Department of Engineering Technology
College of Science and Engineering Technology
SAM HOUSTON STATE UNIVERSITY

Final Report

2023 Scholarship of Teaching and Learning

Development of Sustainable and Durable Concrete Bench for Schools

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1. Introduction

A concrete mix is a combination of five major elements in various proportions: cement, water, coarse aggregates, fine aggregates (i.e., sand), and air. Concrete is one of the most commonly used construction materials in the world, due to its relatively low cost and high compressive strength. However, its weakness in tension makes it susceptible to cracking and thereby exposes any steel reinforcement inside the concrete to harmful agents that cause corrosion. Another key challenge with concrete is its high environmental cost. Cement (one of the key ingredients of concrete) is said to be the third-largest producer of carbon dioxide (CO_2)in the world after transport and energy generation. Cement is the source of about 8% of global CO_2 emissions. If the cement industry were a country, it would be the third-largest emitter in the world after China and the US. As such, there is an urgent need to develop new sustainable concrete mixtures with lower cement content without negatively affecting the strength of these mixtures.

2. Objectives

The objective of this project is to develop an active learning experience for undergraduate students to become creative in developing such mixtures. The students will be able to design and prepare different concrete mixtures with different proportions and evaluate the strength of these mixtures. The students will then select the optimum mixture (most sustainable and durable) for building a concrete bench that can be used in schools, parks, etc. To achieve these objectives, the following was accomplished:

- Prepare a total of 15 different concrete mixtures in the SHSU Engineering Technology concrete lab.
- Test the workability and strength of these 15 mixtures.
- Select the best concrete mixture and use it to construct a concrete bench at SHSU.
- Evaluate the carbon footprint of the constructed concrete bench.

3. Methodology

3.1 Mixture Design

A total of 15 mixtures were prepared by the students in SHSU Engineering Technology concrete lab. Four of these mixtures served as control mixtures since they are the most common concrete mixtures used in Texas. The first control mix included water, gravel, 100% sand and 100% cement and was denoted by CO. The second control mix included the same ingredients (in terms of water, sand, and gravel) but instead of 100% cement (by weight), a total of 90% cement and 10% fly ash (by weight) was used. This mix was denoted as FA10. Fly ash is a by-product of burning coal in power plants. Similarly, the third mix included the same ingredients (in terms of water, sand, and gravel) but instead of 100% cement, a total of 80% cement and 20% fly ash was used. This mix was denoted by FA20. Similarly, mixture FA30 included 70% cement and 30% fly ash. Figure 1 shows students mixing these concrete mixtures in the concrete lab.

Figure 1. Concrete Mixing

Three more mixtures were prepared similar to FA10, FA20, and FA30 but they included a material called "Micron" instead of fly ash. These mixtures were denoted by Mi10, Mi20, and Mi30. Micron is a special form of fly ash with finer particle size. The fly ash has a particle size of 30 to 50 microns, while Micron has a particle size of 2 to 4 microns. These mixtures were prepared to evaluate the effect of reducing the particle size of fly ash on the strength of concrete mixtures.

Six more mixtures were prepared similar to FA10, FA20, and FA30 but they included two natural pozzolans called Kirkland and Metakaolin instead of fly ash. These mixtures were denoted by Ki10, Ki20, and Ki30 and MK10, MK20, and MK30. Kirkland is a natural pozzolan mined from Kirkland, Arizona and used in concrete without processing, while Metakaolin is a natural pozzolan common in

Texas and Georgia that needs to be heated at 1112-1562°F to produce a powder that can be used in concrete. These six mixtures were prepared to determine if green concrete can be produced using natural pozzolans instead of fly ash which will also solve the future expected shortage of fly ash. Three more mixtures were prepared similar to mixture CO but instead of the 100% sand, they included 90% sand and 10% bottom ash (denoted by BA10), 80% sand and 20% bottom ash (denoted by BA20), and 70% sand and 30% bottom ash (denoted by BA30). These mixtures were prepared to see if bottom ash can replace sand in the concrete. Bottom-ash is a by-product of coal combustion which is very detrimental to the environment.

To account for variability, three samples were prepared for each of the 15 concrete mixtures. This resulted in a total of 45 samples (15 mixtures*3 samples=45 samples).

3.2 Slump Cone Test

While mixing the 15 mixtures, the students conducted the slump cone test in the lab as shown in Figure 2. The slump cone test is a standard test method used to measure the consistency and workability of fresh concrete. It is a simple and widely used test that involves filling a metal cone-shaped mold with fresh concrete, compacting it, and then lifting the mold to see how much the concrete slumps or settles. The test is done to ensure that the concrete being used is of the right consistency and workability for the specific application it is intended for. Concrete that is too wet or too dry can lead to problems such as segregation, bleeding, or a lack of strength, and may result in a poor-quality finished product. The typical slump values range between 4 and 6 inches.

Figure 2. Students conducting slump cone test.

3.3 Compressive Strength Test

All the 15 mixtures were left to cure and harden for seven days. After seven days, the students conducted the compressive strength test, see Figure 3. The Compressive Strength Test is a standardized test used to determine the compressive strength of hardened concrete. The test involves applying a compressive load to a cylindrical concrete specimen until failure occurs. The compressive strength of the concrete is then calculated by dividing the maximum load achieved during the test by the cross-sectional area of the specimen. The test is important because the compressive strength of concrete is one of the most important factors in determining the suitability of the concrete for its intended use. Compressive strength is a measure of the concrete's ability to resist axial compressive loads and is a critical parameter in the design of concrete structures, such as buildings, bridges, and dams.

Figure 3. Students conducting compressive strength test.

4. Results

All the students taking ETCM 3368 *"Concrete and Masonry Construction"* in Spring 2023 participated in this project. The results of this project were documented in two PowerPoint slides prepared by the students and revised by Dr. Mousa. These two PowerPoints slides were presented by two groups (each consisting of two students) on April 22, 2023, in the 16th Annual Undergraduate Research Symposium organized by the Elliott T. Bowers Honors College. Both slides presented by both groups are shown on the following pages.

Development of Sustainable and Durable Outdoor Concrete Benches Using Natural Pozzolans

Student Presenters: Brianna Simonton, Reece Richert

Faculty Advisor: Momen Mousa

Agenda

- Introduction
- Problem Statement
- Objectives
- Methodology
- Analysis of Results
- Field Construction
- Carbon Footprint
- Conclusions

Introduction

Introduction

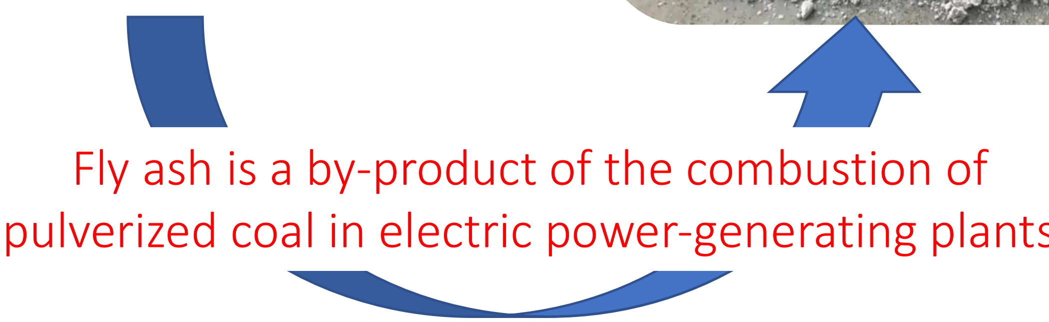
- Concrete is the second most consumed substance on Earth, after water.
- In the U.S, it is widely used for the construction of buildings, bridges, roads, and other infrastructure projects




Cement
Gravel
Water
Sand

Introduction

- Due to the high cost of cement, some concrete applications replace up to 20% of the cement with fly ash.



