will help with mixing the batches that are used for our test cylinders

.

Chapter 3.4: Compression Testing

The concrete filled cylinders will be tested onsite with our Foley Compression Tester. This tester is connected to a computer that outputs the data into a spreadsheet for viewing. The testing will be done on the appropriate days and recorded.

Chapter 3.5: Quoting Out to Bring In-House

After the results have been analyzed, cost analysis on bringing the operation in-house will occur. This will include an additional storage silo, construction on the building for an automated auger into the plant, controls update for our automated batch mixer, and material supply study. The silo's size will be determined by cost for each available silo and demand for material. Then this project will finish with a summary write up and proposal with recommendation to Landscape Structures, including all of the data gathered. The method for project approval and acceptable ROI will be studied before writing the final report.

Chapter 4: Results and Experiment Findings

Chapter 4.1: Gathering Raw Materials for Testing

Preparation for the experiment began by meeting with the materials manager at Landscape Structures. After explaining the project, it was asked of him to bring in 300 pounds of Class F Fly Ash. The preferred method would have been to get various samples from different suppliers to test consistency, but reassurance was found by the information the supply manager received in a memo:

"Coal Creek Fly Ash is the most widely used Fly Ash in Minnesota, North Dakota and South Dakota. This is primarily because it is the most consistent of any regional ashes and it tends to be in abundant supply."

This claim was reconfirmed by the BASF consultant who agreed with the decision for LSI's distributor. The next step was to receive the Fly Ash sample and gather enough of the remaining ingredients to ensure a consistent test. As stated before, one of the parameters required to keep consistency was the variation of material properties found from batch to batch. The production supervisor, who was in charge of stock material levels, ensured that there would be enough to make a minimum of eight batches (one for every input percent being tested).

Chapter 4.2: Precast Testing with Fly Ash Substitute

Chapter 4.2.1: Precast Testing with Fly Ash Substitute – Control Run (Current Practice)

Mike Dorvel (BASF Consultant), Brad Hotchkiss, and I met to discuss the scope of the project at hand and decided we needed to have the mix design planned before any mixing took place. We did not want to waste any time trying to figure out what proportions we needed to have while mixing. This was in an effort to keep noise factors such as time of day, humidity, and temperature consistent. Mike has been the mix designer since the concrete division started ten years ago, so he had previous experience, knowledge, and data relating to the current recipe. He had already designed a template that could be use to manipulate weights to quickly calculate the proportions.

The following table shows the current (now outdated) mix design.

Suggested Mix Design

Material	Weight lbs./CY	Specific Gravity	Abs. Vol. CF/CY	Trial Batch lbs./CF	Production Batch lbs/3.0 CF
Cement (Type I)	846.0	3.15	4.304	31.3	94.0
Silica Fume	0.0	2.20	0.000	0.0	0.0
Fly Ash	0.0	2.56	0.000	0.0	0.0
Coarse Agg. - Pearock	828.0	2.65	5.007	30.7	92.0
Coarse Agg Free Moisture	0.0	1.00	0.000	Incl in Stone	
Coarse Agg #2	864.0	2.71	5.109	32.0	96.0
Coarse Agg #2 Free moisture	0.0	1.00	0.000	Incl in Stone	
Fine Agg.	1098.0	2.65	6.640	40.7	122.0
Fine Agg. Free Moist.	0.0	1.00	0.000	Incl in Fines	
Add Water	323.6	1.000	5.186	12.0	36.0
Air Content		2.8%	0.754		
Totals =	3959.6		27.0		
w/c =	0.383				
Fine Agg Moisture =	0.0%		F100 Fiber at 3 oz./1.5 CF Batch.		
Coarse Agg Moisture =	0.0%				
Coarse Agg 2 Moisture =	0.0%				
Fines to total Agg. Ratio =	0.394				
Calculated Unit Weight =	146.65				
Theoretical Density (air free) =	150.86				
28 Day Strength =					

As shown, there are a few components that go into the precast mix. This includes cement, pea rock, 3/4" aggregate rock, fine aggregate (sand), and water. In addition to those ingredients, there are some additives. These additives were kept constant throughout the Fly Ash testing. These will be the subject of study in the second half of testing in this thesis. Based on the table above, there are specific components that were needed to keep consistent for a successful test. The first is the air content. That should stay as close to 2.5% as possible because that is the optimal range for the products. That percent can be found by the following equations:

Absolute Volume (CF/CY) = Weight (lbs. /CY) / (62.4*specific gravity)

Example: Abs. Vol. of Cement = 846 lbs. /CY / (62.4*3.15) = 4.3 CF/CY

Air Content = 27 CF/CY - ∑ Absolute Volume of all other input variables

Example: Air Content = 27 CF/CY – (4.304 + 5.007 + 5.109 + …) = .754

Air Content as a Percentage = Air Content / 27 = 2.8%

The next output designed to keep constant was the theoretical density (air free). This could be found simply by taking the Weight (lbs. /CY) / ∑ Absolute Volume of all input variables. Five percent fluctuation of the ideal 150 is acceptable for our practice. For the above example it can concluded that:

Theoretical Density = 3959.6 (lbs. /CY) / (4.304 + 5.007 + 5.109 + …) = 146.65.

Chapter 4.2.2: Precast Testing with Fly Ash Substitute – 10%, 15% and 20% Replacement

For this test, a simple weight-to-weight replacement was made without affecting the desired constraints of air and density. For the 10% replacement, nine pounds of Portland cement was removed and replaced with nine pounds of Fly Ash. The mix recipe looked like this:

Suggested Mix Design

Material	Weight	Specific	Abs. Vol.	Trial Batch	Production Batch
	lbs./CY	Gravity	*CF/CY*	*lbs./CF*	lbs/3.0 CF
Cement (Type I)	765.0	3.15	3.892	28.3	85.0
Silica Fume	0.0	2.20	0.000	0.0	0.0
Fly Ash	81.0	2.56	0.507	3.0	9.0
Coarse Agg. - Pearock	828.0	2.65	5.007	30.7	92.0
Coarse Agg Free Moisture	0.0	1.00	0.000	Incl in Stone	
Coarse Agg #2	864.0	2.71	5.109	32.0	96.0
Coarse Agg #2 Free moisture	0.0	1.00	0.000	Incl in Stone	
Fine Agg.	1098.0	2.65	6.640	40.7	122.0
Fine Agg. Free Moist.	0.0	1.00	0.000	Incl in Fines	
Add Water	323.6	1.000	5.186	12.0	36.0
Air Content		2.4%	0.659		
Totals =	3959.6		27.0		
w/c =	0.383				
Fine Agg Moisture =	0.0%		F100 Fiber at 3 oz./1.5 CF Batch.		
Coarse Agg Moisture =	0.0%				
Coarse Agg 2 Moisture =	0.0%				
Fines to total Agg. Ratio =	0.394				
Calculated Unit Weight =	146.65				
Theoretical Density (air free) =	150.32				
28 Day Strength =					

The column on the far right is the actual amount (lbs.) added to each batch. Production used a three cubic foot (CF) concrete mixer, hence the multiplication between cells. For the 15% and 20% replacement of Fly Ash, the same rules were followed while monitoring the desired constants. Again, the poundage amounts of cement were substituted with Fly Ash. Those recipes can be found in Chapter Four - Section Four.

Chapter 4.2.3: Precast Testing with Fly Ash Substitute – 25%, 30%, 35%, 40% and 50% Replacement

The remaining tests had to be manipulated more than the previous to keep the density and air content consistent. Mike's expertise was used to help design the remaining Fly Ash content tests so that the test stayed relevant. He suggested adjusting the input factors such as rock and sand to keep these values consistent. As stated previously in this thesis, by adding Fly Ash and removing cement from the mix, water should be reduced because Fly Ash replaces the "space" within the crystal matrix. The replacement of water with Fly Ash is what provides the matrix with a stronger bond, which leads to the additional strength properties stated before. You will notice in the Wet Cast Design spreadsheet that poundage of water from 30% and above was dropped from 36 pounds to 32 pounds to keep density and air constant. The resulting inputs of sand and rock were adjusted to reach desired values. The orange cells are the weight results after being manipulated. The table below is the mix design for 30% replacement.

