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Compressive Strength Relative to Sustainable Materials in Concrete

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ABSTRACT

The objective of this study is to determine how integrating abundant waste materials into concrete affects its compressive strength. This research will be used to benefit the construction industry by replacing a portion of a conventional concrete mix (cement, stone, sand, and water) with more sustainable materials. In order to create a more sustainable concrete mixture, the following mix design and methodology was followed.

The initial step was to create an updatable MS Excel spreadsheet to aid in the mix development (the spreadsheet is shown in Appendix A). These sheets allowed for easy transitions from one mix to another by controlling variables such as mass and water-to-cement ratio to determine the total volume of the small-scale mixes. After the spreadsheet was created, the materials were selected for mix design and their proportions were determined.

Nine total mix designs were developed during experimentation. The mixes contained a percentage replacement of the abundant waste materials. The replacement percentages were chosen at the discretion of the mix developer, considering most materials would result in a decrease in compressive strength. The waste material included slag cement, silica fume, plastic, alum residual (alum), and granular/powder active carbon (GAC/PAC).

The sustainable waste aggregates and cements yielded different compressive results based on their replacement percentages. Plastic mixes resulted in a -17.5% and -30.9% change in the compressive strength for 2.5% replacement and 5.0% replacement respectively, when compared to the Control mix. Plastic mix strengths decreased with the addition of more plastics, where 5.0% replacement had lower strengths than 2.5% replacement. The Cements Mix resulted in a +20.6% change in compressive strength compared to the Control mix at 28-day strength. The Alum mixes followed the same trend as the plastics, a percent decrease, but had slightly higher compressive strengths than the Plastics mix (6595 psi vs. 5930 psi). The GAC/PAC yielded no results because the concrete did not set. The Composite mix containing plastics, slag, and silica fume, contained the most waste material and had the most comparable compressive strengths to the Control mix, with only a -7.3% difference at 28 days.

The overall results showed that the abundant waste material is a viable alternative to conventional concrete and could help remove a portion of these waste materials from landfills. The research can continue to be expanded upon by controlling the water-to-cement ratio, adding admixtures, and continuing percent replacements of sustainable waste materials.

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Objective

The objective of this study is to determine the compressive strength of abundant waste materials to replace a portion of conventional materials in concrete. Conventional concrete is composed of five ingredients: cement, coarse aggregate, fine aggregate, water, and air. Normal concrete compressive strength requirements of 2500 psi forresidential concrete and 4000 psi (or higher) in commercial structures.[1] The purpose of the recycled materials in this study is to replace a portion of the conventional concrete and maintain compressive strength.

The recycled materials being used in this study are: slag cement, silica fume, plastic, alum, andgranular/powder active carbon(GAC/PAC). Portland cement is used as the main cementitious binder in conventional concrete. However, concrete produced with Portland cement and conventional aggregates produces high levels of carbon dioxide (CO_2) emissions. The utilization of slag cement and silica fume as supplementary cementitious materials helps reduce the total amount of Portland cement used in a concrete mixture and may increase compressive strength. Slag and silica fume are both industrial byproducts,which makes them a sustainable material, and their chemical properties provide their own benefits in concrete.

Aggregates are a major component of the concrete mixture. Generally, stone aggregate is used for the coarse aggregate(e.g., #8 limestone), and sand is used for the fine aggregate (e.g., construction sand). The plastic, alum, and GAC/PAC were utilized as abundant waste materials to reduce the amount of non-renewable aggregate. In the United States alone there are over 100 billion plastic shopping bags used every year and the majority become litter.[2]Replacing a portion of conventional concrete with shredded plastic bags reduces the amount of conventional aggregates needed, which in turn prolongs the useful life of conventional aggregates and reduces the amount of plastic bag litter. Additionally, extensive amounts of alum residual and GAC/PAC are available to use as an aggregate from water-treatment byproducts.

The use of abundant waste materials is a green alternative to combat the high carbon footprint of traditional concrete. The usefulness of industry byproduct cementitious materials(slag and silica fume), and waste material aggregates (plastic, alum, and GAC/PAC) are tested in his experiment. The compressive strength test specimens relative to the recycled materials will be compared against conventional concrete in order to determine the materials' usefulness as well as the amount of recycled material utilized.

MATERIALS

The materials used during this experiment were conventional concrete components and recycled materials. The conventional concrete components include type I Portland cement, limestone for coarse aggregate, and construction sand for fine aggregate. The recycled materials used include two industrial byproduct cementitious materials, slag cement and silica fume. In addition, two water-treatment byproducts were used, alum residual and GAC/PAC. Finally, plastic (to simulate shredded plastic bags) was used as an additional recycled material.

Cements

The mix design during testing and development incorporated the use of three different cementitious materials. The cements include Portland type I cement, Lafarge Slag, and Silica fume.

Portland cement is the standard binder in conventional concrete. Portland cement is also considered hydraulic cement, as defined by ASTM C150,[A] which means that it hardens by reacting with water and forms a water-resistant product. The typical specific gravity for Portland type I cement is 3.15, which was used during mix design.

Lafarge Slag was used in this study as a sustainablereplacement to the Portland cement. Slag cement was utilized because it a byproduct of the iron-making process, which makes it a green alterative from an all Portland cement mix.Slag cement has several properties that improve upon conventional concrete when its hydration reaction occurs, which includeresistance to chlorides, high sulfate resistance, and improved workability.[3] The slag utilized in this study has a lower specific gravity than the Portland cement at 2.94, which results in an increased cement paste. This means there will be a greater volume of slag cement present compared to the same amount of Portland cement, by mass, which therefore improves finishing.

Lafarge silica fume was also utilized inthis study as a sustainable replacement to the Portland cement. Silica fume is a byproduct of producing silicon metal or ferrosilicon alloys. Because of its chemical and physical properties ($1/100^{th}$ the size of the average cement particle, meaning a larger surface area), it is a very reactive pozzolan.[4] Concrete containing silica fume can have very high strength and can be very durable. Silica fume has a specific gravity of 2.20.

Aggregates

The mix design during testing and development incorporated the use of two different conventional aggregates. The first aggregate was #8 limestone, utilized as the coarse aggregate in the mix design. The second aggregate was construction sand, utilized as the fine aggregate during mix design.

#8 limestone is crushed and cleaned limestone that is between 3/8” – 1/2” in size. Crushed limestone was chosen to utilize in the mix because it is a conventional aggregate used in the construction industry. Limestone is an angular aggregate, which allows for stronger bonding with the cement paste because the surface is rough and pitted, creating effective holds for the particles.

Construction sand was utilized as the fine aggregate in this study. Construction sand was chosen because the gradation is more disperse than fine sand and is more comparable to a standard construction mix. The sand is also utilized for tighter packing of the concrete and cost reduction.

<u>Recycled Aggregates</u>

The mix design during testing and development incorporated the use of three different recycled aggregates. The recycled aggregates include plastics, alum, and GAC/PAC. All materials are treated as fine aggregates and incorporated into the mix design at a percentage replacement of construction sand.

The plastic used in the mix development simulated shredded plastic bags ranging from 1/4" to 1" in length. The material used was PNTA™ coarse snow to simulate the plastic bags. The purpose of this product was to determine how much recycled material can be incorporated into the mix without major negative impacts to compressive strengths. The goal is to produce a mix with sufficient compressive strength for the construction industry and remove theportion of the100 billion plastic bags wasted as litter and put into landfills each year.[2]The material is highly available in all areas.

Alum residual is a byproduct of the water treatment process. Alum is the coagulant used in many industrial water-treatment applications, and because it is widely used the amount of alum residual available is high.[5]This material is normally shipped to landfills or stored in pits onsite after its useful life. The material would be available to use because it is normally treated as waste after its useful life in the water-treatment processes.

Another byproduct of water treatment tested was activated carbon. One way to adsorb natural organic, taste, and odor compounds is to utilize activated carbon. [6]Activated carbon can also reduce synthetic organic chemical content in drinking water. The carbon material is very porous and is generally composed of organic materials. Again, since the material is handled as waste after its useful life, it would be available to use in concrete.

MIX DEVELOPMENT

Concrete Mixes

The mix design was composed for nine concrete mix designs to test the abundant waste materials in the concrete. The general information for each mix is listed in Table 1, and it displays all nine concrete mixes. More information on each specific mix is shown in Appendix A, which contains all mix design sheets used during the experiment.

Table 1: Concrete Mix Information	
Control Mix	Contained 0.5 lbs of Portland Cement Limestone and Sand Aggregates 0.40 W/C ratio Used as the baseline for all other mixes
Cement Mix	Contained 0.5 lbs of Cement Combination (55% Portland, 40% slag, 5% silica fume) Limestone and Sand Aggregates 0.40 W/C ratio Used to optimize the cementitious combination
Plastic 2.5 Mix	Contained 0.5 lbs of Portland Cement Contained Limestone, Sand, and 2.5% replacement of plastics 0.40 W/C ratio Used to determine compressive strength with plastic addition
Plastic 5.0 Mix	Contained 0.5 lbs of Portland Cement Contained Limestone, Sand, and 5.0% replacement of plastics 0.40 W/C ratio Used to determine compressive strength with plastic addition
Alum 5.0 Mix	Contained 0.5 lbs of Portland Cement Contained Limestone, Sand, and 5.0% replacement of alum residual 0.40 W/C ratio Used to determine compressive strength with alum addition
Alum 10.0 Mix	Contained 0.5 lbs of Portland Cement Contained Limestone, Sand, and 10.0% replacement of alum residual 0.40 W/C ratio Used to determine compressive strength with alum addition
Alum 20.0 Mix	DID NOT SET (harden), therefore yielded no compressive results
Composite Mix	Contained 0.5 lbs of Cement Combination (55% Portland, 40% slag, 5% silica fume) Contained Limestone, Sand, and 7.5% replacement of plastics 0.40 W/C ratio Use to determine effect of cement combination with plastics
PAC/GAC Mix	DID NOT SET (harden), therefore yielded no compressive results

Mix Sheet Calculations

Mix development began by creating an MS Excel spreadsheet to determine the quantities of the cements, aggregates, water and air incorporated into the mix. The method used was the absolute volume method. Since, the Specific Gravity (SG) of each material was known, and the masses of the materials were calculated, the volume could be determined. The mix scale is 42.41in^3 (0.0245ft^3), which is the standard volume of a 3-inch by 6-inch cylinder. The mix sheets are included in Appendix A.