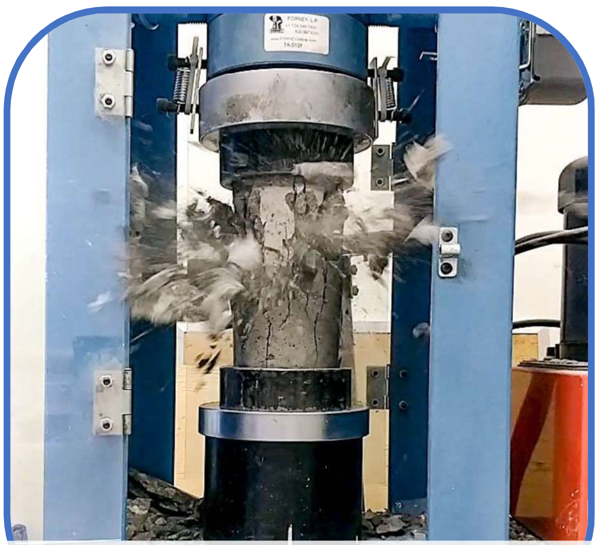
Introduction

- After mixing, the concrete is in a "fresh state"
- Fresh concrete should have enough plasticity so that it can be molded into the desired shape during construction.

A slump cone test is conducted on fresh concrete to ensure it has enough plasticity

Introduction

- After the concrete is placed, a hydration reaction takes place, and over time concrete hardens.
- Hard concrete should have enough strength to tolerate loads



Compression test on a hard concrete cylinder to ensure it can tolerate ***compression*** loads

Introduction

- Hard concrete should also have enough durability to resist weather and chemical attack

This could be mitigated through

Surface resistivity test evaluates the electrical resistivity of water-saturated concrete to provide a rapid indication of the concrete's resistance to chloride ion penetration

Problem Statement

Problem Statement

1. Cement (one of the key components of concrete) has significant environmental impacts

1 cubic yard (3900 lbs.) of concrete

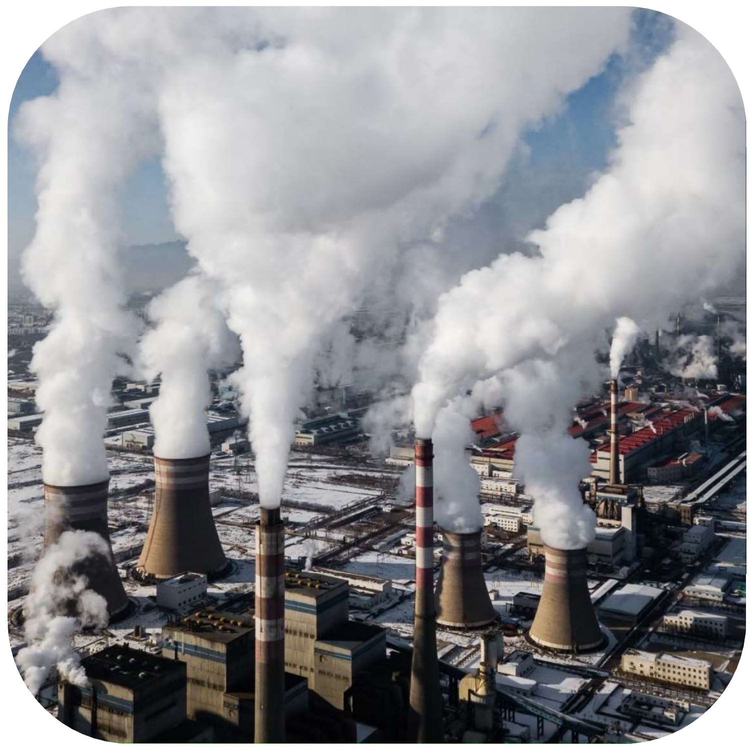
↓

400 lbs. of cement

↓

400 lbs. of CO_2

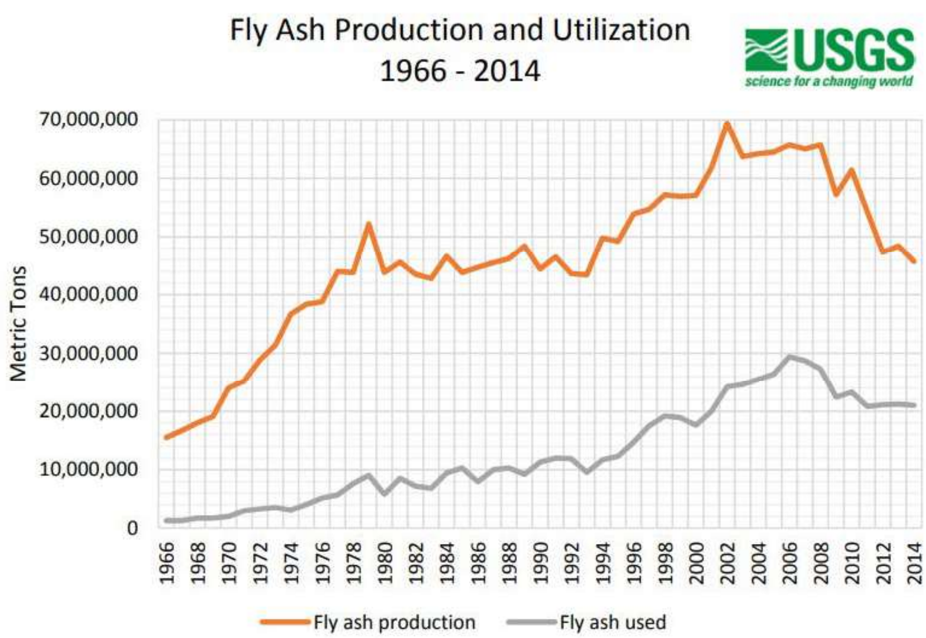
- *Burning through an average tank of gas in a car*
- *Using a home computer for a year*
- *Using a microwave oven in a home for a year*



Problem Statement

2. Shortage of fly ash supply in the future with increased demand

- Coal-fired power plants are retired and replaced with other forms of energy generation
- Stricter environmental regulations on the disposal of fly ash



Objectives

Objectives

Optimize the sustainability, strength, and durability of concrete mixtures in Texas by using natural pozzolans as cement partial replacement:

- Quantify the strength and durability of concrete mixes with natural pozzolans as compared to control mixes
- Determine optimum percentage of cement partial replacement
- Construct an outdoor bench at SHSU using the new concrete mix with natural pozzolans
- Quantify the carbon footprint of the outdoor bench

Two natural pozzolans were used in this research:

Kirkland

Mined from Kirkland, Arizona and used in concrete without processing

Kaolin

Common in Texas and Georgia. Needs to be heated at 1112-1562°F to produce a powder “Metakaolin” which can be used in concrete.

Methodology

Methodology

- 8 mixtures were prepared in SHSU Engineering Technology concrete lab.
- All the 8 mixtures had the same volumes of all the ingredients except for the cement.