Suggested Mix Design

Material	Weight	Specific	Abs. Vol.	Trial Batch	Production Batch
	lbs./CY	Gravity	CF/CY	lbs./CF	lbs/3.0 CF
Cement (Type I)	592.0	3.15	3.012	21.9	65.8
Silica Fume	0.0	2.20	0.000	0.0	0.0
Fly Ash	254.0	2.56	1.590	9.4	28.2
Coarse Agg. - Pearock	820.0	2.65	4.959	30.4	91.1
Coarse Agg Free Moisture	0.0	1.00	0.000	Incl in Stone	
Coarse Agg #2	890.0	2.71	5.263	33.0	98.9
Coarse Agg #2 Free moisture	0.0	1.00	0.000	Incl in Stone	
Fine Agg.	1140.0	2.65	6.894	42.2	126.7
Fine Agg. Free Moist.	0.0	1.00	0.000	Incl in Fines	
Add Water	287.6	1.000	4.610	10.7	32.0
Air Content		2.5%	0.673		
Totals =	3983.6		27.0		
w/c =	0.340				
Fine Agg Moisture =	0.0%		F100 Fiber at 3 oz./1.5 CF Batch.		
Coarse Agg Moisture =	0.0%				
Coarse Agg 2 Moisture =	0.0%				
Fines to total Agg. Ratio =	0.400				
Calculated Unit Weight =	147.54				
Theoretical Density (air free) =	151.31				
28 Day Strength =					

Chapter 4.3: Procedure for Precast Testing with Fly Ash Substitute

This section will describe the procedures taken to mix the concrete with Fly Ash, fill sample cylinders, and store the samples.

The actual standard procedure followed to produce batches can be referenced in the document "Mixing Work Instructions.doc". This document provides step by step procedures which reference time between spin cycles, speed of each spin cycle, when to add each ingredient, etc. The only alteration to this procedure was that the Fly Ash was added at the same time as the Portland cement. During mixing the slump test and the air entrainment tests were run to ensure accurate mixes. Corrective action was taken per the documents if the air content was not between five and eight percent and if the slump test was not between a one and two. The tests can be referenced in documents “Slump Test Rev B.doc” and “Air Entrainment Testing Instructions Rev B.doc”.

When the mix was complete, the concrete was poured into a wheelbarrow for easy access. Measurement of the temperature for each batch was taken to ensure consistent starting points. The ASTM C31 standard requires the cement to be 73 ± 3°F. All the batches complied with that. The test cylinders were a certified four inch by eight inch column and placed on a flat table top surface. Since there wasn’t a vibrator small enough to fit in the cylinders, a size three re-rod bar was used for stamping and mixing. ASTM standard require that the cylinders be filled up one-third of the way and then vibrated to remove any air pockets. One could also use a rod to agitate the concrete by stamping down a minimum of 25 times. Then the next third can be added followed by more stamping. Finally, the last portion should be added and stamped followed by light taps to the side walls of the cylinder to remove any pocketing against the wall. This should be done until the air bubbles stop surfacing. The next step is to level off the top edge to provide a smooth, flat surface parallel to the bottom surface. Once this procedure was finished, the lids were capped off and set aside. The following pictures were taken during the creation of the samples.

The picture below illustrates the process of tapping the side walls to surface any air pockets attached to the sides.

The picture below shows the method used to ensure a smooth top surface. The rebar is rolled across the flat cylinder creating a leveler.

After all the samples were made, using the above procedure, they were moved to a secure and level location to begin the ambient cure cycle.

Chapter 4.4: Results for Precast Testing with Fly Ash Substitute

When the creation of samples were finished, the samples were allowed time so that the concrete could ambient cure. Again, this means that the concrete cured in room temperature (68°F) without the use of an accelerant. While testing the Fly Ash, LSI was also testing a steam cure process that would increase the hydration process and reduce cure time. To stay consistent within this study, the samples were left out to ambient cure. After the first day, the first 24 samples were gathered that were marked for the one day compression test. All the samples were broke using the calibrated Forney compression tester. After the seventh, fourteenth, and twenty-eighth day cure, all the samples were broken the data was collected. The following tables and graphs are a representation of the results.

This table shows the mix design for each batch.

Ingredients FlyAsh %	Cement (lbs)	FlyAsh (lb)	PeaRock (lb)	3/4" Rock (lb)	Sand (lb)	Water (lb)	Rheobuild (oz)	Liquid Air (mL)	Air Entrain Test (%)
0%	94	0	92	96.00	122.00	36	10	20	6.20%
10%	85	9	92	96.00	122.00	36	10	20	3.50%
15%	80	14	92	96.00	122.00	36	10	20	3.50%
20%	75.2	18.8	89	96.00	122.00	36	6	30	6.20%
25%	70.4	23.6	87.8	96.00	122.00	36	4.5	30	3.40%
30%	65.8	28.2	91.1	98.90	126.70	32	5	40	7.50%
40%	56.4	37.6	88.9	97.80	126.70	32	4	35	6.60%
50%	47	47	87.8	97.80	126.70	32	3	35	5.70%

The next table shows the compression strengths for each test specimen throughout the testing cycle. The PSI column was calculated by taking the compression strength divided by the cross sectional area of the test cylinder (π*r^2 = 12.56 sq. in.)

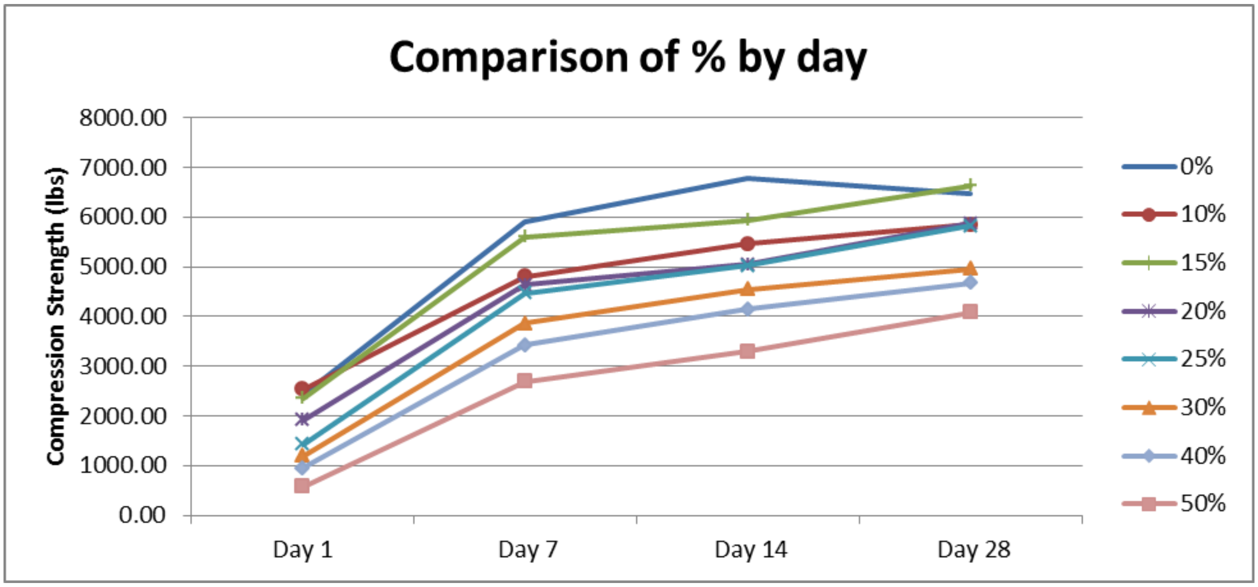
Results					
Day 1	**Sample A**	**Sample B**	**Sample C**	**Average**	**PSI**
0% (1)	28530	30220	32210	30320.00	2414.01
10% (2)	30745	34870	29925	31846.67	2535.56
15% (3)	29680	32115	26905	29566.67	2354.03
20% (4)	23795	26165	22150	24036.67	1913.75
25% (5)	19290	16420	17820	17843.33	1420.65
30% (6)	16000	14815	14190	15001.67	1194.40
40% (7)	12020	12040	11960	12006.67	955.94
50% (8)	6950	7605	7325	7293.33	580.68