Volume of Materials

All volumes are summed to ensure the volume of one 3”x6” cylinder (42.41in^3) is filled

Known
Material specific gravity – SG
Density of water = 62.4 lb/ft^3
Mass of material used = X (g)

Example: Portland SG = 3.15
Portland used = 239.2g

Conversion Factors
Grams per pound: 453.59 g/lb
Cubic inches per cubic foot: 1728 in^3/ft^3

$$Volume(in^3) = \frac{Mass(g) / 453.59\frac{g}{lb}}{SG \times 62.4\frac{lb}{ft^3}} \times 1728\frac{in^3}{ft^3} \qquad (1)$$

$$Portland\ Cement\ Volume\ (in^3) = \frac{239.2g / 453.59\frac{g}{lb}}{3.15 \times 62.4\frac{lb}{ft^3}} \times 1728\frac{in^3}{ft^3} = 4.363 in^3 of\ Portland \qquad (2)$$

Equation 1&2 were used to determine the volume that each material occupied in the 3” x 6” cylinder. This ensured that the concrete materials adequately filled the entire cylinder mold to perform proper testing.

Water for Aggregate SSD

All aggregate totals are summed to give the total amount of water to achieve saturated surface dry SSD conditions.

Known

Aggregate absorption percentage – Abs. (%) Example: Limestone abs. = 2.5%

Mass of aggregate used = X (g) Limestone used = 788.3g

$$Water\ \ for\ SSD\,(g) = Absorption(\%) \times Mass(g) \tag{3}$$

$$Limestone\ SSD\,Water\ (g) = 2.5\% \times 788.3g = 19.7g\ of\ Water \tag{4}$$

Equation 3&4 were used to determine the additional water necessary to create an SSD condition for the construction sand, limestone, and the recycled aggregates used. The recycled aggregates include the plastics, alum residual, and GAC/PAC.

Water-to-Cement Ratio (W/C ratio)

This is used to dose the water to achieve the proper W/C ratio after aggregates are in SSD condition.

Known

W/C ratio = Water (g)/Cements (g) Example: W/C ratio = 0.40

Mass of total cements used = X (g) Cements used = 239.2g

$$Water(g) = {}^{W}\!/_{C}\ ratio \times Mass(g) \tag{5}$$

$$Water(g) = 0.40 \times 239.2g = 95.7g\ of\ Water \tag{6}$$

Equation 5&6 change directly with the amount of cements used and the selected water-to-cement ratio. This experiment held the W/C ratio consistent at 0.40 and this is used to back-calculate the amount of water needed based on the total amount of cements.

Fine Aggregate Replacement (by Volume) of Recycled Aggregates

This system of equations was used to determine the mass of the recycled aggregate based on the SG of each material. This equation determines both fine aggregate and recycled aggregate in the mix in grams.

Known
Material specific gravity– (SG)
Density of water = 62.4 lb/ft^3
Percent replacement = X (%)

Example:
Constr. Sand (SG) = 2.65
Plastic (SG) = 0.50
Percent replacement = 2.5%

Conversion Factors
Grams per Pound: 453.59 g/lb
Cubic Inches per Cubic Foot: 1728 in^3/ft^3

Step 1 – Determine New Fine Aggregate Volume

$$New\ Fine\ Aggregate\ \ Volume\,(in^3) = (Eq.1)\times[1 - X(\%)] \tag{7}$$

$$New\ \ Constr.\ \ Sand\ \ Volume\,(in^3) = (14.053 in^3)\times[1-2.5\%] = 13.072 in^3 of\ \ Sand \tag{8}$$

Step 2 – Determine New Recycled Aggregate Volume

$$\mathrm{Recycled}\ Aggregate\ \ Volume\,(in^3) = (Eq.1)\times X(\%) \tag{9}$$

$$Plastic\ \ Aggregate\ \ Volume\,(in^3) = (14.053 in^3)\times 2.5\% = 0.351 in^3 of\ \ Plastic \tag{10}$$

Step 3 – Calculate New Fine Aggregate Mass (g)

$$Mass\ of\ \ Fine\ \ Aggregate\,(g) = (Eq.4)\times Fine\ \ Agg.(SG)\times 62.4\frac{lb}{ft^3}\times\frac{1 ft^3}{1728 in^3}\times 453.59\frac{g}{lb} \tag{11}$$

$$Mass\ of\ \ Constr.Sand\ (g) = 13.072 in^3\times 2.65\times 62.4\frac{lb}{ft^3}\times\frac{1 ft^3}{1728 in^3}\times 453.59\frac{g}{lb} = 594.7 g\ of\ \ Sand \tag{12}$$

Step 4 – Calculate New Recycled Aggregate Mass (g)

$$Mass\ of\ \ \mathrm{Recycled}\ Aggregate\,(g) = (Eq.5)\times \mathrm{Recycled}\ Agg.(SG)\times 62.4\frac{lb}{ft^3}\times\frac{1 ft^3}{1728 in^3}\times 453.59\frac{g}{lb} \tag{13}$$

$$Mass\ of\ \ Plastic\ (g) = 0.351 in^3\times 0.50\times 62.4\frac{lb}{ft^3}\times\frac{1 ft^3}{1728 in^3}\times 453.59\frac{g}{lb} = 2.9 g\ of\ \ Plastic \tag{14}$$

The equations listed were used to determine all parts of the MS Excel spreadsheet shown in Appendix A. In addition, a few assumptions and fixed variables were included to maintain consistency and allow results from compression testing to be compared. The W/C ratio was held at a consistent 0.40for all nine mixes to promote workability. The specific gravities of all mix components stayed the same throughout development. The individual absorption rates of each aggregate remained constant. The amount of #8 limestone in all nine mixes remained constant at 788.3g, which made up 56% of the total aggregate volume. The amount of entrapped air was assumed to be 3% of the total cylinder volume (1.272in^3). The amount of cementitious material, either Portland cement or a combination of cements (Portland, slag and silica fume), remained at 239.2 grams per 3”x6” cylinder. The mix design chosen was a modification based off a “rule of thumb” for concrete, which consists of 1 part cement, 2 parts sand, and 3 parts gravel. The final ratio of the ingredients was 1:2.5:3.3; because the amount of cement was kept constant, the aggregates had higher ratios to fill the remaining volume.

The two mixes utilizing a combination of cements, Cements Mix and Composite Mix, had a ratio of 55% Portland cement to total cementitious material (by mass), 40% slag cement to total cementitious material, and 5% silica fume to total cementitious material. The slag replacement at 40% was chosen because typically the percentage of slag cement for maximum compressive strength is between 40 and 50 percent.[7] The silica fume replacement was chosen at 5% because it is usually dosed at between 4 - 15% of the cement mass to produce high performance concrete.[8] The percentages chosen between the two ranges were at the discretion of the mix developer.

When using the recycled aggregates, several mixes were developed at varying percent replacements of the fine aggregate (construction sand). The plastic material used in the Plastics 2.5 mix had a 2.5% replacement of fine aggregates by volume. The plastic material used in the Plastics 5.0 mix had a 5.0% replacement of fine aggregates by volume. Plastic was also used in the Composite mix at 7.5% replacement of fine aggregate, in addition to the cement combination previously stated. The alum residual used in Alum 5.0 had a 5.0% replacement of fine aggregates by volume. Likewise, Alum 10.0 and Alum 20.0 had 10% and 20% replacement of fine aggregates, respectively. The GAC/PAC percentage replacements followed the same format with GAC/PAC 5 and GAC/PAC 10. These percentage replacements were chosen at the discretion of the mix developer.

MIX PROCEDURES

Preparing 3"x6" Cylinder Mold

Since sustainability was a main goal of the project, a new removal method was utilized to enable cylinder molds themselves to be recycled. Originally to produce the 72 test specimens, 72 total 3" x 6" cylinder molds would have been needed for the testing process. With the use of this method the total number of cylinder mold used was reduced to 24, which is a 67% decrease in the original estimate. This was achieved by using air to de-cap the cylinders instead of the traditional method of cutting and scrapping the cylinder mold. The cylinder molds were prepared as follows:

Step 1

Gather all materials, as shown in Figure 1:

- 3"x6" cylinder molds
- Power drill
- ¼" drill bit
- Tape
- Marker
- Safety equipment

Figure 1: Prepping 3"x6" Cylinder Molds

Step 2

Use power drill to bore a hole on the bottom of the 3"x6" cylinder (as centered as possible), as shown in Figure 2.