	Co	FA20	KR10	KR20	KR30	MK10	MK20	MK30
Gravel	All have the same volume of gravel							
Sand	All have the same volume of sand							
Water	All have the same volume of water							
Cement	100	80	90	80	70	90	80	70
Admix.	0	20	10	20	30	10	20	30

2 control mixes

Material Selection

Cement

Gravel

Sand

Fly-Ash

Kirkland

Metakaolin

Mixing Process

Slump Cone Test

Compression Test

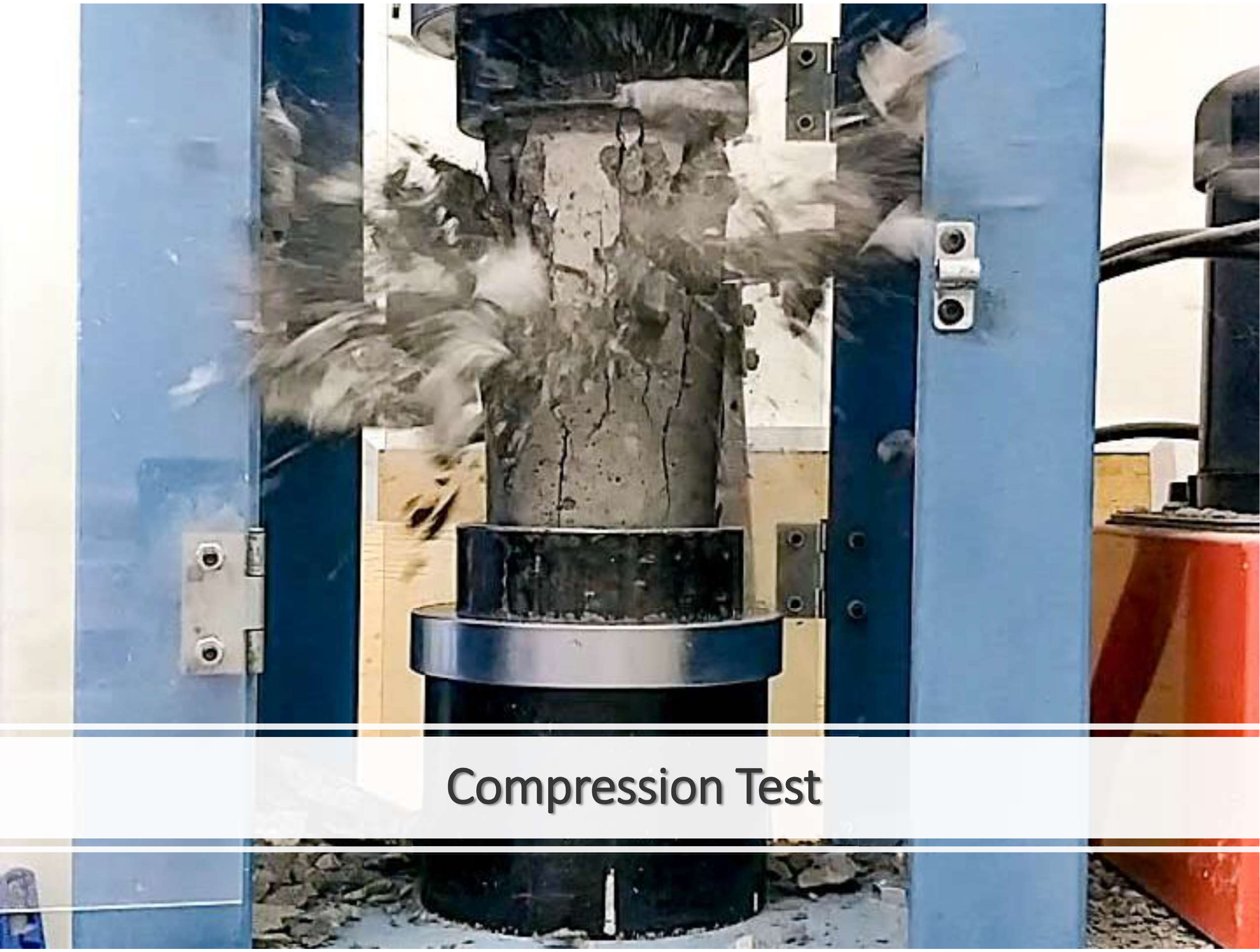
Analysis of the Results

Slump Cone Test

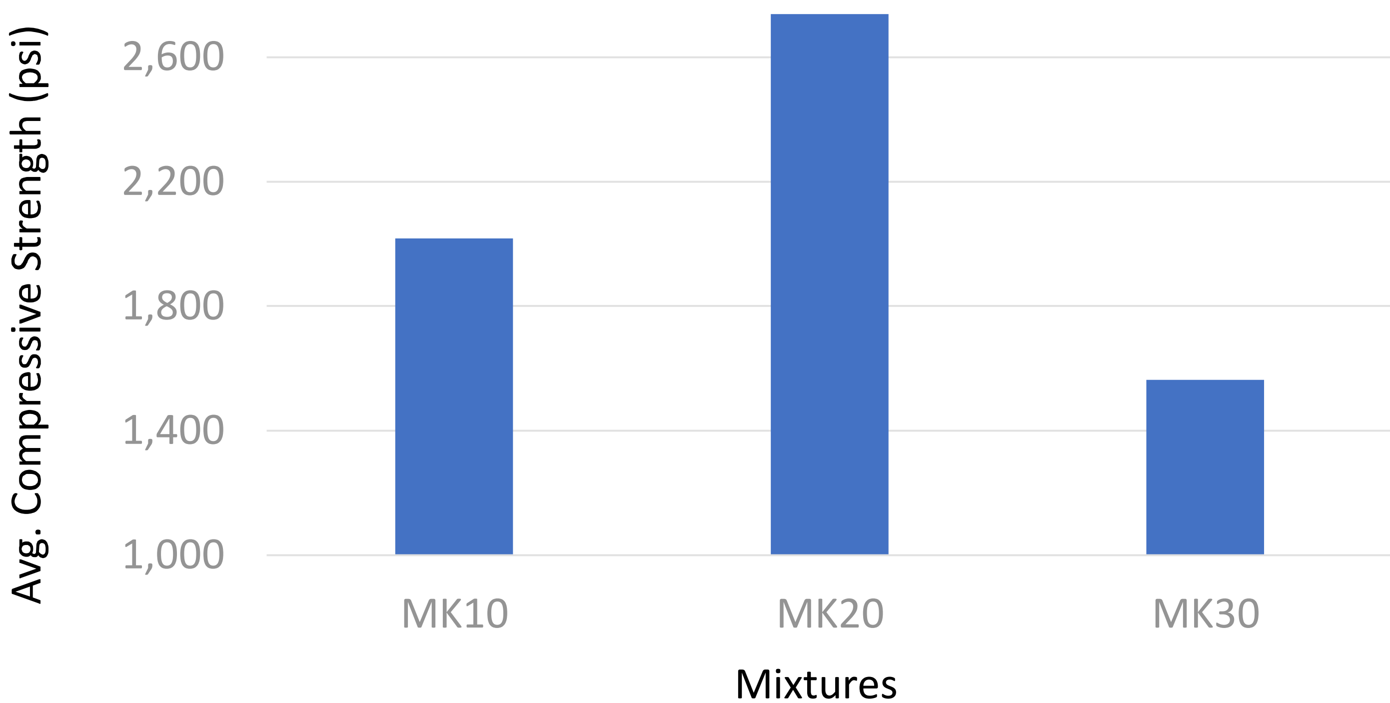
Slump Cone Results

	Co	FA20	KR10	KR20	KR30	MK10	MK20	MK30
Average Slump (in.)	6.5	6	6	5	6	6.25	6.5	6.5

All the mixes had a slump within the typical range which is 4-6 in.