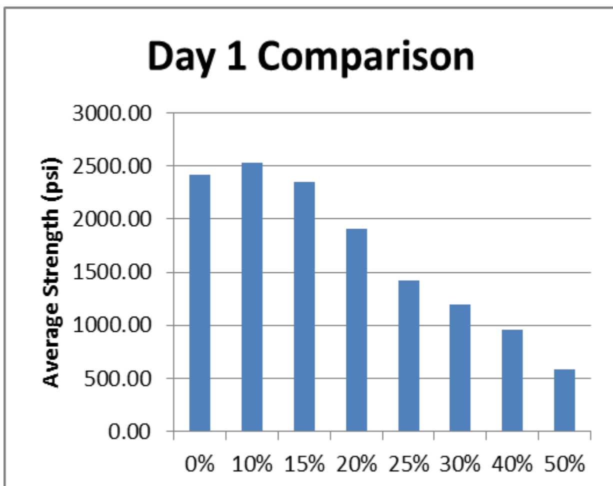
Day 7	Sample D	Sample E	Sample F	Average	PSI
0% (1)	74085	75065	73180	74110.00	5900.48
10% (2)	61235	61570	58225	60343.33	4804.41
15% (3)	70290	70660	70285	70411.67	5606.02
20% (4)	59570	55440	59835	58281.67	4640.26
25% (5)	54495	59685	54375	56185.00	4473.33
30% (6)	48910	47555	48860	48441.67	3856.82
40% (7)	42700	41990	44390	43026.67	3425.69
50% (8)	33440	35020	32810	33756.67	2687.63

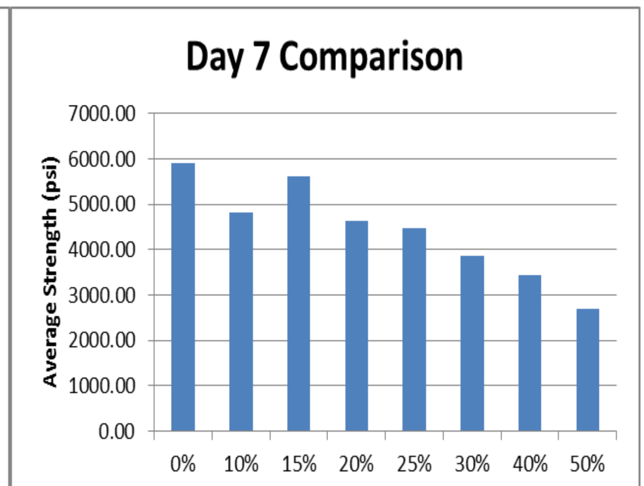
Day 14	Sample G	Sample H	Sample I	Average	PSI
0% (1)	81,015	87,240	87,085	85113.33	6776.54
10% (2)	69,735	66,785	68,955	68491.67	5453.16
15% (3)	80,700	66,920	75,855	74491.67	5930.87
20% (4)	63,295	60,860	66,205	63453.33	5052.02
25% (5)	62,530	62,085	64,565	63060.00	5020.70
30% (6)	57,305	57,145	56,885	57111.67	4547.11
40% (7)	55,460	50,655	50,230	52115.00	4149.28
50% (8)	42,505	41,110	40,755	41456.67	3300.69

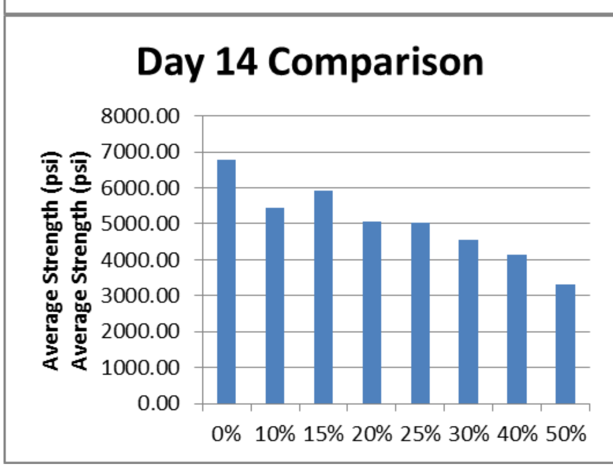
Day 28	Sample J	Sample K	Sample L	Average	PSI
0% (1)	95475	56125	91865	81155.00	6461.39
10% (2)	77355	71755	70980	73363.33	5841.03
15% (3)	66500	90230	93340	83356.67	6636.68
20% (4)	74965	74345	71825	73711.67	5868.76
25% (5)	67235	77345	74595	73058.33	5816.75
30% (6)	62385	62000	62505	62296.67	4959.93
40% (7)	59305	60055	56665	58675.00	4671.58
50% (8)	51510	51680	50695	51295.00	4084.00

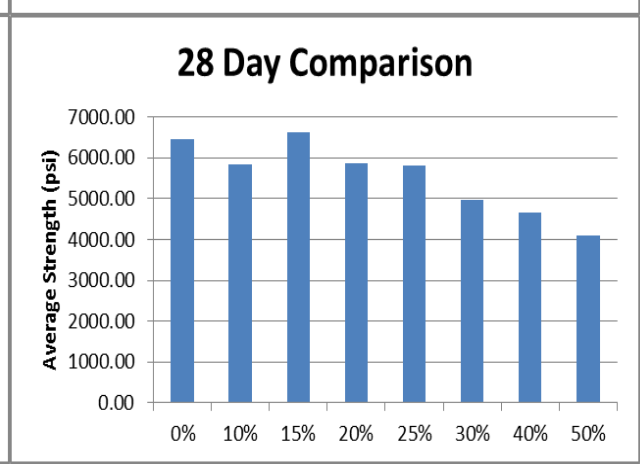
Graphically, this data can be shown by the following graphs.











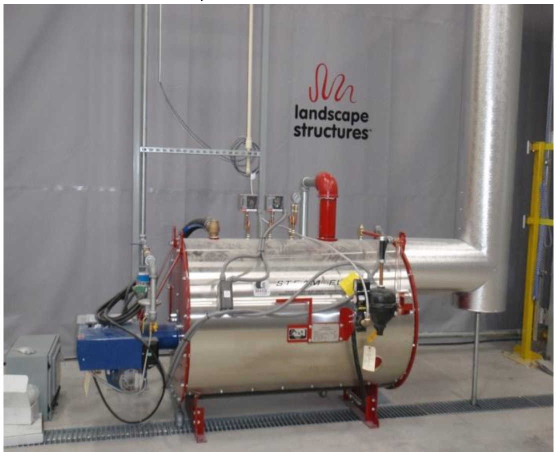
From this data, it is easily concluded that Fly Ash has an affect on compression strength in concrete. It appears that after the first day, if there is more than 15% Fly Ash substitution, strength drops off significantly. It also appears that each sample follows the same curve pattern for curing. From days one to seven, there is an initial spike in strength gain, and from day seven on there is a more gradual increase. As the graphs above show, we can comfortably stay well above the 5,000 pound range with concrete that has up to 25% Fly Ash substitution. After 25%, the figures start to drop off and lose strength. This is why the next test will use 25% substitution for the DOE testing. Analysis regarding Fly Ash results will be further discussed in chapter five.