Step 3

Place tape over the hole while filling the cylinder

Step 4

Place cylinder upside-down on a flat surface and remove tape after concrete has set. Use air compressor with ¼" nozzle to remove the 3"x6" test specimen via compressed air removal.

Figure 2: Drilled 3"x6" Cylinders

Standard Mix Procedure

This mix procedure was used for seven of the nine mixes. These mixes include: Control Mix, Alum 5.0, Alum 10.0, Alum 20.0, Plastics 2.5, Plastics 5.0, and GAC/PAC 10.0. These mixes contained only Portland type I cement as the cementitious binder.

The mix scale is $42.41in^3$ ($0.0245ft^3$), which is the standard volume for a 3" x 6" cylinder. The absorption rates for the aggregates were determined to dose the proper water into the mix before cement was added to obtain a saturated surface dry (SSD) condition for all aggregates.

Materials:

- Large mixing bowl
- Trowel
- Rod
- Spoon
- 4 – Quart Containers
- 3x6 Testing Cylinder
- 3x6 Cylinder Cap

Step 1

Measure all cements, aggregates and water.

Step 2

Dose all aggregates to the mixing bowl with sufficient water to reach SSD conditions.
Mix for one minute.

Step 3

Add cements to the SSD aggregates and dose remaining water to achieve proper water-to-cement ratio (W/C).
Mix for three minutes.

Step 4

Stop mixing and let the ingredients rest for two minutes.

Step 5

Resume mixing for two minutes.

Step 6

End the mixing process and begin loading 3”x6” testing cylinder.

Total Mix Time: 8 minutes

Silica Fume Mix Procedure

This mix procedure was used for two of the nine mixes. These mixes include the Cements and Composite mixes. Both mixes contain three cementitious materials: Portland type I, slag cement, and silica fume. With the use of silica fume, a mix procedure was utilizedto properly incorporate and disperse silica fume into the concrete mix. To remain consistent between the two mix methods, the total mixing time followed the 3 minutes mixing, 2 minutes rest, followed by 3 minutes mixing (the timing used for the other seven mixes), instead of the 5 minutes, 3 minutes, 5 minutes outlined in the silica fume procedure.

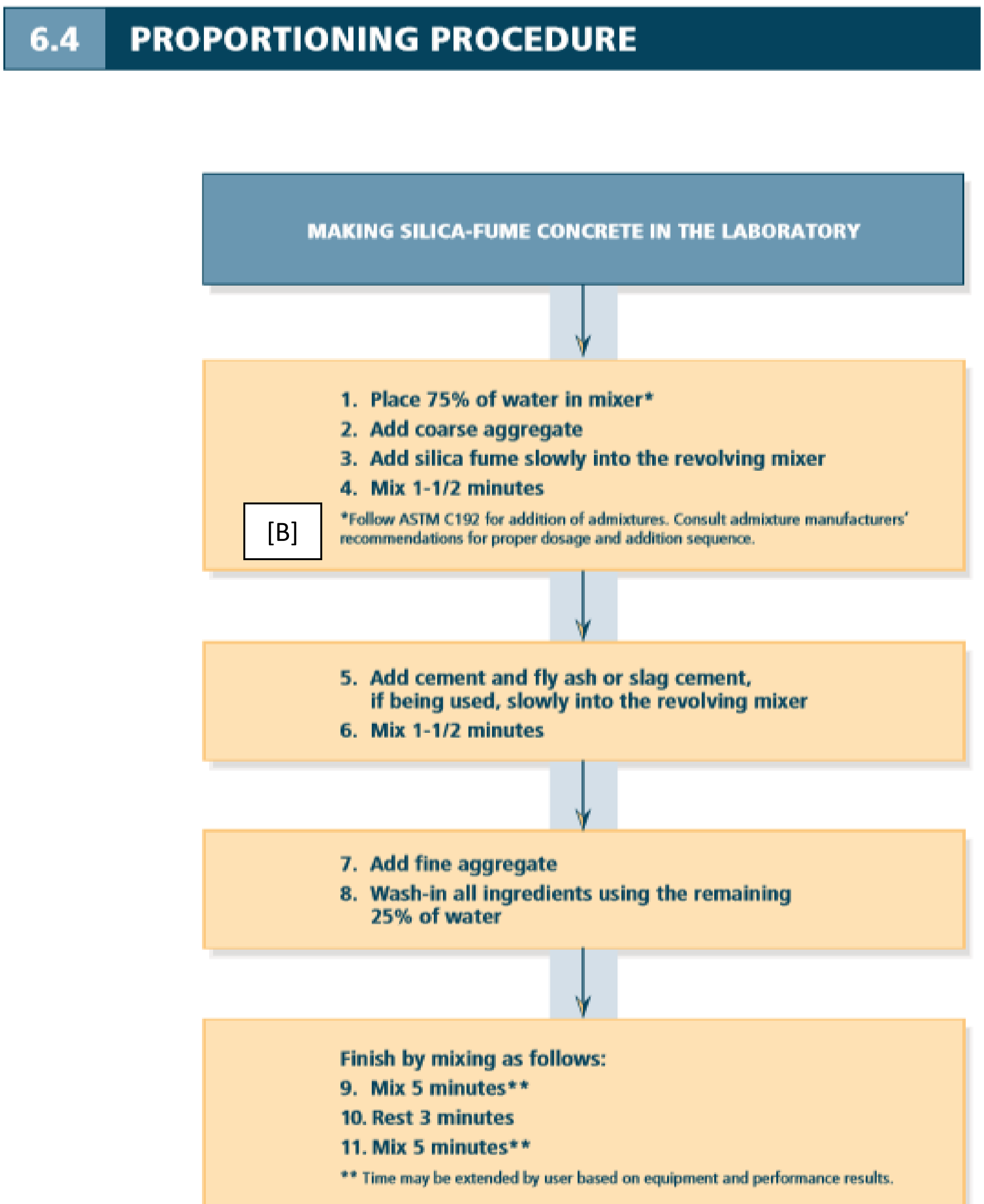

Figure 3: Procedure for Making Silica-fume Concrete in Lab [8]

RESULTS/DISCUSSION

The intended goal of this project is to compare the compressive strength of conventional concrete to the compressive strength of concrete made using recycled materials. The average compressive strengths for the nine mixes are shown in Table 2 based on compressive strengths tested per ASTM C39/C39M[C].

Table 2: Average Strengths of Concrete

Control Mix		Cements Mix		GAC/PAC 5 and 10 *DID NOT SET	
Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)
0	0	0	0	0	N/a
7	5831	7	6279	7	N/a
14	6472	14	7594	14	N/a
28	7185	28	8667	28	N/a
Plastics 2.5		**Plastics 5.0**		**Composite Mix**	
Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)
0	0	0	0	0	0
7	5317	7	4574	7	5680
14	5732	14	4899	14	6097
28	5930	28	4966	28	6664
Alum 5.0		**Alum 10.0**		**Alum 20.0 *DID NOT SET**	
Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)	Curing Time (days)	Average Strength (psi)
0	0	0	0	0	N/a
7	4425	7	4231	7	N/a
14	5739	14	5681	14	N/a
28	6596	28	6093	28	N/a

The average 7-day, 14-day, and 28-day compressive strengths for all nine mixes are listed in Table 1 above. The Control mix was considered the baseline mix to compare all compressive strengths in the remaining eight mixes. The average strengths are displayed for all nine mixes except for the GAC/PAC mixes and Alum 20.0. These mixes did not have any compressive results during testing. The GAC/PAC and Alum 20.0 mixes were left 24 hours to set; however, the mixes did not harden in that time period.

The mixes were compared to the Control mix by grouping similar mixes together and comparing the 7-day, 14-day, and 28-day compressive strengths. The first grouping was between the Control and Cements mix, to determine the effect of the addition of sustainable cements (slag and silica fume) on compressive strength relative to traditional Portland cement. The next grouping was plastics, which contained Control, Plastic 2.5, and Plastic 5.0 compressive results. The next grouping contained alum residual mixes (5.0, 10.0, and 20.0) compared to the Control mix strength. Lastly, the Composite mix was formed using 7.5% plastic replacement of fine aggregates and the sustainable cement combination (55% Portland cement, 40% slag, and 5% silica fume) compared to the Control and Cements mix.

The first round of testing compared the results from the Control Mix and Cements Mix, as shown in Figure 4. These results were used to determine the benefit of the addition of slag cement and silica fume as a weight percentage replacement of traditional Portland cement. The resulting compressive strengths showed a change of 7.7% at seven days. The 14-day strengths exhibiteda 17.3% increase from the Cements mix compared to the Control mix. The 28-day strength (assumed to be 100% compressive strength) yielded a 20.6% average increase. The addition of the two sustainable cements resulted in an increase in compressive strength during testing and produced an average compressive strength of 8667 psi at 28-days, compared to 7185psi for the Control mix. The Cements mix showed that with addition of the two supplemental cements the compressive strength of this concrete mixture will increase.

The benefits of the addition of slag cement and silica fume can be seen in a couple of different ways. The increase of strength achieved by incorporating these materials can reduce the overall materials needed. For example, a column requiring a 12” x 12” size at a lower strength concrete can be reduced to 10” x 10” or smaller by using higher strength, which saves material. This would correspond to cost saving for the reduction in material needed because of the higher strength concrete. Additionally, the 55% Portland cement, 40% slag, and 5% silica fume reduces the amount of Portland cement if it were used at 100% from 580 lbs/yd^3 to 320 lbs/yd^3 based on the Cements mix design.