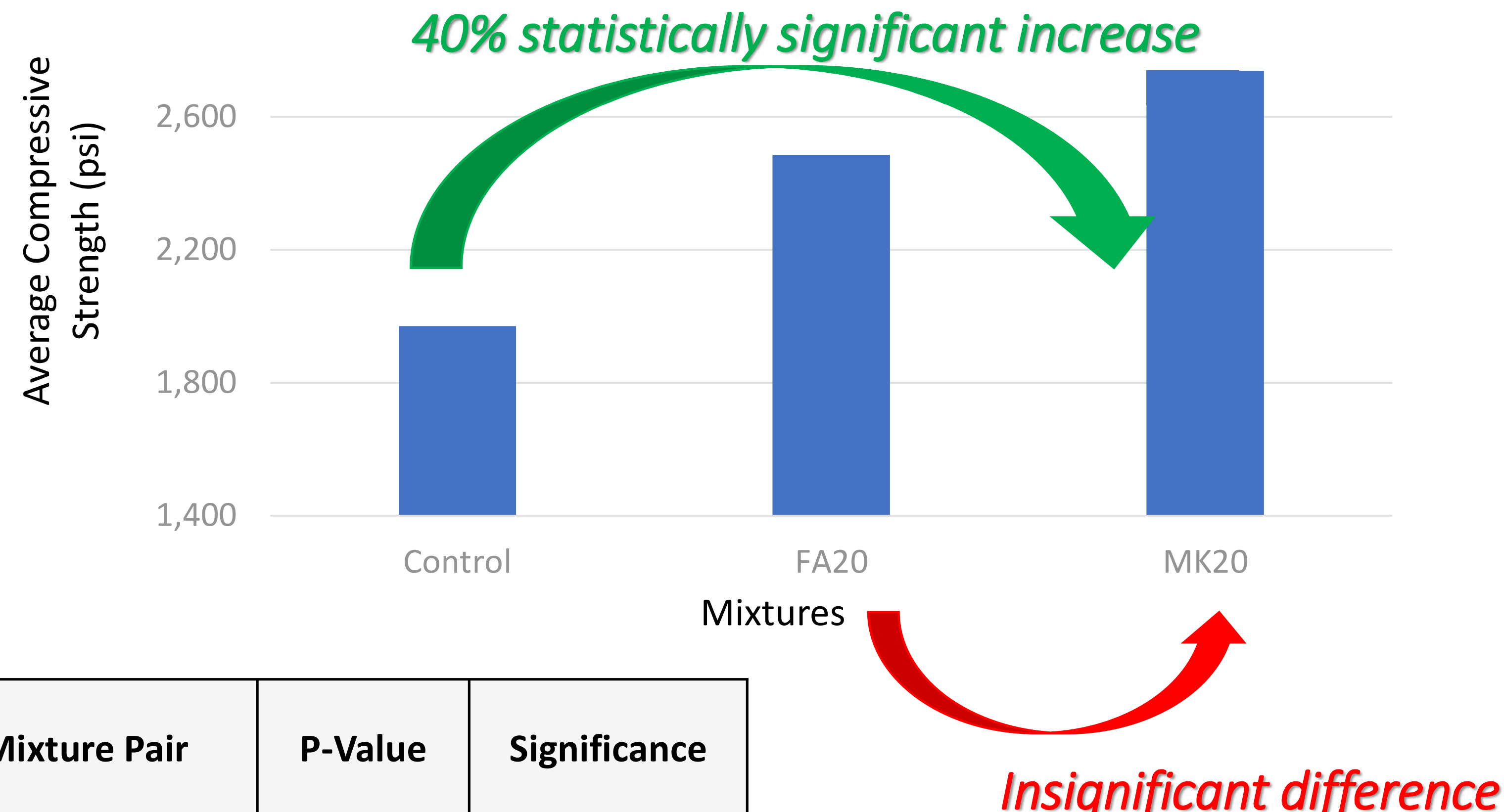

Compression Test

Comparing MK mixes together



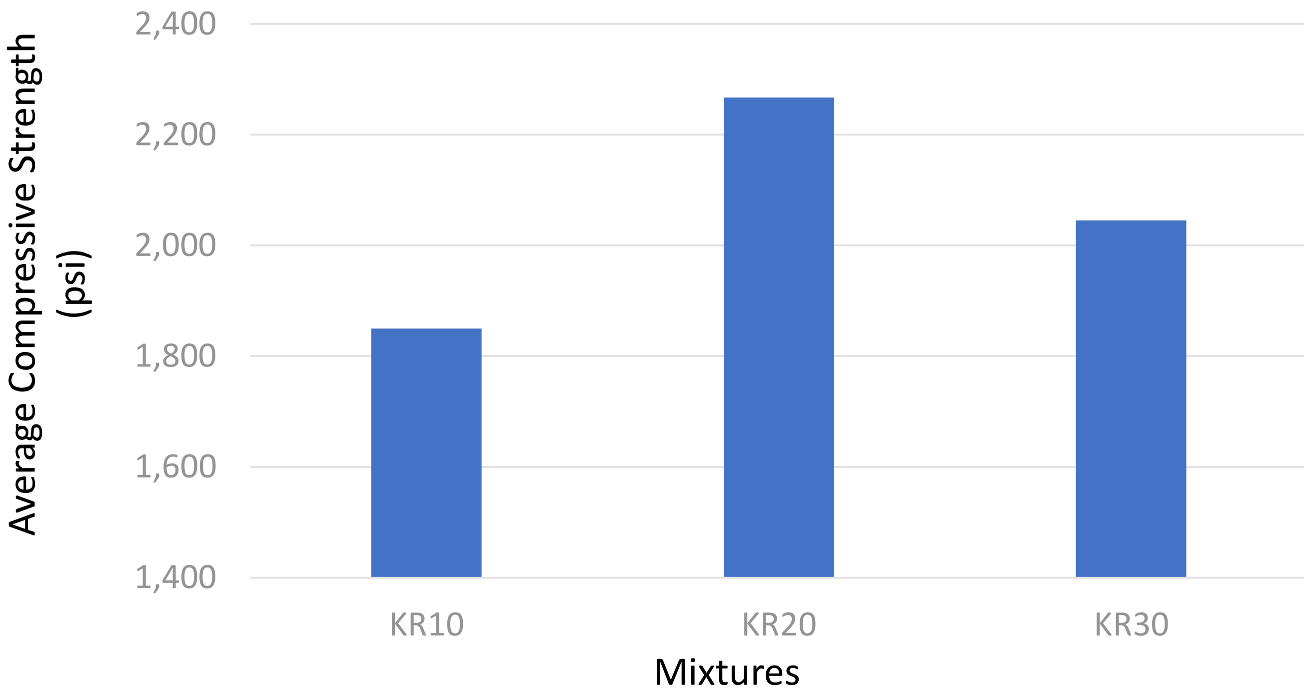
The optimum cement replacement percentage with Metakaolin is 20%