Chapter 4.5: Steam Cure Introduction

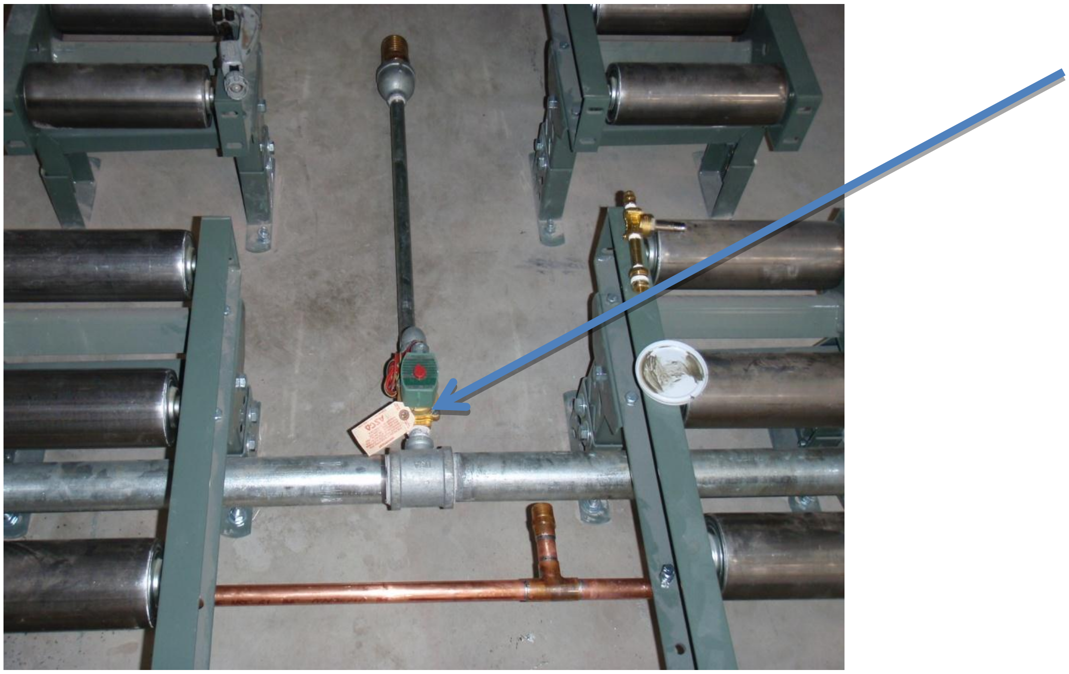
Between the time that the Fly Ash testing finished and the DOE started, LSI made their transition down into the new production building. During this time LSI also bought an extensive amount of capital to ensure long term success to the new processes and internal flow. One of the purchases included a boiler system and steam tents. As stated in Chapter 2.1, steam has a significant impact on cure strengths and cure time. Steam testing was done during the transition by Brad, where he found the optimal process to incorporate steam into the product to increase strength and reduce cure time in half. He found that the ideal cure cycle that utilized steam for the precast product was to allow an ambient one day initial setup cure instead of steam right away. It was learned that if the concrete is allowed a day to setup before being accelerated, the bonds end up much more uniform, abundant, and strong. After the one day ambient cure, the samples were to be placed in the cure tent with a specific steam program:

Ramp up Time: 180 Minute @ 3°F
Hold Time: 540 Minute @ 110°F
Ramp down Time: 120 Minute @ 10°F

This program is run at the end of the production day when the team loads and unloads the tents with new precast product and finished product. The total cycle time for the steam cure is fourteen hours where during the day's production, it is maintained at 100% humidity within the tent for a warm, moist environment. Pictures of the boiler and steam tent are shown below.



The tents are actuated and self regulated through the use of solenoid valves and PLC programs.



Chapter 4.6: Deciding on DOE Factors

Due to time constraint and waste minimization, the amount of input factors that was originally desired had to be cut to a single DOE, instead of two. After meeting with the new Manufacturing Engineer in the concrete building, Kevin Kangas, a conclusion was reached regarding the new factors that should be used in the test. The discussion was about which materials were thought to have the most affect on the concrete strength as well as have a monetary significance to help justify change. The three factors that were identified were the plasticizing agent called Rheobuild, poly fiber, and water. The next step was to determine what the high and low values should be. The current recipe called for 54oz of Rheobuild, 0.8 pounds of the poly fiber, and 38.8 gallons of water. It was decided that increasing the amount of Rheobuild by ten ounces was the route to take, because five ounces was too insignificant. For the poly fiber, the test would show if there is a significant difference between the mix design having no fiber reinforcement and if it had three times as much. Lastly, water was decided to be bumped up two gallons to 40.8 for a 5% increase. The DOE factors, high and low, were established; this is going to be a 3^2 DOE.

		+	-
A	Rheobuild	64 oz.	54 oz.
B	Poly Fiber	2.4#	0#
C	Water	40.8 gal	38.8 gal

Chapter 4.7: Procedure for DOE Testing

The biggest addition to the new facility was the automated batch mixer. This makes the entire operation more flexible and consistent because it follows the exact same sequence, with all the input parameters by the touch of a button. Another nice feature is that it can make any proportion of the batch desired. If 10% of a normal batch is required, it has the ability to do so. For this test, production assisted while they were actually pouring the precast products as well. The recipe input was set to match the (-1) treatment combination each time. The (-1) combination was close to the regular recipe, minus the poly fiber. As soon as a sample bucket was gathered, production would add the poly fiber to make the rest of the batch normal. When a bucket of the (-1) treatment combination was filled, the bucket's weight was subtracted from the total weight to find the amount of concrete it contained.

The exact same procedure was followed for the Fly Ash testing previously explained. This included slump test, air entrainment, temperature consistency, filling up the sample cylinders in thirds and stamping, and then tapping the side walls. The first full bucket would allow us to take just the (-1) combination. The proportions were calculated to get all the other treatments. The treatments are shown below.

	A (Rheobuild)	B (Poly Fiber)	C (Water)	Treatment Combination
1	-	-	-	-1
2	+	-	-	a
3	-	+	-	b
4	+	+	-	ab
5	-	-	+	c
6	+	-	+	ac
7	-	+	+	bc
8	+	+	+	abc

As you can see here, the pluses and minuses match the high and low values from the table above. The table shows every combination you can have with the three factors. This matrix of testing each possible combination allows us to gather consultable data to draw conclusions from. You can see whether each input factor is most beneficial by itself, as a combination with another, as well as how much of each factor provides the most optimal strength.

The (-1) treatment combination was the starting batch, which was just the raw mud out of the mixer. The three samples were filled up and the lids were closed on them. The next treatment that was chosen to complete was the (a) combination. A new weight was taken of how much concrete was in the bucket and multiplied that by the proportion of factor (a) that was needed to add.

As an example, let's say the bucket of concrete weighed 80 pounds after subtraction of the bucket weight. To find out how much Rheobuild to add to that you would have to take:

Recipe content of Rheobuild = 80 (lbs.) / 3927.6 (lbs. / CY) * 54 (oz. / CY) = 1.0999 oz.

Desired recipe content of Rheobuild = 80 (lbs.) / 3927.6 (lbs. / CY) * 64 (oz. / CY) = 1.3036 oz.

Desired – Actual = 1.3036 oz. – 1.0999 oz. = .2037 oz. = 6.02 mL

A syringe was used to add 6 mL of Rheobuild to the bucket and an auger was used to mix. After the bucket was completely mixed through, this was now considered to be the (a) factor sample concrete. It could now be used to fill up the next set of samples. After those cylinder samples were done, the test could reuse this concrete and test treatment combination (ab) by simply adding just the (b) factor of poly fibers. Next, this batch added factor (c) making the last sample (abc) by following the same proportional approach. After those four cylinder samples were completed, the remaining mud was recycled and a new batch at treatment combination (-1) was made. The (b) factor was the first round for the cylinders this time. Then the (c) factor was added to the mix to match the concrete treatment combination (bc). The last round went from (-1) to (c), and from (c) to (ac). After all the cylinder samples were filled up, stamped, and leveled, they were allowed to sit out over night. The next day they were placed in the steam tents to receive the optimal steam cycle and on the sixth day, they were taken out to receive ambient cure for the remainder of the 28 days.