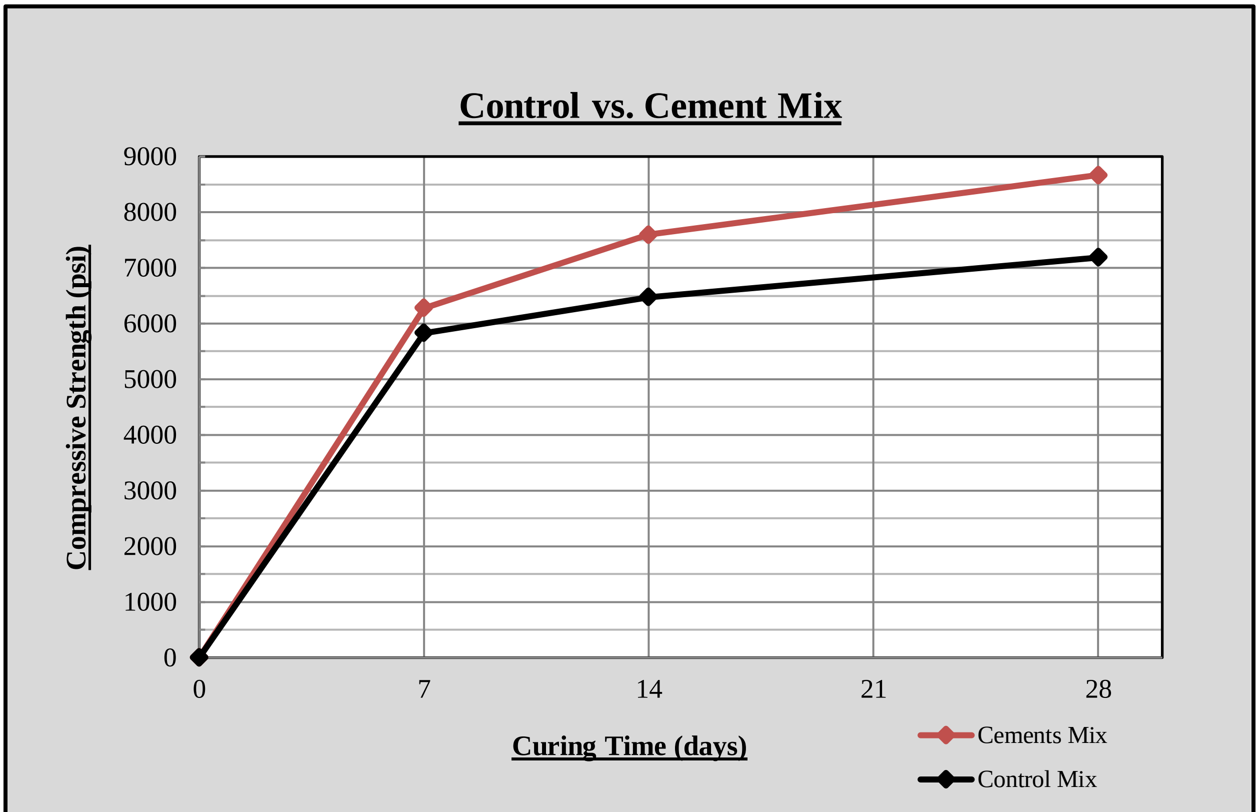

Figure 4: Control and Cement Mix Compressive Results

Testing continued by utilizing plastics as a percentage replacement of the fine aggregate in the mix development. The percentages of plastics were a 2.5% replacement of fines and a 5.0% replacement of fines and were selected assuming the addition of plastic would negatively affect the compressive strength. The replacement percentage values corresponded to 1.1% and 2.2% of the total aggregate volume in the mixes, respectively. The replacement of plastics at 2.5% and 5.0% both resulted in decreases in compressive strength at 7-, 14-, and 28-days, as shown in Figure 5. The 7-day strength of the Plastic 2.5 mix yielded a percentage change of -8.8%, and Plastic 5.0 yielded a percentage change of -21.6% when compared to the Control mix. Both mixes resulted in a decrease of the 28-day strength (2.5: -17.5%, 5.0: -30.9%) compared to the Control mix. The addition of plastic aggregate in the concrete results in a decrease in compressive strength. The decrease in compressive strength was expected with the plastics material, and results show an almost linear decrease in strength corresponding with the percent increase of plastics in the concrete. This trend is expected to follow a decrease in compressive strength with higher plastic dosages.

The coarse snow material (shredded plastic) was used to simulate shredded plastic bags. However, further research can be conducted to determine if the utilization of other plastic materials would provide different compressive results in concrete. The materials could include shredded bottles and/ or containers that are composed of a more ridged plastic body and could possibly result in stronger plastic composite mixes.

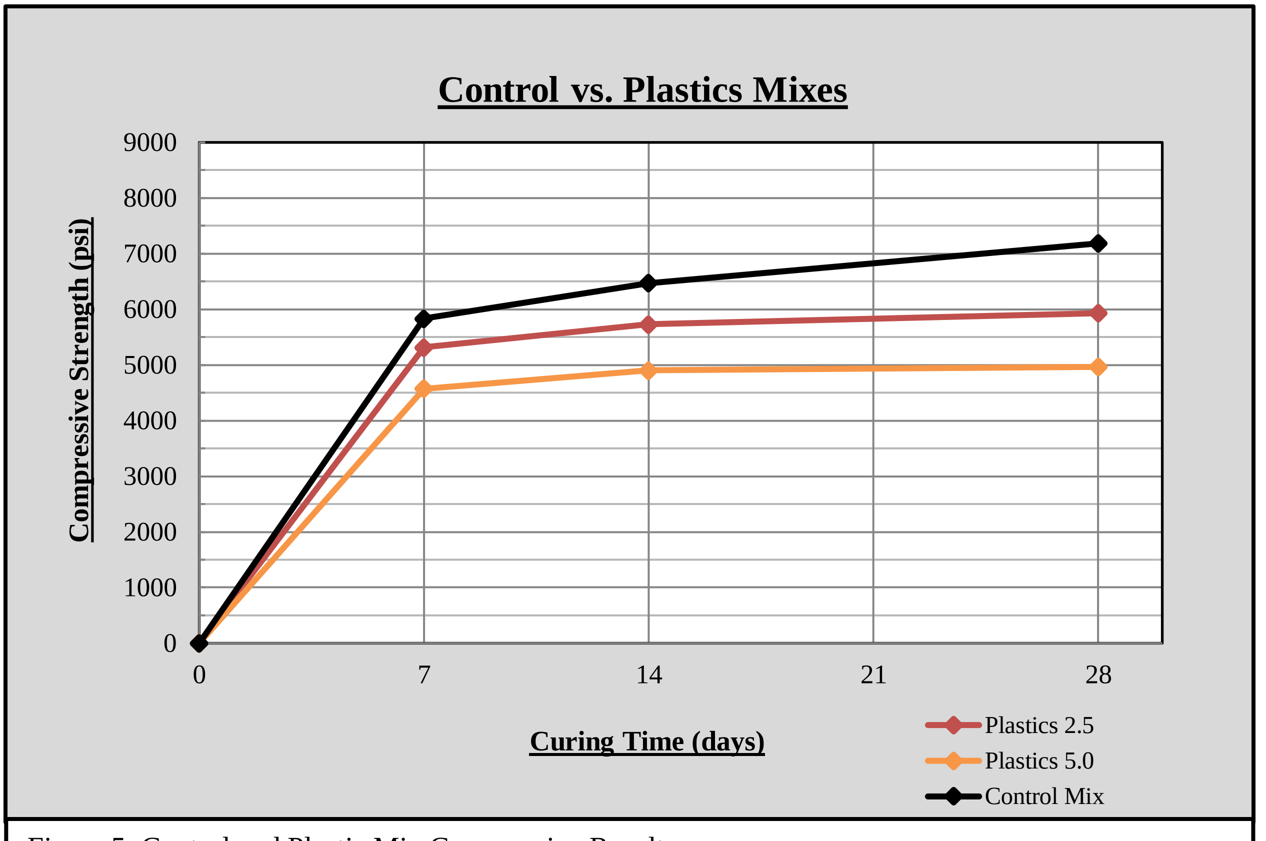

Figure 5: Control and Plastic Mix Compressive Results

Before the mix design sheet was created for alum replacement percentages the absorption rate of the material needed to be determine. This was important to determine the SSD conditions for the alum residual in order to dose the proper amount of additional water. The results are shown in Table 3, which outlines alum's absorption rate.

Table 3: Alum Absorption Rates	
[A]: Mass of Oven Dry Sample (g)	515.6
[B]: Mass of SSD Sample (g)	531.1
[C]: Difference (g) = [B]-[A]	15.5
Absorption (%) = [C]/[A] *100	3.0%

The alum residual was utilized at three separate percentage replacements of the fine aggregate. The mixes consisted of a 5.0%, 10.0%, and 20.0% replacement, as shown in Figure 6. The 20% replacement mix was very dry and difficult to pack into the 3"x6" cylinder, which ultimately did not produce compressive results. Alum 5.0 and Alum 10.0 both yielded a decrease in compressive strength for 7-, 14-, and 28-day strengths. The 28-day strength for Alum 5.0 exhibited an average percent changeof -8.2% and Alum 10.0 at -15.2% with respect to the Control mix. The 7- and 14-day strengths for Alum 5.0 and Alum 10.0 produced similar compressive strengths, with a 4.4% and 1.0% difference between the two mixes, respectively. However, the compressive strength of these test cylinders, shown in Appendix B, did not produce consistent breaks, which can skew the results. While the alum residual produced a decrease in compressive strength in the concrete, the difference was less than that of the plastic mixes. Therefore, the percentage replacement of alum is feasible below 20% aggregate replacement.