Comparing MK20 with Controls



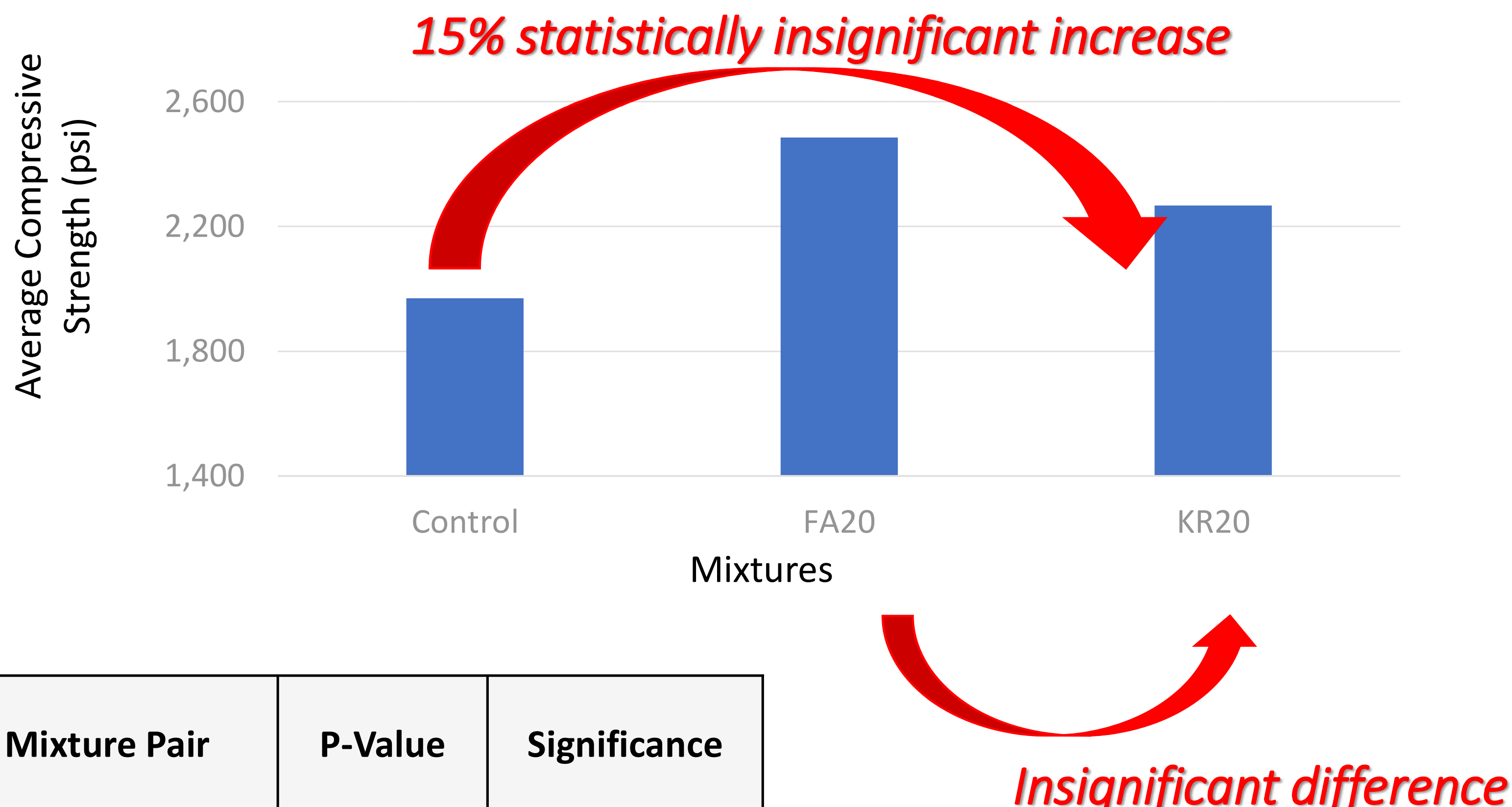
Mixture Pair	P-Value	Significance
MK20 Vs Control	<0.05	Significant
MK20 Vs FA20	>0.05	Insignificant

Comparing KR mixes together



The optimum cement replacement percentage with Kirkland is 20%

Comparing KR20 with Controls



Mixture Pair	P-Value	Significance
KR20 Vs Control	>0.05	Insignificant
KR20 Vs FA20	>0.05	Insignificant

Field Construction

Field Construction

- Based on lab testing, the best performing mix was MK20
- This mix was used to construct an outdoor concrete bench in front of the Engineering Tech concrete lab at SHSU.

Field Construction

Field Construction

Carbon Footprint

Carbon Footprint

Point of Comparison	Conventional Concrete Bench (CO)	Constructed Concrete Bench (MK20)
Total weight of cement used (lb.)	144	115
Total weight of natural pozzolans (lb.)	0	29
Average CO_2 released during production (lb.)	144	115
Reduction in CO_2 in lb. (%)	**29 (20%)**	

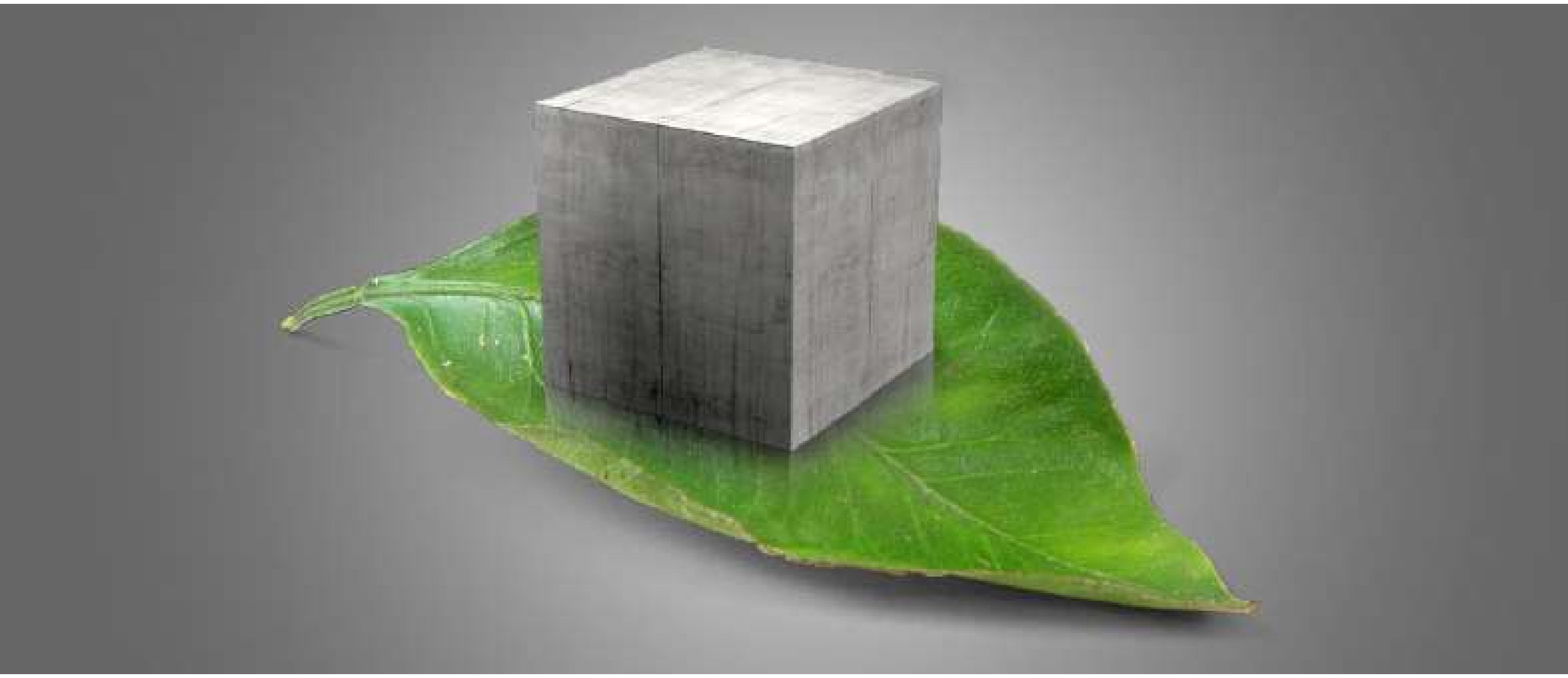
The concrete bench constructed with the developed mix reduced CO_2 emissions by 20%

Conclusions

Conclusions

- Two new concrete mixtures were developed in this study using local materials in Texas and through replacing 20% of cement by natural pozzolans:
  - ✓ More sustainable than conventional mixes (reduce CO_2 emissions by about 20%)
  - ✓ Have higher strength (or similar) as conventional mixes
  - ✓ Can solve the shortage of supply of fly-ash
- Processed natural pozzolans (Metakaolin) provide relatively higher concrete strength as compared to unprocessed natural pozzolans (Kirkland).

Questions



Development of Green Concrete Using By-Products & Local Materials in Texas

Student Presenters: Dawson Pope, Cameron Beasley

Faculty Advisor: Momen Mousa

Agenda

- Introduction
- Problem Statement & Objectives
- Methodology
- Analysis of Results
- Field Construction
- Carbon Footprint
- Conclusions

Introduction

Introduction

- Concrete is the most common construction material in the U.S.
- As of 2022, 55 million cubic yards of ready-mixed concrete were produced in Texas.