Chapter 4.8: Results of DOE

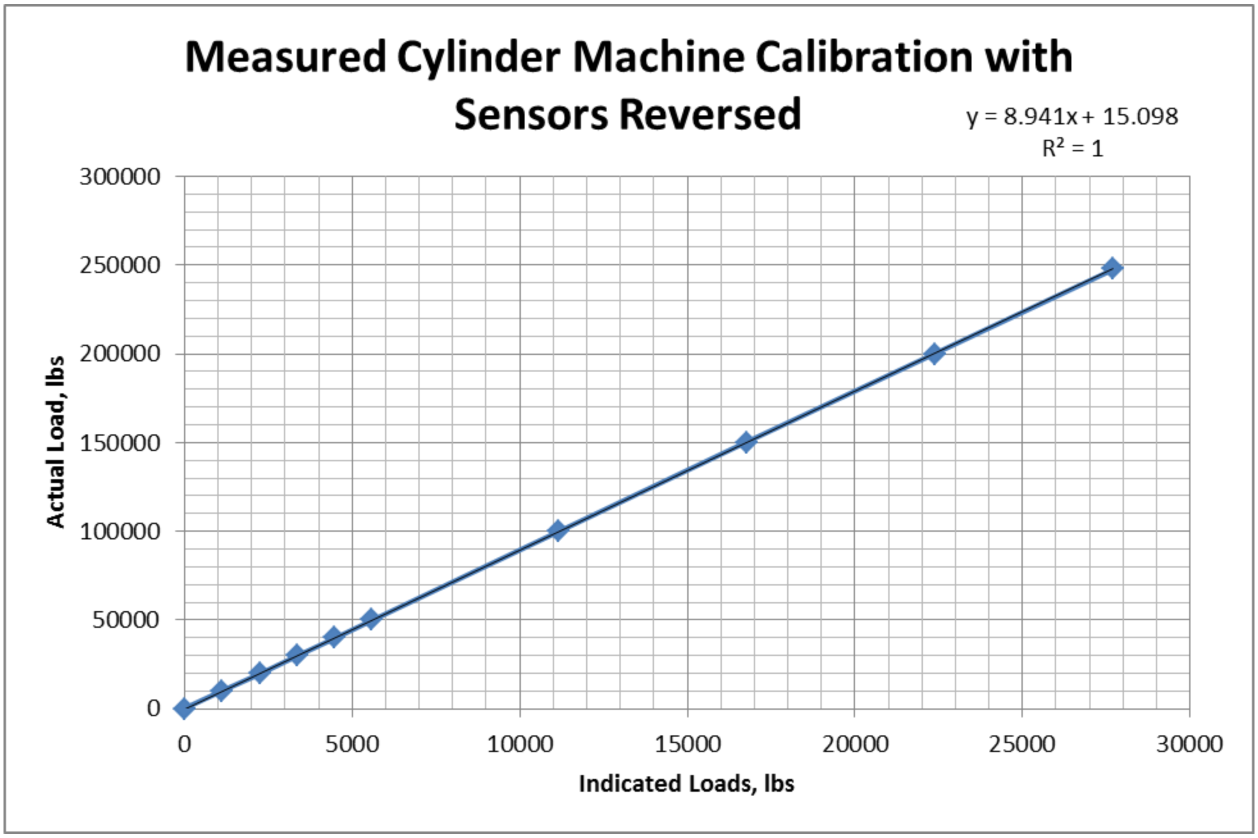
At the 28 day mark, the cylinder samples were collected and were ready to break. The first step was to remove them from the sleeve. Next, the weight of each sample was acquired to verify the samples all weighed the same amount. After the weight of all 24 samples was taken, it was concluded that they were all within 2% total weight of each other. The ASTM standard for load rate on a cylinder is a controlled 20 to 50 lbs./in^2/s or a deformation rate of 0.05 in/min. This was well within tolerance already, but verification was done before continuing with breaking the samples and recording the results.

The sample compression strengths (lbs.) were collected and assembled into the table below.

	A (Rheobuild)	B (Poly Fiber)	C (Water)	Treatment Combination	I	II	III
1	-	-	-	-1	9092.5	9396	9351
2	+	-	-	a	9710.5	9645.5	9834
3	-	+	-	b	8899.5	8702	8672
4	+	+	-	ab	8863.5	8506.5	8709
5	-	-	+	c	8767.5	8340	8447
6	+	-	+	ac	8450	8619	8937.5
7	-	+	+	bc	9237	9262	9004.5
8	+	+	+	abc	8209	8472.5	8225

At the time these cylinders were broken, it was later found out that calibration wasn't accurate. This was found out by dividing the compression strength by the cross sectional area once again and receiving less than a thousand pounds, even for the control samples. Kevin Kangas quickly figured out the cause and found a solution. He also said that the data could be transposed with the conversion factor it was consistently off from. A quick study was completed to find the conversion factor and that study is shown below.

Indicated	Actual	Difference
0	0	
1117	10000	8.952551
2240	20000	8.928571
3359	30000	8.93123
4479	40000	8.930565
5591	50000	8.942944
11150	100000	8.96861
16771	150000	8.94401
22388	200000	8.933357
27710	247800	8.94262
	Average	8.941607



With the conversion factor of 8.9416 and the R^2 value at 1, the data should be strong. The new strengths (psi) are shown.

	A (Rheobuild)	B (Poly Fiber)	C (Water)	Treatment Combination	I	II	III	Average
1	-	-	-	-1	6469.8	6685.7	6653.7	6603.075
2	+	-	-	a	6909.5	6863.3	6997.4	6923.392
3	-	+	-	b	6332.4	6191.9	6170.6	6231.646
4	+	+	-	ab	6306.8	6052.8	6196.9	6185.514
5	-	-	+	c	6238.5	5934.3	6010.5	6061.111
6	+	-	+	ac	6012.6	6132.9	6359.5	6168.318
7	-	+	+	bc	6572.6	6590.4	6407.2	6523.382
8	+	+	+	abc	5841.1	6028.6	5852.5	5907.416

Chapter 5: Results and Conclusions

Chapter 5.1: Fly Ash Testing

If we look at the graphs of strengths by day, we see that Fly Ash does have a significant impact on overall compression strengths. From day one, we see that ten percent Fly Ash incorporation actually has higher one day compression strengths than no Fly Ash. As explained before, Fly Ash doesn't have any cementitious material within it, so the strength added is purely within the crystalline matrix produced from the hydration process. At fifteen percent we see a drop to a level similar to no Fly Ash content. After fifteen percent, we see that our strengths diminish rapidly. What we are really looking for here is that we have adequate strength to transport and move the concrete after the first day so that operations can begin the value added processes. Anything less than 1000 psi, LSI would not feel comfortable with, so we can exclude the forty and fifty percent testing.

Next we look at the one week comparison and see a somewhat opposing trend. Instead of the ten percent concentration of Fly Ash immediately increasing the strength from zero percent, we see a drop in strength. The fifteen percent once again is at a level close to the current mix design. One trend to notice here is that the rate of strength formed throughout the hydration process is highest from one to seven days, after seven days it slowly climbs.

The fourteen day is a reflection of the seven day, without any special anomalies. We do continue to see that the fifteen percent Fly Ash mix is higher than the ten and twenty but has dropped a little from the control batch.