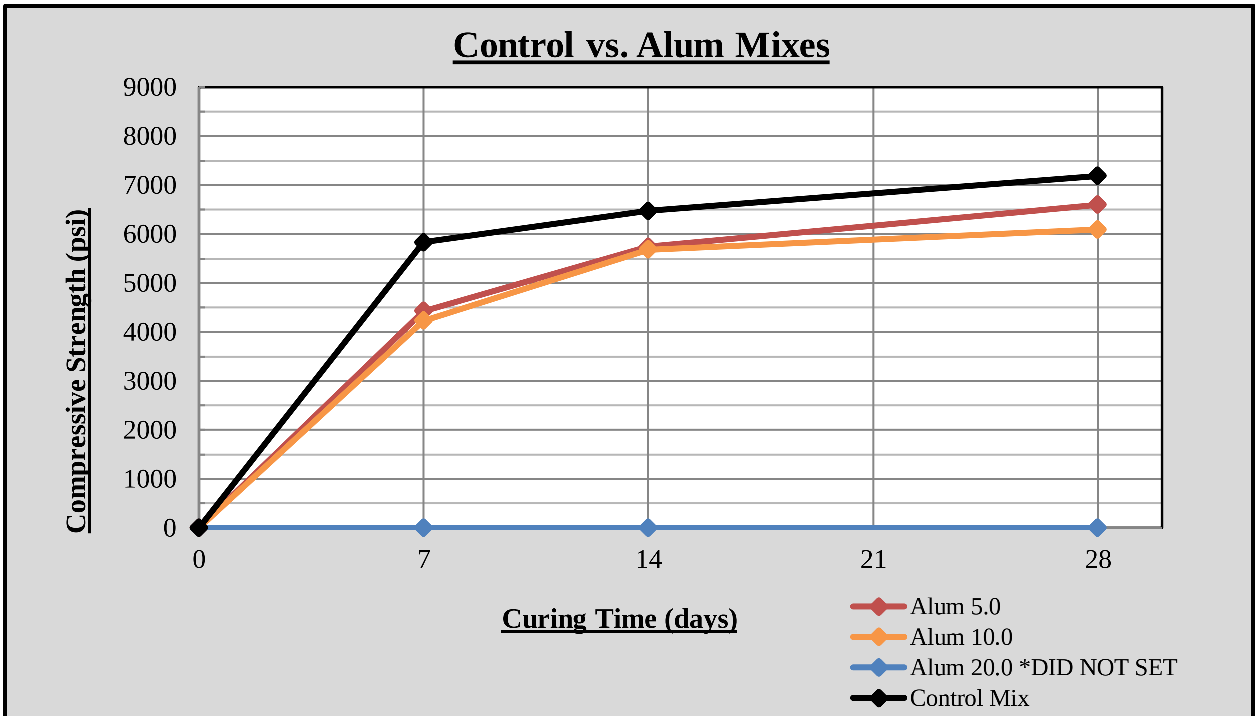

Figure 6: Control and Alum Mix Compressive Results

Afterobtaining the results from the Plastic and Cements mixes, the development progressed with a Composite mix that contained the cement combination and 7.5% plastic replacement of fine aggregate. The recycled aggregate replacement was 3.3% of the total aggregate volume of the mix design. With the utilization of the cement combination explored in earlier testing (55% Portland cement, 40% slag, and 5% silica fume), the Composite mix obtained higher compressive strengths than the Plastic 5.0 at a higher replacement percentage. Figure 7 displays the Composite mix results as follows: 7-day is a -2.6% percentage change, 14-day is a -5.8% percentage change, and 28-day yields a -7.3% percentage change when compared to Control mix. These results are in increase from the 7-, 14-, and 28-day compressive results for Plastic 5.0 (7: -21.6%, 14: -24.3%, and 28: -30.9%). The increase in compressive strength is due to the cement combination. This showsthat by utilizing the sustainable cements, a higher dosage of recycled aggregates can be used to produce higher compressive strengths.

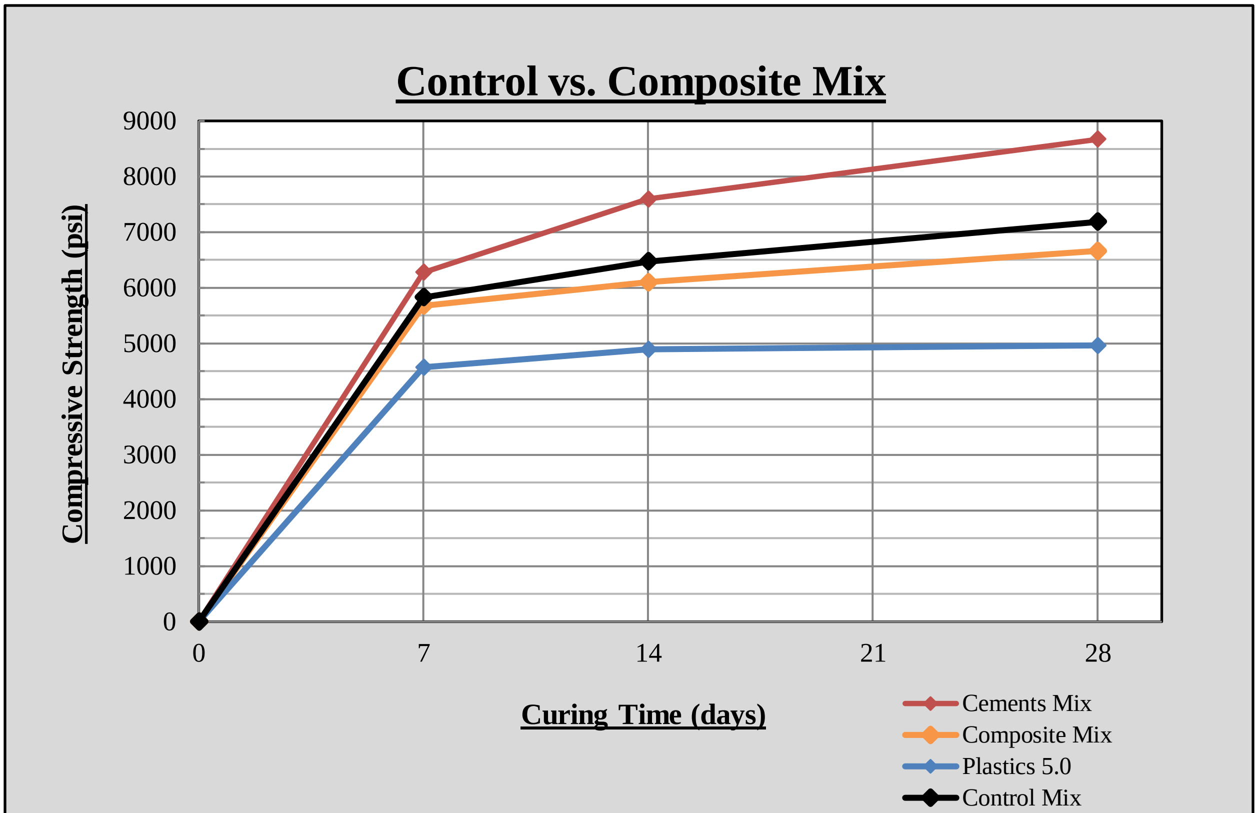

Figure 7: Control and Composite Mix Compressive Results

Before the mix design sheet was created for GAC/PAC replacement percentages the absorption rate of the material needed to be determine. This was important to determine the SSD conditions for the GAC/PAC material in order to dose the proper amount of additional water. The results can be seen in Table 4 which outlines GAC/PAC's absorption rate.

Table 4: GAC/PAC Absorption Rates	
[A]: Mass of Oven Dry Sample (g)	548
[B]: Mass of SSD Sample (g)	767.3
[C]: Difference (g) = [B]-[A]	219.3
Absorption (%) = [C]/[A] *100	40.0%

The GAC/PAC was tested at three different replacement percentages of the fine aggregate: 5%, 10%, and 20% replacement. The cylinder composites were given 24 hours to set before they were placed into the curing room. However, at all three replacement percentages the test cylinders did not harden and broke apart. The consistency was that of a malleable clay and compressive results were unable to be obtained.

The testing and development of the sustainable cements and recycled aggregates showed a variety of results. The sustainable cements produced an increase in the ultimate strength of the concrete with a 40% replacement of Portland cement with slag cement by mass and the addition of the 5% replacement of Portland cement with silica fume by mass. The Plastic 2.5 mix yielded lower compressive strengths when compared to the Control. Based on the results from the Plastic 5.0 mix, additional plastic replacement of fine aggregates will cause the compressive strength to decrease. The alum residual mixes (Alum 5.0, 10.0, and 20.0) all resulted in lower compressive strengths than the control mix. Alum 5.0 and 10.0 yielded similar compressive strengths when compared to each other's 7-, 14-, and 28-day results, as shown in Table 1. Building upon the results for the Cement mix and Plastic mixes, the Composite mix was tested. The results show that when the cement combination is utilized, the percentage of recycled aggregate can also be increased to produce 28-day strength within 7.5% ofthe Control mix.