Concrete's Durability

- Concrete is subject to a multitude of weathering agents that vary by environment
- Consideration of these is vital to concrete's durability

Physical wear such as

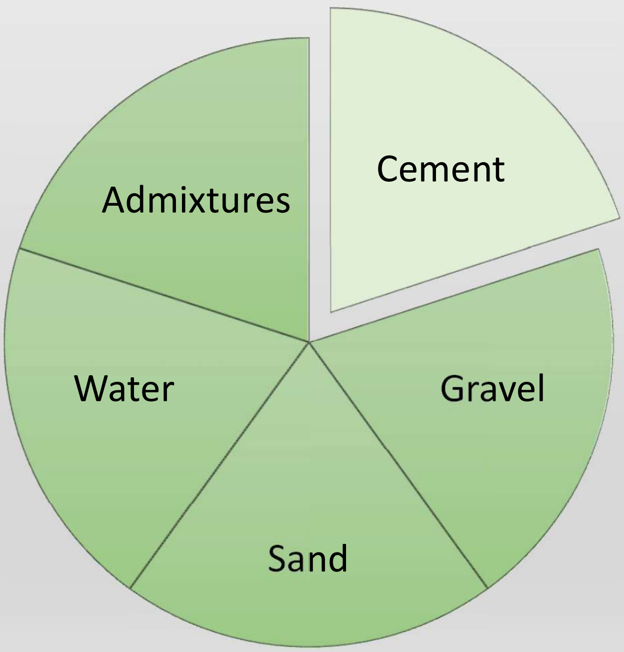
- Erosion
- Freezing
- Thawing
- Abrasion

Chemical wear such as

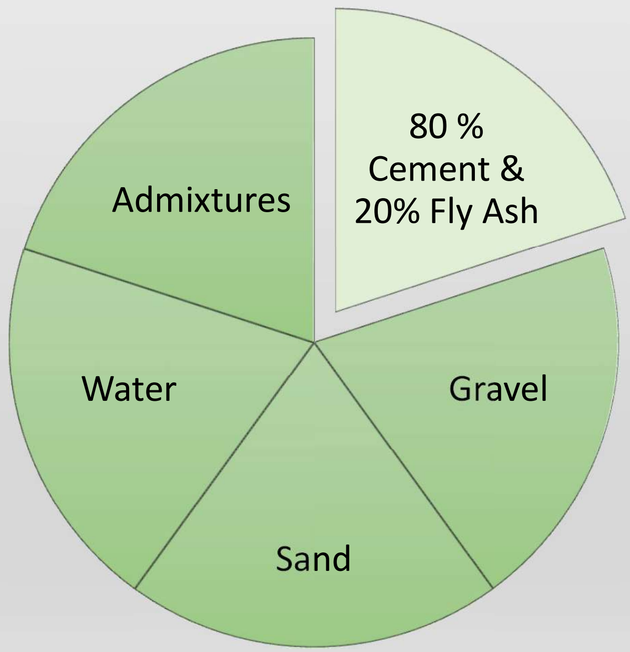
- Expansion
- Alteration
- Dissolution

Ready-Mix Concrete in Texas

About 40% of Mixes used in Texas

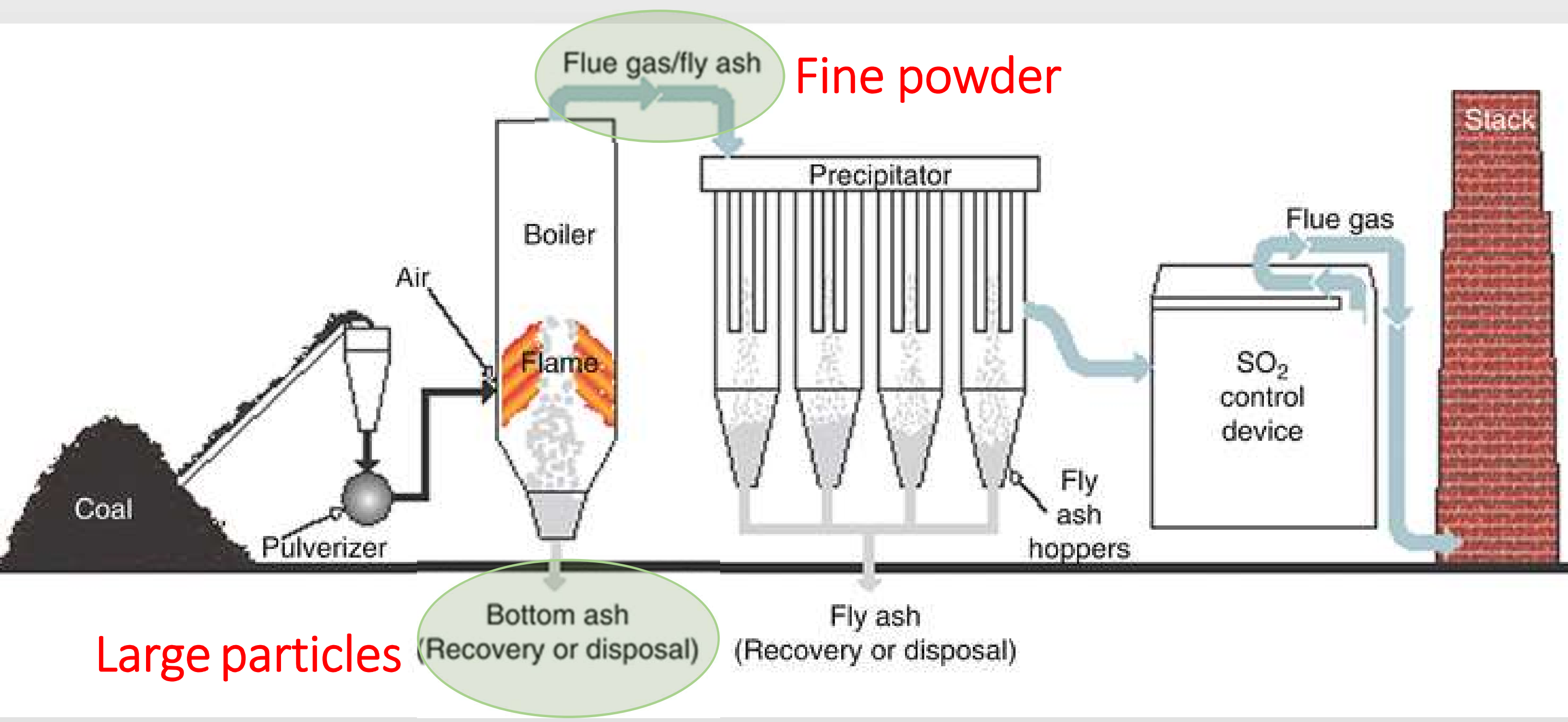


About 60% of Mixes used in Texas



What is Fly-Ash?

- Fly-ash and bottom ash are byproducts of burning coal to generate electricity in power plants.



Fly-Ash and Bottom-Ash

Fly-Ash

Bottom-Ash

Slump Cone Test

- After mixing, the concrete is in a “fresh state”
- Fresh concrete should have enough plasticity so that it can be molded into the desired shape during construction.