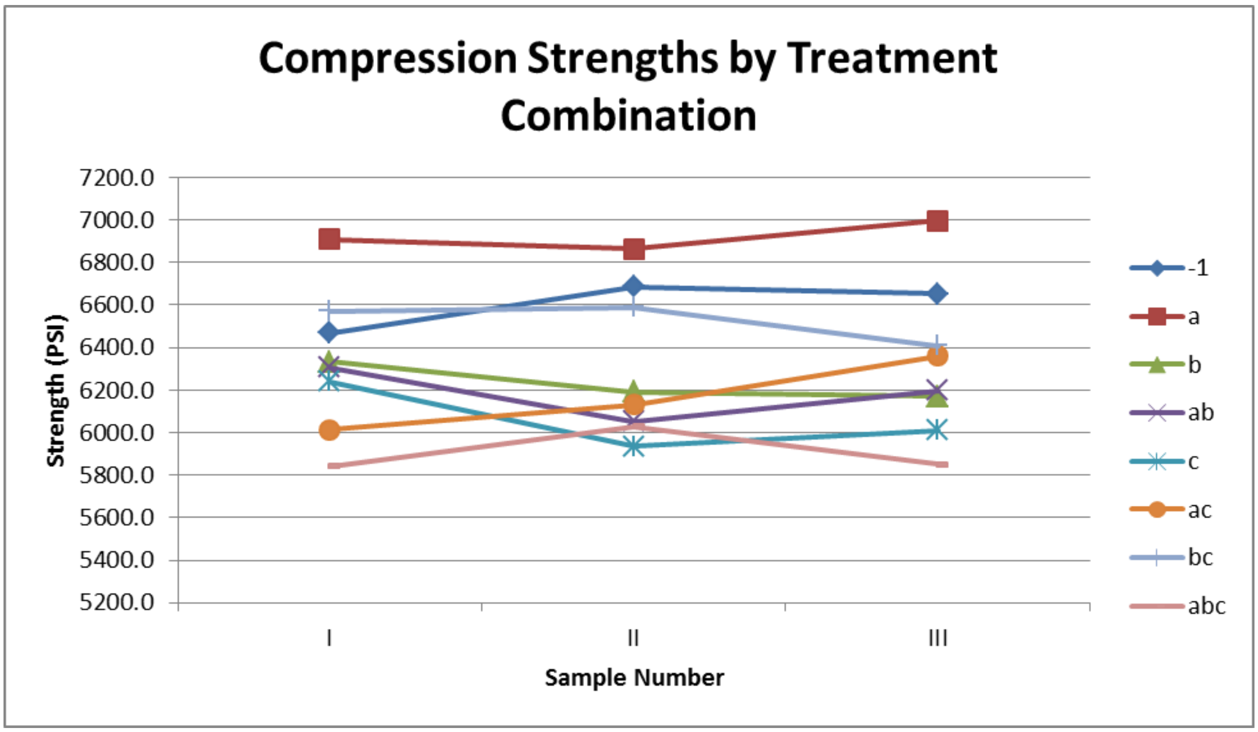
Lastly, the twenty-eight day cure shows us our concluding data. The control batch of our current design finished the cure cycle at 6461psi, well above our minimum. Ten percent, which initially had a leg up on the one day cure, came in at final compression strength of 5841psi. Fifteen percent actually beat out the control batch and measured at 6636psi. Twenty and twenty-five was a near tie at 5868psi and 5816psi respectively. After twenty-five percent, the remaining batches didn't meet the minimum criteria of 5,000psi. This was set per Brad Hotchkiss and his experience developing the concrete division. Thirty, forty, and fifty had final compression strengths of 4559psi, 4671psi, and 4084psi, respectively.

Based off the day by day data and the final cure strengths, we want to optimize using Fly Ash with the criteria of maintaining 5,000psi minimum compression strength of precast concrete. One can conclude that twenty-five percent Fly Ash was the most that we could add and still maintain these requirements. With the additional material properties being affected positively, and environmental and fiscal advantages as well, this study will move forward using 25% Fly Ash content.

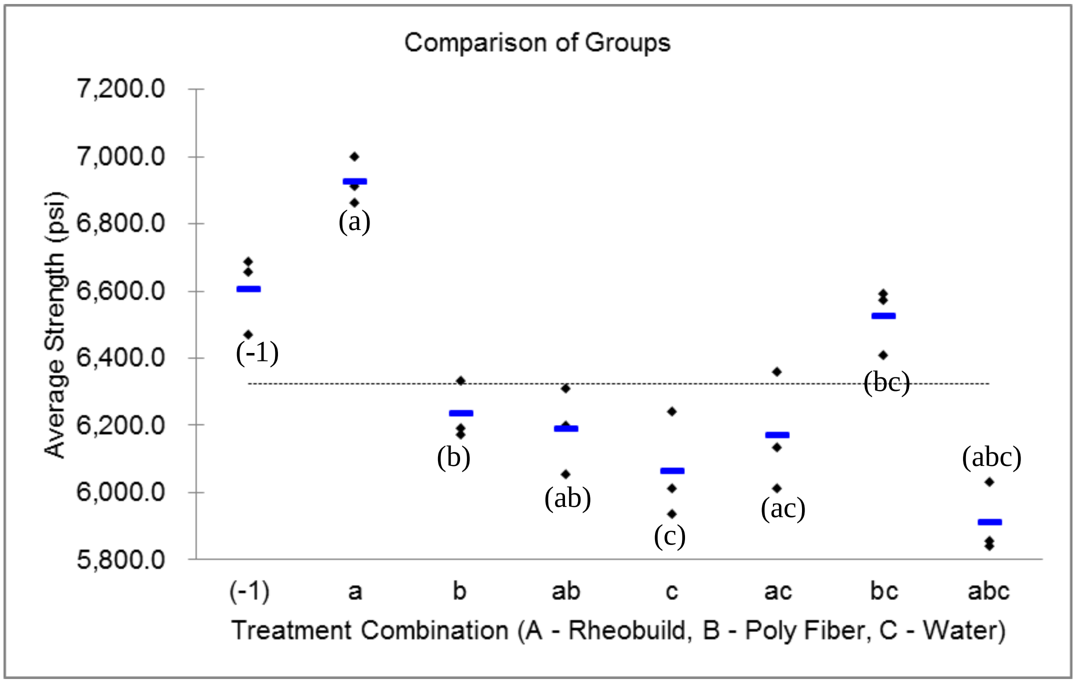
From the results of Fly Ash testing, one can conclude that the mix design can incorporate up to 25% Fly Ash as a replacement to Portland cement. The minimum criteria of 5,000 psi will still be met.

Chapter 5.2: Design of Experiment Testing

When the cylinders were initially broken, the compression force to break the cylinders was surprisingly low. They received forces less than 10,000lbs, where they should have been ten times those numbers. The numbers gathered can be seen above after the conversion factor has been applied. Graphically, the data looks like the following:



If we do a quick comparison, one can see that the (a) combination has the highest compression strength with an average of 6923.4psi. The second highest combination was the current design (-1) averaging at 6603.1psi. My initial thought is that treatment combination (a) looks to be the best combination, but let's dive into the DOE to see how the ingredients interact with each other.



To begin a DOE analysis, we need to compute the main effects and calculate the contrasts. In short, the contrasts are used as a statistical measure to see which sources of variation have a positive or negative effect. The contrast is calculated by adding the treatment combinations that have the factor included, then subtracting the combinations that do not include the factor. For example, the contrast for the source of variation (a), which is Rheobuild, can be calculated by adding the average of treatment combinations (a), (ab), (ac), and (abc). Take that sum and subtract the remaining four averages. This will show a positive or a negative number. If the number is positive, then the contrast being calculated has a positive influence in the output, which in this case is compression strength. If negative, this means that, for this example, Rheobuild hinders and lowers compression strengths.