CONCLUSION

The addition of recycled aggregates and/or sustainable cements in concrete produces a difference in compressive strengths of concrete. The difference in compressive strength is related to the material being incorporated in the mix design and can be a percentage increase or decrease. During the experiment, plastics, alum residual, granule/powered active carbon, Lafarge slag cement, and Lafarge silica fume were tested. The mix containing a combination of sustainable cements (Cement mix) yielded a percentage increase in compressive strengths, while the mixes containing the recycled aggregates yielded a percentagedecrease in compressive strength when compared to the Control mix.

The Cements mix achieved the highest compressive strength during testing and development. It achieved an average 28-day strength of 8667 psi, compared to the Control mix at 7185 psi. Neglecting the non-setting cylinders, Alum 20.0 and the GAC/PAC cylinders, the lowest strength cylinder was Plastic 5.0. Plastic 5.0 achieved a 28-day strength of 4966 psi, compared to the Control mix at 7185 psi. To achieve a greater volume of recycled aggregates in the mix, the cement combination was added to a 7.5% replacement of fines with plastic.

The Composite mix integrated the highest amount of plastics in this study. If traditional type I Portland cement was used, as opposed to the cement combination, the 7.5% replace of fines with plastic would have produced lower compressive results than the 5.0% replacement. However, the utilization of the slag cement and silica fume produced higher compressive strengths than any other recycled/sustainable mix during testing. The 28-day strength achieved was 6664 psi,which is a mere 7.3% decrease from the Control Mix (7185 psi). The benefit of this mix is that it contains the highest amounts of recycled material and sustainable cements.

The overall results of the experiment show that with the addition of the byproduct cements it is possible to increase the compressive strength of the concrete. Additionally, the percent replacements of the abundant waste material caused a decrease in the compressive strength of the cylinder, but maintain strength above 4000 psi, as shown in Table 2. The addition of waste material in concrete will benefit the construction industry by prolonging the life of conventional aggregates by replacing a percentage with recycled aggregate. Furthermore, there is an abundant supply of the materials (plastic [plastic bags], alum residual, slag cement, and silica fume) to be utilized. The goal would be to normalize the use of these materials in the construction industry to lower concretes carbon footprint. Further research and development could promote a more sustainable concrete for implementation in the future.

FUTURE RESEARCH

My recommendations for further research into recycled aggregates are to explore admixtures, adjust W/C ratio, and add more sustainable aggregates, and study different slag and silica fume combinations. The addition of admixtures can improve workability of the concrete as well as aid in the reduction of the W/C ratio. A reduction in the W/C ratio theoretically should increase strength in concrete. With the improved workability it could be possible to dose recycled aggregates at higher amounts. Experimenting with different ratios of slag and silica fume to achieve the optimum workability and strength could also be explored. Continuing to develop composite cylinders with the sustainable cements and aggregates will be the best course of action for future research.

Possible testing to explore:

- Tensile properties of plastic cylinders compared to conventional reinforcement fibers
- Flexural tension of plastic specimens
- Cost-to-benefit ratio of addition of recycled aggregates
- Large-scale batching testing
- Air content testing
- Slump testing

APPENDIX A - MIX DESIGN SHEETS

2016/2017 Mix Design Sheet				Recycled Aggregate Project	Cylinder Test Name	
					Control Mix	
Cementitious Material	***Specific Gravity***	***Mass (g)***	***Volume (in ^{3})***	***Percentage***	***C/CM RATIO***	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.2**	**4.64**	100.0%		
AGGREGATES				***Absorption***	**Volume (%)**	
# 8 Limestone (Washed)	2.70	788.30	17.825	2.5%	56.0%	
Construction Sand	2.65	607.90	14.005	3.0%	44.0%	
TOTAL =		**1396.20**	**31.83**		**100.0%**	
WATER						
For Aggregates (SSD)	1.00	37.94	2.317		**W/C Ratio**	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**133.6**	**8.16**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		**1769.0**	**43.58**	**Good**		
Cylinder Volume:			**42.41 in^3**			
Theoretical Density:			**154.6 *lbs/ft^3***	**Estimated weight:**		**1721.6**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12^3/42.41				***lbs/ft^3***		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was decreased from .42 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Control Mix Revised was very wet (washed limestone most likely cause) dose limstone dry

cyl + mix = 1728.3 grams, used all material

Adjust course fine percentage to 56% : 44% respectively, increase 3% to fill cylinder

2016/2017 Mix Design Sheet			Recycled Aggregate Project		Cylinder Test Name	
					Cements Mix	
CEMENTITIOUS MATERIAL	*Specific Gravity*	*Mass (g)*	*Volume (in ^{3})*	*Percentage*	*C/CM RATIO*	
Portland Type I	3.15	131.50	2.549	55.0%	**55.0%**	
Slag	2.94	95.80	1.989	40.0%		
Silica Fume	2.20	12.00	0.333	5.0%		
TOTAL =		**239.3**	**4.87**	100.0%		
AGGREGATES				*Absorption*	Volume (%)	
# 8 Limestone (washed)	2.70	788.30	17.825	2.5%	56.0%	
Construction Sand	2.65	607.90	14.005	3.0%	44.0%	
TOTAL =		**1396.2**	**31.83**		**100.0%**	
WATER						
For Aggregates (SSD)	1.00	37.94	2.317		W/C Ratio	
Additional Water	1.00	95.72	5.844		**0.40**	
TOTAL =		**133.7**	**8.16**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.0**	**1.272**			
GRAND TOTAL =		**1769.2**	**43.82**	**Good**		
Cylinder Volume:			**42.41** in^3			
Theoretical Density:			**153.8** *lbs/ft^3*	**Estimated weight:**		**1712.4**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12^3/42.41				***lbs/ft^3***		
Material Remaining (g):				**Grams**		

Notes: **Following mix procedure on Silica fume reference**

2016/2017 Mix Design Sheet				Recycled Aggregate Project	Cylinder Test Name	
					Plastics 2.5	
CEMENTITIOUS MATERIAL	*Specific Gravity*	*Mass (g)*	*Volume (in³)*	*Percentage*	*C/CM RATIO*	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.2**	**4.64**	100.0%		
AGGREGATES				*Absorption*	Volume (%)	Replace %
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	594.7	13.702	3.0%	43.0%	97.5%
Plastics	0.50	2.9	0.351	1.0%	1.1%	2.5%
TOTAL =		**1385.9**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	37.58	2.294		W/C Ratio	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**133.3**	**8.14**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.0**	**1.272**			
GRAND TOTAL =		1758.4	43.63	Good		
Cylinder Volume:			42.41 in³			
Theoretical Density:			153.5 *lbs/ft³*	**Estimated weight:**		1709.4
Actual Cylinder Weight:				Grams		
Calculated Density: D = (mass(g)/453.59)*12³/42.41				*lbs/ft³*		
Material Remaining (g):				Grams		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumption of SG of Plastic is .5 (floating on water)

2016/2017 Mix Design Sheet			Recycled Aggregate Project		Cylinder Test Name	
					Plastics 5.0	
CEMENTITIOUS MATERIAL	*Specific Gravity*	*Mass (g)*	*Volume (in^3)*	*Percentage*	*C/CM RATIO*	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.20**	**4.64**	100.0%		
AGGREGATES				*Absorption*	Volume (%)	Replace %
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	579.5	13.350	3.0%	41.9%	95.0%
Plastics	0.50	5.8	0.703	1.0%	2.2%	5.0%
TOTAL =		**1373.54**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	37.15	2.268		W/C Ratio	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**132.8**	**8.11**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		**1745.6**	**43.63**	**Good**		
Cylinder Volume:			**42.41** in^3			
Theoretical Density:			**152.4** *lbs/ft^3*	**Estimated weight:**		**1696.9**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12^3/42.41				*lbs/ft^3*		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumption of SG of Plastic is .5 (floating on water)

2016/2017 Mix Design Sheet				RECYCLED AGGREGATE PROJECT	Cylinder Test Name	
					GPC/PAC 10	
CEMENTITIOUS MATERIAL	***Specific Gravity***	***Mass (g)***	***Volume (in ^{3})***	***Percentage***	***C/CM RATIO***	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.20**	**4.64**	100.0%		
AGGREGATES				***Absorption***	**Volume (%)**	**Replace %**
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	549.0	12.648	3.0%	39.7%	90.0%
GAC/PAC	2.00	46.0	1.405	40.0%	4.4%	10.0%
TOTAL =		**1383.32**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	54.59	3.333		**W/C Ratio**	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**150.3**	**9.17**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		**1772.8**	**43.63**	**Good**		
Cylinder Volume:			**42.41** in ^{3}			
Theoretical Density:			**154.8** *lbs/ft ^{3}*	**Estimated weight:**		**1723.4**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12 ^{3}/42.41				***lbs/ft ^{3}***		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumed SG 2.00

2016/2017 Mix Design Sheet			RECYCLED AGGREGATE PROJECT		Cylinder Test Name	
					ALUM 5.0	
CEMENTITIOUS MATERIAL	*Specific Gravity*	*Mass (g)*	*Volume (in^3)*	*Percentage*	*C/CM RATIO*	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.20**	**4.64**	100.0%		
AGGREGATES				*Absorption*	Volume (%)	Replace %
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	579.5	13.350	3.0%	41.9%	95.0%
ALUM	1.90	21.9	0.703	12.0%	2.2%	5.0%
TOTAL =		**1389.65**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	39.72	2.425		W/C Ratio	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**135.4**	**8.27**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		**1764.2**	**43.63**	**Good**		
Cylinder Volume:			**42.41 in^3**			
Theoretical Density:			**154.1** *lbs/ft³*	**Estimated weight:**		**1715.1**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12³/42.41				*lbs/ft³*		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumed SG 1.34, ADJUSTED TO 1.9