A slump cone test is conducted on fresh concrete to ensure it has enough plasticity

Compression Test

- After the concrete is placed, a hydration reaction takes place, and over time concrete hardens.
- Hard concrete should have enough strength to tolerate loads

Compression test on a hard concrete cylinder to ensure it can tolerate compression loads

Problem Statement & Objectives

Problem Statement

1-Cement production emits significant CO_2 emissions

1 cubic yard (3900 lbs.) of concrete
↓
400 lbs. of cement
↓
400 lbs. of CO_2

- *Burning through an average tank of gas in a car*
- *Using a home computer for a year*
- *Using a microwave oven in a home for a year*

Objective

A-Develop a new concrete mix with lower cement by using finer fly-ash

B-Use the proposed concrete mix to construct a green concrete bench at SHSU

C-Quantify the expected reduction of CO_2 emissions by using the proposed mix

Objective

A-Develop a new concrete mix with lower cement by using finer fly-ash

B-Use the proposed concrete mix to construct a green concrete bench at SHSU

C-Quantify the expected reduction of CO_2 emissions by using the proposed mix

Fly-Ash

Particle size of 20 to 50 microns

Micron^3

Particle size of 2 to 4 microns

Problem Statement

2-Bottom-Ash is detrimental:

- Coal ash (which includes bottom ash) is the second-largest waste material in the U.S behind household trash
- When disposed, can leach to groundwater causing cancer

If you live near a coal ash disposal area, and you drink from a well, you have a 1 in 50 chance of getting cancer

Objective

A-Develop a new green concrete mix incorporating bottom ash without reducing the concrete strength

Objective

A-Develop a new green concrete mix incorporating bottom ash without reducing the concrete strength

Fly-Ash

Particle size of 20 to 50 microns

Bottom-Ash

Particle size of 1 to 20 mm

Methodology

Methodology

- To achieve objective 1-A, B, and C, a total of 7 mixtures were prepared in SHSU Engineering Technology concrete lab.

	Base	FA10	FA20	FA30	Mi10	Mi20	Mi30
Gravel		All have the same volume of gravel					
Sand		All have the same volume of sand					
Water		All have the same volume of water					
Cement	100	90	80	70	90	80	70
FA/Mi	0	10	20	30	10	20	30

4 control mixes

Methodology

- To achieve objective 2-A, other 3 mixtures were prepared.

	Base	BA10	BA20	BA30
Gravel	All have the same volume of gravel			
Cement	All have the same volume of cement			
Water	All have the same volume of water			
Sand	100	90	80	70
BA	0	10	20	30

1 control mix

Material Selection

Cement

Gravel

Sand

Fly-Ash

Micron^3

Bottom Ash

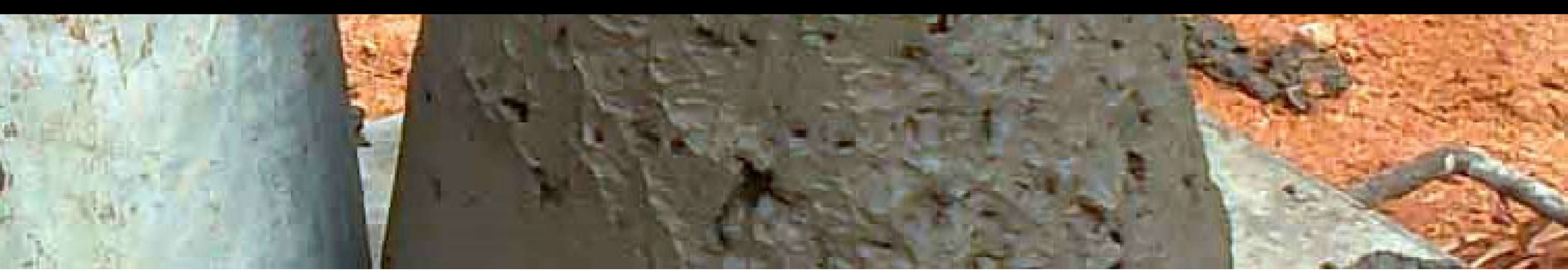
Mixing

Slump Cone Test

Compression Test

Results Analysis

Slump Cone Test



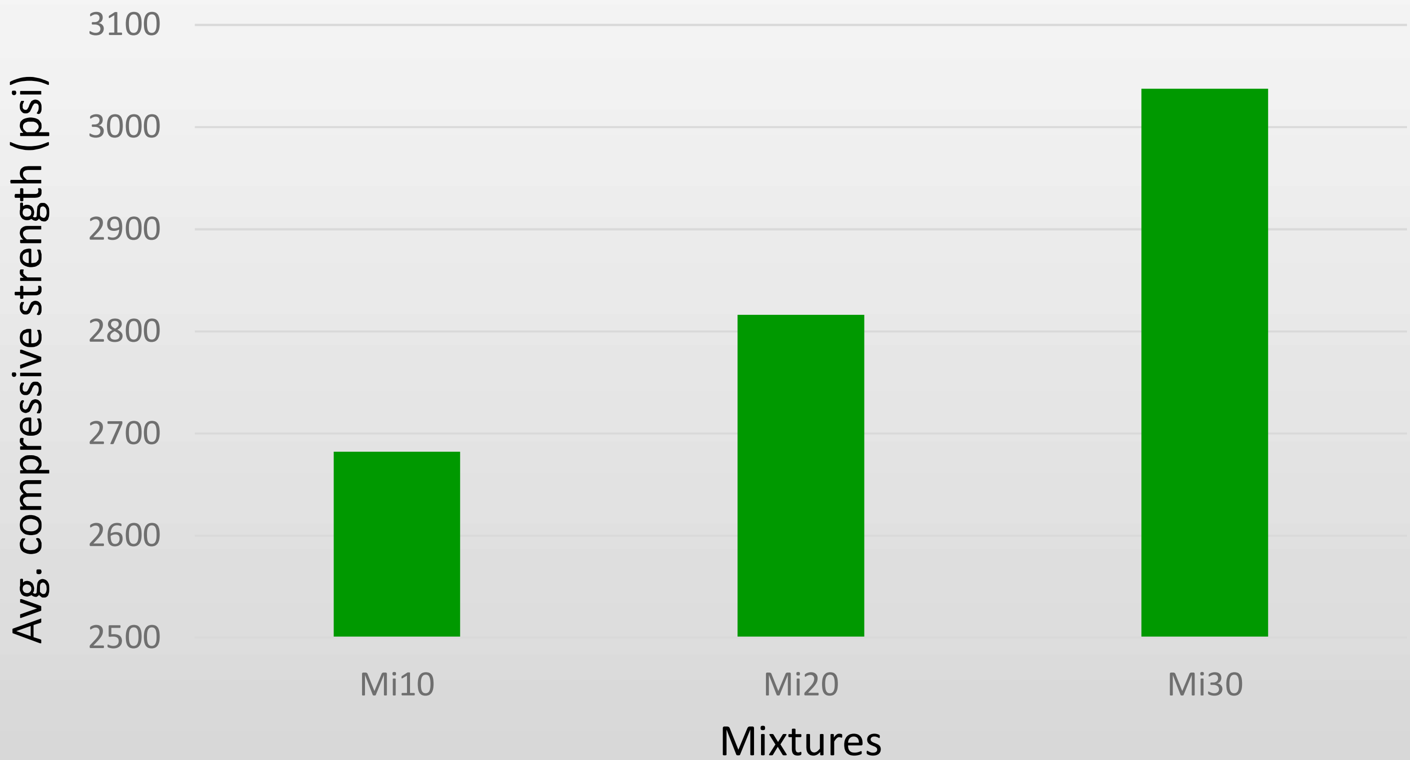
Slump Cone Results

	Base	FA10	FA20	FA30	Mi10	Mi20	Mi30	BA10	BA20	BA30
Average Slump (in.)	6.5	6	6	3.5	3	4	6	7.2	7	7

All the mixes had a slump within the typical range which is 4-6 in.