$Contrast_A$ = Avg(a) + Avg(ab) + Avg(ac) + Avg(abc) – Avg(b) – Avg(c) – Avg(bc) – Avg(-1)

$Contrast_B$ = Avg(b) + Avg(ab) + Avg(bc) + Avg(abc) – Avg(a) – Avg(c) – Avg(ac) – Avg(-1)

$Contrast_C$ = Avg(c) + Avg(ac) + Avg(bc) + Avg(abc) – Avg(a) – Avg(b) – Avg(ac) – Avg(-1)

$Contrast_{AB}$ = Avg(abc) - Avg(bc) + Avg(ab) - Avg(b) - Avg(ac) + Avg(c) – Avg(a) + Avg(-1)

$Contrast_{AC}$ = Avg(-1) - Avg(a) + Avg(b) - Avg(ab) – Avg(c) + Avg(ac) – Avg(bc) + Avg(abc)

$Contrast_{AC}$ = Avg(-1) + Avg(a) - Avg(b) - Avg(ab) – Avg(c) - Avg(ac) + Avg(bc) + Avg(abc)

$Contrast_{ABC}$ = Avg(abc) - Avg(bc) – Avg(ac) + Avg(c) – Avg(ab) + Avg(b) + Avg(a) - Avg(-1)

Main Effect = $Contrast_N$ / (4*n); n = number of samples

Source of Variation	Main Effect	Contrast
A (Rheobuild)	-19.54788933	-234.575
B (Glass Polymer)	-75.66159792	-907.939
C (Water)	-106.95008	-1283.4
AB Interaction	-90.80182363	-1089.62
AC Interaction	-65.24528076	-782.943
BC Interaction	109.2230904	1310.677
ABC Interaction	-29.7270228	-356.724

Next, the sum of squares will be found. The sum of squares is related to variance and how much "weight" it applies to our experiment. This will help us determine if the source of variation is critical or has little to no effect.

Sum of Squares = $Contrast_N^2$ / (abcn); a, b, and c = how many factors are you testing (we are testing two a piece, high and low)

$Sum\ of\ Squares_T$ = ∑ each compression strength squared / (abcn)

$Sum\ of\ Squares_E = SS_T - \sum SS_N$

SS_N	Sum of Squares
SS_A	2292.719863
SS_B	34348.0644
SS_C	68629.91771
SS_{AB}	49469.82705
SS_{AC}	25541.67997
SS_{BC}	71578.10088
SS_{ABC}	5302.175307
SS_T	930,010,035.62
SS_E	929,752,873.13

Next, the table will be completed to find our F_{crit} and our p-values. This will tell us if our factors are significant enough to have a measured effect on our output or not.

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	F_0	P-Value	$F_{0.05,1,16}$	%
Model	257162.4852	7	36737.4979	0.000632	1.0000	2.66	
A	2292.7199	1	2292.7199	0.000039	0.9951	4.49	0.0002%
B	34348.0644	1	34348.0644	0.000591	0.9809	4.49	0.0037%
C	68629.9177	1	68629.9177	0.001181	0.9730	4.49	0.0074%
AB	49469.8270	1	49469.8270	0.000851	0.9771	4.49	0.0053%
AC	25541.6800	1	25541.6800	0.000440	0.9835	4.49	0.0027%
BC	71578.1009	1	71578.1009	0.001232	0.9724	4.49	0.0077%
ABC	5302.1753	1	5302.1753	0.000091	0.9925	4.49	0.0006%
ERROR	929752873.133	16	58109554.5708				99.97%
Total	930010035.618	23					

The results for the DOE are actually disappointing. What was expected was a F_0 value for any source of variation to be higher than the $F_{.05,1,16}$ values. This would have indicated that for which ever value that was higher, there would have been a strong correlation to the compression strength. Since the P-values are also very high and near one, this means there is no strength in the model. Basically, what this chart tells us is that based on the DOE results; there is no consultable data to measure a conclusion from. To verify this, the error in the experiment equates to 99.97% of my total sum of squares.

This doesn't mean that the experiment was bad, or had mistakes in the design or testing. This simply means that based on the numbers received; we can not conclude that any of the factors make a significant difference in the compression strength of our concrete. This also means that the next experiment should have different factors to test so that a relevant model can be found. However, it does raise a couple questions as to why some of our ingredients are included in the recipe if not for strength properties.

Chapter 5.3: Discussion and Conclusions

With all the preparation work completed, the tests run, and results analyzed, it is time to draw some conclusions. With 25% Fly Ash as the ideal state, we need to analyze the cost for incorporating this alternative. This includes capital purchases to house the material, maintenance costs for installation, and any additional overhead. The cost for the additional silo and chute is $15,185 which included the air valves, regulators for aeration and the dust collector, two level switches, dust collector timer panel, and a large dust collector. While we were constructing the new building, we knew that this was the direction we would want to go due to preliminary testing of Fly Ash. Because of our results, we planned for including Fly Ash into our process where we were able to include auguring the hole through the wall for chute placement at no additional cost.

Installation was done in-house by Landscape Structure's team as well as programming and start up. Our supply manager was able to quote out and lock a price for the purchase of Fly Ash at $.027 / lb. If we look at usage of Portland cement in the past few years we see an upward trend. In 2011, we saw a demand of 541,000 pounds of concrete. Based off our year-to-date trend, we are averaging 55,100 pounds per month for this year's expected total of 661,200 pounds. The upward trend can be correlated to the new concrete facility and the increased capacity capability to produce. If we take the cost of Portland cement at our most recent cost of $.062 / lb. and multiply it by our demand of 661,200 pounds, we see a yearly cost of $40,994.40. Now, if we substitute 25% of the Portland cost with the Fly Ash cost, we arrive at $35,208.90 for a difference of $5,785.50 for this year. With the demand of our concrete products rising, this should only increase per year.

Above the return on investment, we will also benefit from Fly Ash's chemical properties as explained in chapter two. These desirable traits include an improved density which will allow the matrix to be less permeable to water which results in erosion protection, a reduction in shrinkage and thermal cracking, a higher ultimate strength, and an overall improved durability to lessen the affect of long-term environmental shifting. As stated above, the green initiative aspect will also benefit the environment where we will be manufacturing a recycled bi-product. Normally, Fly Ash is dumped in a landfill allowing its hazardous materials to leech into the environment; with locking the material in our cement matrix, we can benefit from the properties as well as produce a non-hazardous product. At the same time, we will be reducing our demand for the cement that uses a high consumption of natural resources to manufacture.

A beneficial outcome that might be hard to equate a monetary value to is the reduction in obsolescence seen in the field. We may also see cracking, shrinkages, and brittleness. Normally, Landscape Structures would either pay for a repair or replace the entire product under warranty and with the new beneficial chemical properties, we can assume less cost due to longer lasting product for new products sent out into the field.

The time it will take for this new product to reach the market will be equivalent to our current process. Even though Fly Ash accelerates the hydration process resulting in a shorter cure time, we will keep the same work flow for this new product to keep our standards consistent. Since we are not changing the design of our formed final product, time to market will solely depend on the time it takes to incorporate the Fly Ash into our recipe.

Citations

1. Hanson, J. A., *Optimum Steam Curing Procedures for Structural Lightweight Concrete,* Development Department Bulletin DX092, Portland Cement Association.

2. Smoothwhirl. "Tips on Concrete Curing." *Bright Hub*. Lamar Stonecypher, 12 Jan. 2010. Web. 10 Nov. 2010. <http://www.brighthub.com/engineering/civil/articles/48992.aspx>.

3. Marshall, Mel. "Quick Cure." *Precast Magazines*. Precast Solutions, 2009. Web. 10 Nov. 2010.

4. McCall, Calvin. "Accelerated Concrete Curing: The Basics." *PUBLICATION #J960680* (1996). The Aberdeen Group, 1996. Web. 10 Nov. 2010.