Moved absorption from 3% to 12%

2016/2017 Mix Design Sheet			RECYCLED AGGREGATE PROJECT		Cylinder Test Name	
					ALUM 10.0	
CEMENTITIOUS MATERIAL	***Specific Gravity***	***Mass (g)***	***Volume (in^3)***	***Percentage***	***C/CM RATIO***	
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**	
Slag	2.94		0.000	0.0%		
Silica Fume	2.20		0.000	0.0%		
TOTAL =		**239.20**	**4.64**	100.0%		
AGGREGATES				***Absorption***	**Volume (%)**	**Replace %**
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	549.0	12.648	3.0%	39.7%	90.0%
ALUM	1.90	43.7	1.405	12.0%	4.4%	10.0%
TOTAL =		**1381.02**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	41.43	2.529		**W/C Ratio**	
Additional Water	1.00	95.68	5.841		**0.40**	
TOTAL =		**137.1**	**8.37**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		**1757.3**	**43.63**	**Good**		
Cylinder Volume:			**42.41** in^3			
Theoretical Density:			**153.5** ***lbs/ft^3***	**Estimated weight:**		**1708.3**
Actual Cylinder Weight:				**Grams**		
Calculated Density: $D = (mass(g)/453.59)*12^3/42.41$				***lbs/ft^3***		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumed SG 1.34, ADJUSTED TO 1.9

Moved absorption from 3% to 12%

2016/2017 Mix Design Sheet				Recycled Aggregate Project		Cylinder Test Name: ALUM 20.0	
CEMENTITIOUS MATERIAL	***Specific Gravity***	***Mass (g)***	***Volume (in^3)***	***Percentage***	***C/CM RATIO***		
Portland Type I	3.15	239.2	4.636	100.0%	**100.0%**		
Slag	2.94		0.000	0.0%			
Silica Fume	2.20		0.000	0.0%			
TOTAL =		**239.20**	**4.64**	100.0%			
AGGREGATES				***Absorption***	**Volume (%)**	**Replace %**	
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%		
Construction Sand	2.65	488.0	11.242	3.0%	35.3%	80.0%	
ALUM	1.90	87.5	2.811	12.0%	8.8%	20.0%	
TOTAL =		**1363.76**	**31.88**		**100.0%**	**100.0%**	
WATER							
For Aggregates (SSD)	1.00	44.84	2.738		**W/C Ratio**		
Additional Water	1.00	95.68	5.841		**0.40**		
TOTAL =		**140.5**	**8.58**				
AIR							
Air	3%	0.00	1.272				
TOTAL =		**0.000**	**1.272**				
GRAND TOTAL =		**1743.5**	**43.63**	**Good**			
Cylinder Volume:			**42.41 in^3**				
Theoretical Density:			**152.2** *lbs/ft^3*	**Estimated weight:**		**1694.9**	
Actual Cylinder Weight:				**Grams**			
Calculated Density: D = (mass(g)/453.59)*12^3/42.41				*lbs/ft^3*			
Material Remaining (g):				**Grams**			

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumed SG 1.34, ADJUSTED TO 1.9

2016/2017 Mix Design Sheet			RECYCLED AGGREGATE PROJECT		Cylinder Test Name	
					Composite Mix	
CEMENTITIOUS MATERIAL	*Specific Gravity*	*Mass (g)*	*Volume (in³)*	*Percentage*	*C/CM RATIO*	
Portland Type I	3.15	131.50	2.549	55.0%	**55.0%**	
Slag	2.94	95.80	1.989	40.0%		
Silica Fume	2.20	12.00	0.333	5.0%		
TOTAL =		**239.30**	**4.87**	100.0%		
AGGREGATES				*Absorption*	Volume (%)	Replace %
# 8 Limestone (Washed)	2.70	788.3	17.825	2.5%	55.9%	
Construction Sand	2.65	564.2	12.999	3.0%	40.8%	92.5%
Plastics	0.50	8.6	1.054	1.0%	3.3%	7.5%
TOTAL =		**1361.17**	**31.88**		**100.0%**	**100.0%**
WATER						
For Aggregates (SSD)	1.00	36.72	2.242		W/C Ratio	
Additional Water	1.00	95.72	5.844		**0.40**	
TOTAL =		**132.4**	**8.09**			
AIR						
Air	3%	0.00	1.272			
TOTAL =		**0.000**	**1.272**			
GRAND TOTAL =		1732.9	43.86	Good		
Cylinder Volume:			42.41 in^3			
Theoretical Density:			150.5 *lbs/ft³*	**Estimated weight:**		**1675.5**
Actual Cylinder Weight:				**Grams**		
Calculated Density: D = (mass(g)/453.59)*12^3/42.41				*lbs/ft³*		
Material Remaining (g):				**Grams**		

Notes: **Water Cement Ratio was increased from .38 to .40**

The construction sand absorption rate was raised from 2.5% to 5%, back down to 3.0%

Assumption of SG of Plastic is .5 (floating on water)

APPENDIX B

The individual concrete cylinder test specimen compressive strength is listed for all nine concrete mixes. Tables 5, 6, and 7 display the compressive results for the 7-day, 14-day, and 28-day compressive strengths respectively.

Table 5: 7-Day Strength

Mix Name	Mix ID	Mix Strength (psi)
Control	1	5788
Control	1	5810
Control	1	5895
Cement	2	6237
Cement	2	6441
Cement	2	6160
Plastic 2.5	3	5203
Plastic 2.5	3	5431
Plastic 5.0	4	4899
Plastic 5.0	4	4250
Alum 5.0	5	4386
Alum 5.0	5	4465
Alum 10.0	6	3388
Alum 10.0	6	5073
Alum 20.0	7	N/a
Composite	8	5816
Composite	8	5646
Composite	8	5577
GAC/PAC	9	N/a
Avg. 1	1	5831
Avg. 2	2	6279
Avg. 3	3	5317
Avg. 4	4	4574
Avg. 5	5	4425
Avg. 6	6	4231
Avg. 7	7	N/a
Avg. 8	8	5680
Avg. 9	9	N/a

Table 6: 14-Day Strength

Mix Name	Mix ID	Mix Strength (psi)
Control	1	6641
Control	1	6389
Control	1	6386
Cement	2	7512
Cement	2	7631
Cement	2	7639
Plastic 2.5	3	5556
Plastic 2.5	3	5908
Plastic 5.0	4	4909
Plastic 5.0	4	4889
Alum 5.0	5	5805
Alum 5.0	5	5673
Alum 10.0	6	6029
Alum 10.0	6	5333
Alum 20.0	7	N/a
Composite	8	6022
Composite	8	6369
Composite	8	5899
GAC/PAC	9	N/a
Avg. 1	1	6472
Avg. 2	2	7594
Avg. 3	3	5732
Avg. 4	4	4899
Avg. 5	5	5739
Avg. 6	6	5681
Avg. 7	7	N/a
Avg. 8	8	6097
Avg. 9	9	N/a

Table 7: 28-Day Strength

Mix Name	Mix ID	Mix Strength (psi)
Control	1	7105
Control	1	7277
Control	1	7173
Cement	2	8722
Cement	2	8816
Cement	2	8464
Plastic 2.5	3	5789
Plastic 2.5	3	6071
Plastic 5.0	4	4980
Plastic 5.0	4	4951
Alum 5.0	5	6451
Alum 5.0	5	6741
Alum 10.0	6	6527
Alum 10.0	6	5659
Alum 20.0	7	N/a
Composite	8	6901
Composite	8	6552
Composite	8	6540
GAC/PAC	9	N/a
Avg. 1	1	7185
Avg. 2	2	8667
Avg. 3	3	5930
Avg. 4	4	4966
Avg. 5	5	6596
Avg. 6	6	6093
Avg. 7	7	N/a
Avg. 8	8	6664
Avg. 9	9	N/a

The mixes used in the experiment are shown in Table 8. This table provides the name and identification number for each of the nine mixes, so they can be referenced for Figures 8, 9, and 10. These figure display all cylinder compressive results during test for the 7-, 14-, and 28-day compressive strengths and their respective averages.