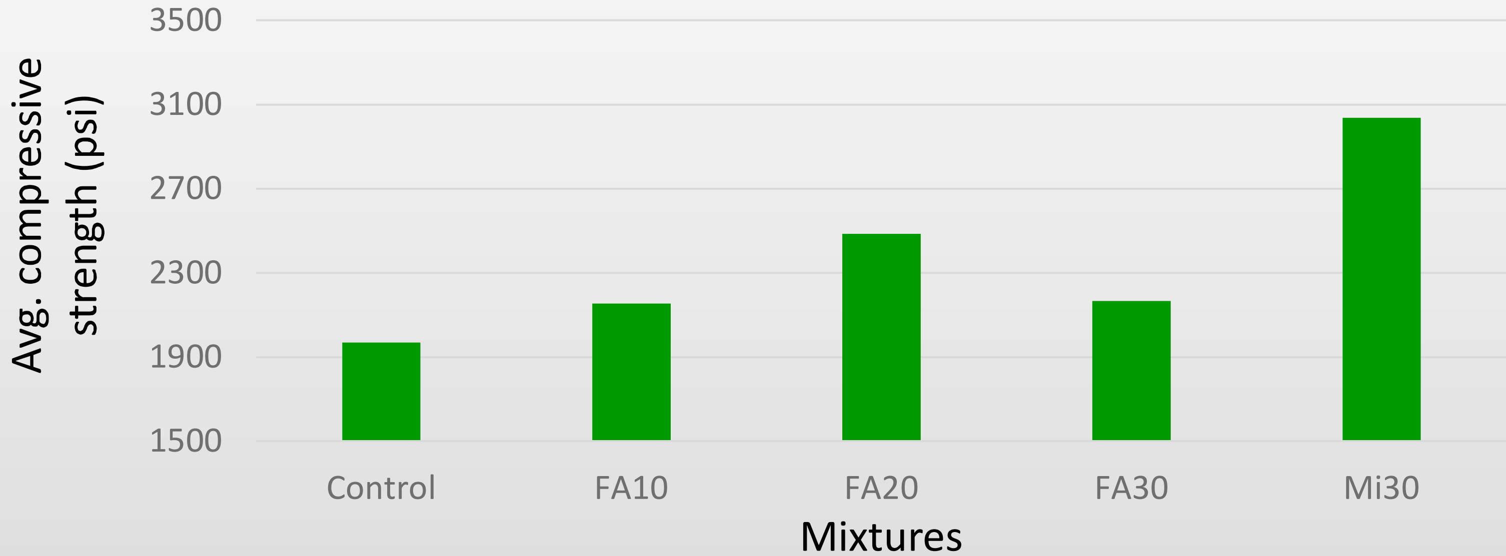

Compression Test
DO NOT THROW OUT

Comparing Mi mixes together



The optimum cement replacement percentage with Mi is 30%

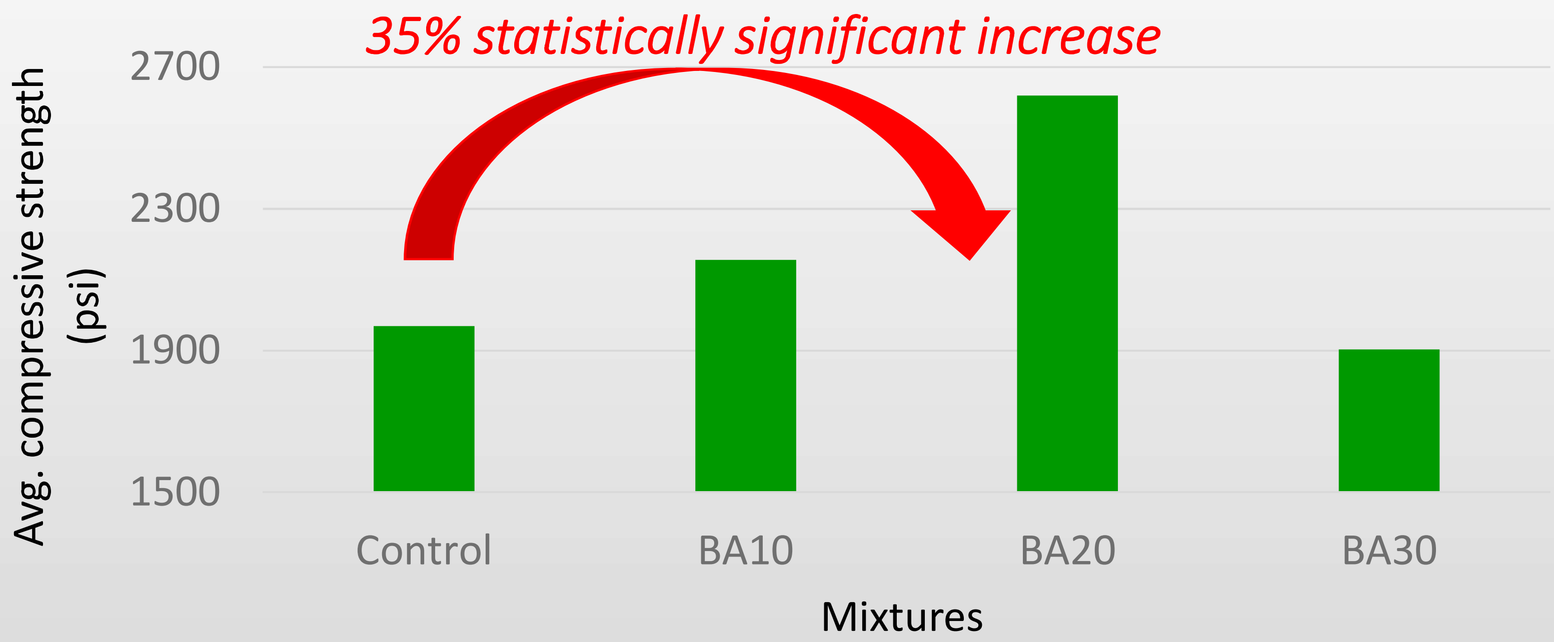
Comparing Mi30 with Controls



The optimum cement replacement percentage with fly-ash is 20%

Increasing the fineness of fly-ash (using micron[3] instead of fly-ash) can increase cement replacement from 20% to 30% while increasing the concrete compressive strength

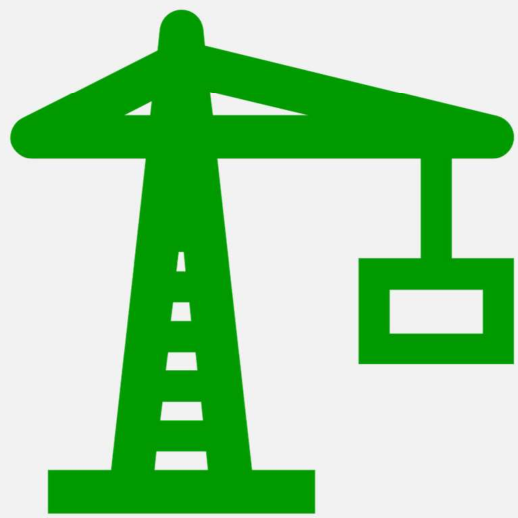
Comparing BA with Control



Mixture Pair	P-Value	Significance
Control Vs BA20	0.027	Significant

20% of sand used in concrete mixes can be replaced by bottom ash, while also increasing the compressive strength by 35%

Field Construction



Field Construction

- Based on lab testing, the best performing mix was Mi30
- This mix was used to construct an outdoor concrete bench in front of the Engineering Tech concrete lab at SHSU.

Carbon Footprint

Point of Comparison	Conventional Concrete Bench (CO)	Constructed Concrete Bench (Mi30)
Cement weight (lb.)	144	101
Weight of Micron³ (lb.)	0	43
Average CO_2 released (lb.)	144	101
Reduction in CO_2 in lb. (%)	**43 (30%)**	

The concrete bench constructed with the developed mix reduced CO_2 emissions by 30%

Conclusions

- Increasing the fineness of fly-ash (using micron3 instead of fly-ash) can increase cement replacement from 20% to 30%:
  - ✓ Less cement means a more sustainable mix
  - ✓ In addition to increasing the compressive strength

- 20% of sand used in concrete mixes can be replaced by bottom ash, while also increasing the compressive strength by 35%

Questions