5. DOT. (2011, April 7). Fly Ash. *FHWA*. Retrieved October 3, 2011, from <http://www.fhwa.dot.gov/infrastructure/materialsgrp/flyash.htm>.

6. Fly Ash Concrete. (2005, August 17). *Build It Green*. Retrieved October 3, 2011, from <http://www.builditgreen.org/attachments/wysiwyg/3/Fly-Ash-Concrete.pdf>.

7. Design of Experiments (DOE). (2011). *MoreSteam.com*. Retrieved October 3, 2011, from <http://moresteam.com/toolbox/t408.cfm>.

8. Montgomery, D. C. (2009). *Design and analysis of experiments* (7th ed.). Hoboken, NJ: Wiley.

Mixing Process for GFRC

Resources Needed

- PolyPlex
- Water
- 40/30 grade sand
- 40/75 grade sand
- Concrete mix
- Rheobuild-1000
- Brickform Liquid Color (Phoenix Tan)
- Vacuum hoist
- Jib Crane
- Spray Machine
- Mixer
- Torit

Additional PPE Required

- Dust mask (while dumping concrete)

Before starting any of the mixing procedures, make sure that the Vacuum hoist and Torit are on and running.

At the beginning of the day run the well water into the pit until the water is cold. Water that sits in the pipes overnight will warm to room temp and the well water coming out of the ground is much colder. The cold water will give us more workable time with the cement. Record all information.

Procedure

1. Measure correct amounts of PolyPlex, water, 40/30 grade sand, 40/75 grade sand, Rheobuild-1000, and Brickform liquid color (refer to recipe)
2. Add the PolyPlex, water, and Brickform liquid color into the mixer
3. Ensure the grating is down and start the mixer on “LOW” speed
4. Add both the 40/30 and 40/75 grades of sand
5. Using vacuum hoist, lift a bag of concrete to the top of the mixer and set on grating
6. Dump concrete through the grating

7. Repeat steps 5 and 6 for the second bag of concrete
8. Slowly add the Rheobuild 1000 into the mix
9. Allow to continue mixing for 1 minute on “LOW” speed, then increase to “HIGH” speed for approximately 15 seconds. While the mixer is on “LOW” speed slowly add the Rheobuild 1000 to the mix
10. Stop mixer and raise grate
11. Completely scrape the concrete off the internal sides of the mixer and let sit for 3 minutes - *this is called flashing*
12. Lower grate and start mixer on “LOW” speed for 30 seconds and then switch to “HIGH” speed for 15 seconds. Stop mixer
13. Perform “Slump” test. Results should be between 1 and 2.0. If the test does not slump far enough the add 1 oz. of Rheobuild 1000 and repeat steps 11 and 12 until you reach the slump required. The key is to maintain a consistent slump level throughout the day
14. Unload into the tray hopper
15. Turn on sieve vibrator
16. Use jib crane to unload tray hopper into sprayer sieve
17. Allow the cement in the spray machine to reach the level of the second grate before added new cement. This will insure we are turning off the cement each load

RINSE OUT MIXER WITH WATER AFTER EVERY COMPLETE MIX

Slump Test Work Instructions

Resources Needed

- Cylinder
- Measuring board
- Small scooping cup

Additional PPE

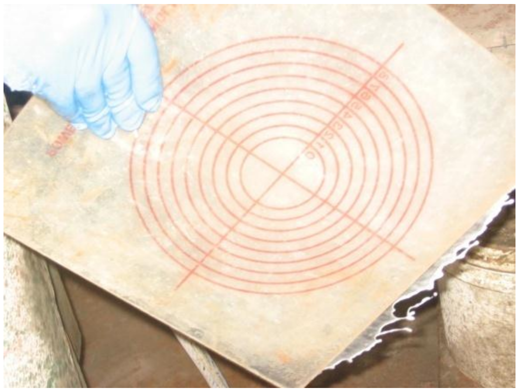
- Nitrile gloves
- Protective sleeves

NOTE

Slump tests are performed to validate process changes, recipe adjustments and AT MINIMUM once per week. Use the record form to capture test results, and any adjustments made.

Perform a Slump test:

1. Prep the measuring board and cylinder by spraying them down with water.



2. Place the measuring board on a flat, level surface and place the cylinder in the exact center of the target.

3. Using a small cup, scoop enough concrete out of the mixer to fill the cylinder.

4. Pour concrete into the cylinder and fill to the top.

5. Lift the cylinder off of the concrete firmly, allowing the concrete to “slump” over.
6. Measure the slump by observing the furthest edge of the concrete, the slump should fall between 1 and 2 on the measuring board. Record the data in the log.

7. Once performed, dump the concrete back into the mixer and clean off all tools.
   Note: DO NOT USE A SCAPER TO CLEAN THE MEASURING BOARD. IT WILL SCRATCH THE MEASURING SURFACE.

Air Entrainment Testing Instructions

Resources Needed

- **Forney Press-Aire Meter**
- **Dead Blow Hammer**
- **5 gallon bucket of water**

Additional PPE Required

- Rubber Gloves

Note

Air Entrainment testing is required only when process changes in the batch plant are performed, specifically: recipe adjustments to TYPE or QUANTITY of ingredients. Perform at least three air entrainment tests on random batches to validate correct air entrainment levels. Record the data in all cases.

PERFORM THE TEST:

1. Prepare Forney Press-Aire Meter on a level surface



2. Prepare 5 gallon bucket of water

3. Unclamp the top of the Forney Press-Aire Meter

4. Wet down the Forney pot using a damp sponge; dump out any excess water from the pot

5. Partially fill a 5 gallon bucket with mixed wet cast concrete, put in enough to fill the Forney pot

6. Transfer the Wet cement into the Forney pot

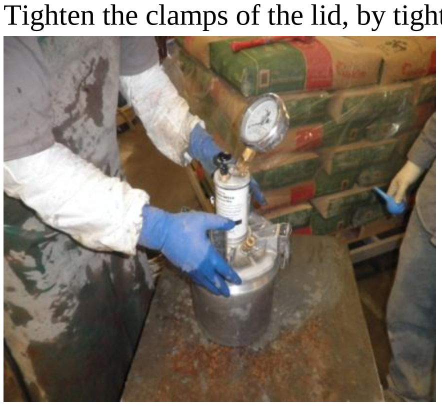
7. Once the pot is full, using the Dead Blow Hammer, tap the sides of the Forney pot to level out the concrete

8. Using the metal rod, screed off the concrete so it is level with the top of the Forney pot

9. Using a damp sponge wipe off the top rim and tapered edge of the Forney pot; be sure to clean thoroughly to ensure a tight seal

10. Using a damp sponge, wet down the rubber gasket on the under side of the lid to the Forney Press-Aire Meter

11. Seat the lid of the meter on to the bottom, rotating the top will ensure sure you have a good seal. Tighten the clamps of the lid, by tightening the opposite sides at the same time



12. Make sure both valves are in the open position. (the valve handles should be pointing up, parallel with the valve stem). Using the blue rubber, fill one of the valves with water until it comes out of the valve on the other side. Do not force the water in, it should flow out the other side with no air bubbles


13. When you have water flowing out the other side with no air bubbles, use the black pump handle to pump up the pressure to 3mpa (noted as % air, or initial pressure, on the meter at the far right)

14. When you have the pot pressure at 3 %, close the valves by rotating the handles perpendicular to the valve stems

15. Once the valves are closed, press the brass pressure lever on the top of the Forney Press-Aire meter and read the gauge (note: tapping the gauge with your finger will give you a more accurate reading)

16. The gauge should read between 5 and 8%. Record the actual reading to one decimal place (e.g. 5.8% - as shown on the gage in the photo below)

17. Open the valves and relieve the pressure, then unclamp the top and remove it. Dump the concrete from the pot into the hopper and clean all of the tools used

18. Wipe all of the equipment down and place it back into the case

19. Close up the case and put it away