Table 8: Mix Identification	
Mix ID	**Mix Name**
1	Control Mix
2	Cements Mix
3	Plastic 2.5
4	Plastic 5.0
5	Alum 5.0
6	Alum 10.0
7	Alum 20.0 – DID NOT SET
8	Composite Mix
9	GAC/PAC – DID NOT SET

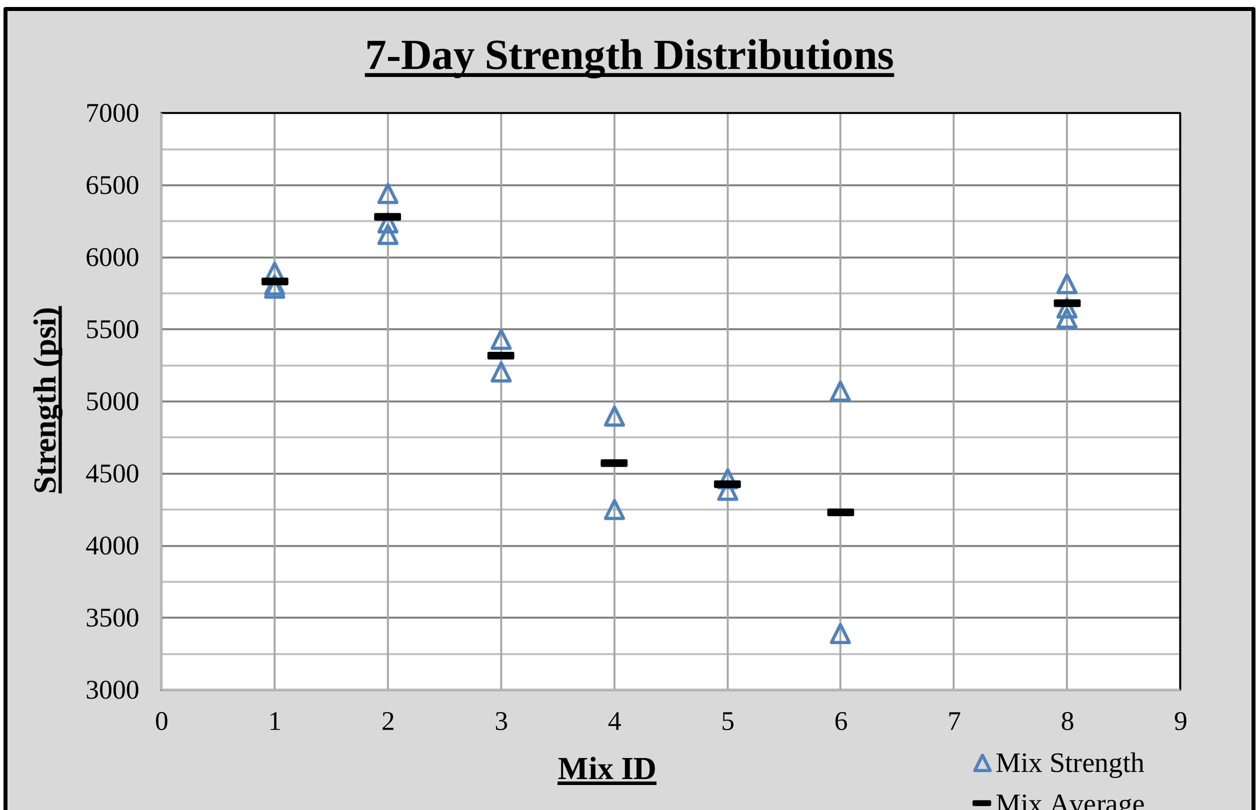

Figure 8: 7-Day Strength Distributions

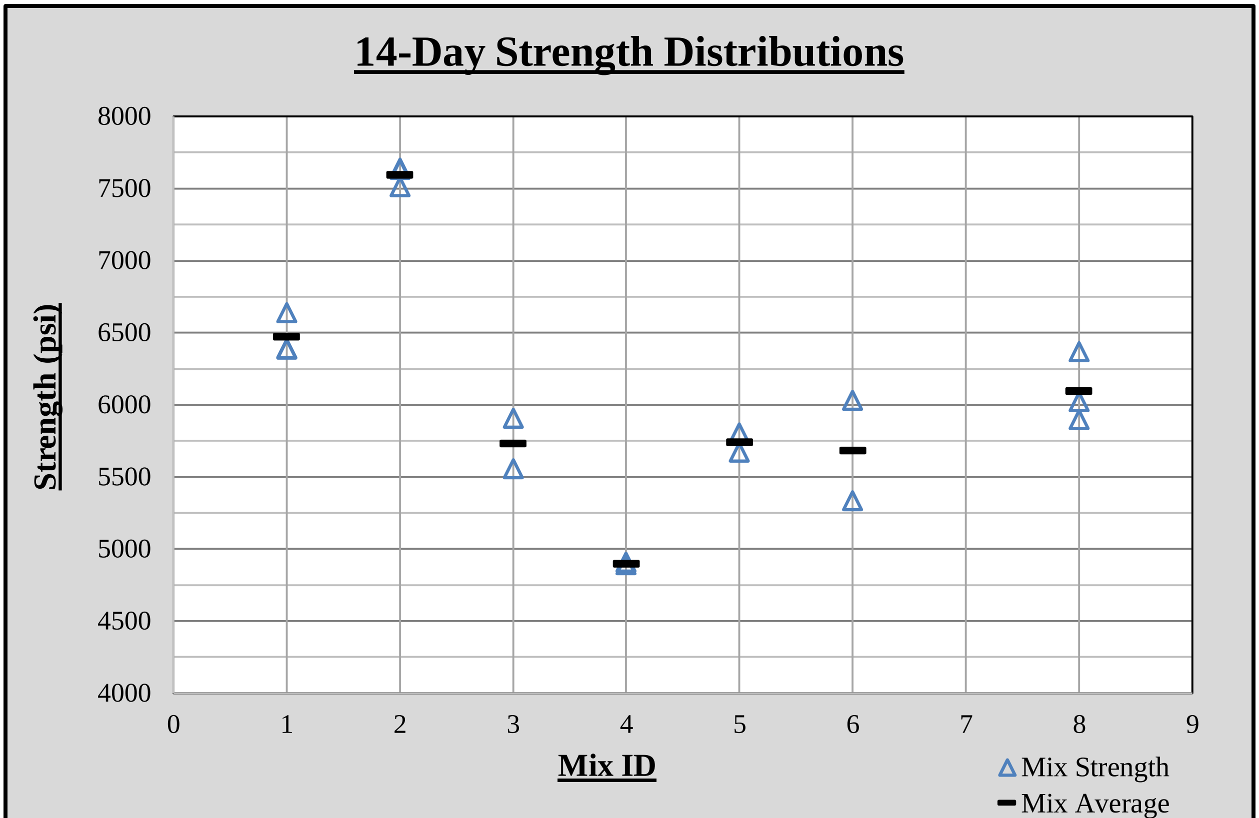

Figure 9: 14-Day Strength Distributions

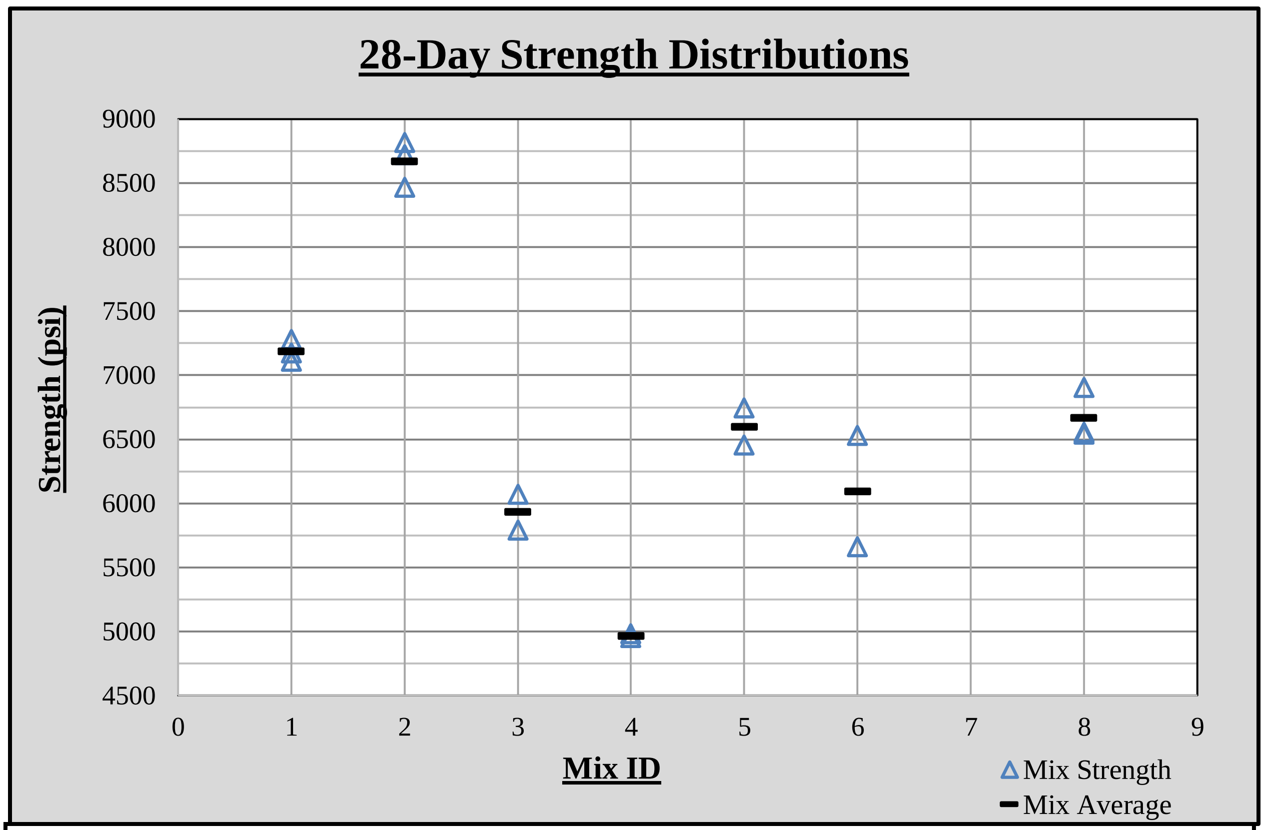

Figure 10: 28-Day Strength Distributions

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