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Quantifying the Change in Water Demand with the Use of Supplementary Cementitious Materials

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Background

Research Question:

- Can we quantify the change in water demand in relation to the percent replacement of Portland Cement with Supplementary Cementitious Materials (Silica Fume & Fly Ash)?

Why?

- Every ton of Portland cement, produces one ton of carbon dioxide.
- Concrete industry has a high demand for “green” concrete.

How?

- Measuring the water to cementitious material ratio while maintaining a 4” slump across known SCM replacement quantities.

Background – SCMs

- Maximize the use of industrial by-products
  - Silica Fume is a by-product of electric arc furnaces
  - Fly Ash is a by-product of pulverized coal
- ~200,000 tons of Silica Fume produced annually in the US
- Current research has been focused on Silica Fume, whose properties behave as listed below

↑ Water demand
Early strength gain
Long term strength gain
Durability

↓ Workability
Air Content
Segregation
Absorption

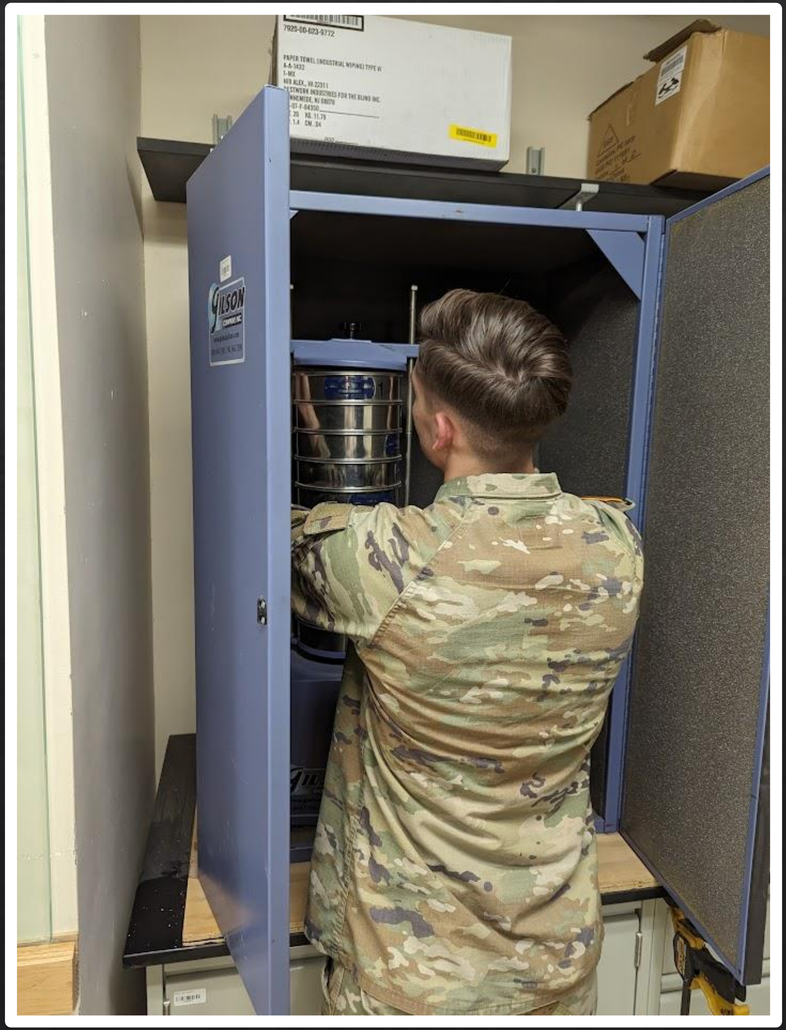
PCA Design and Control of Concrete Mixes 15th Edition

Methodology

STEP 1: CLASSIFYING CONSTITUENTS

- Coarse Aggregates
  - Gradation Test (ASTM C33)
  - Specific Gravity Test (ASTM C127)

- Cementitious Materials
  - Silica Fume (ASTM C1240)
  - Portland Cement (ASTM C150)



Methodology

STEP 2: BATCHING

- Coarse aggregate and 50% of estimated water: 2 min
- Add fine aggregates and 25% of estimated water: 2 min
- Add cementitious materials: 10 min
- Rest: 3 min
- Add water as needed: 10 min

- Conduct slump test (ASTM C143)
  - Slump < 4 in → add water and mix for 3 min
  - Slump > 4 in → add 10% of all constituents and mix for 3 min

Methodology

STEP 3: CURING

- Remove from the mold after 24 hours
- Wet Cure at 20°C ± 2° (ASTM C511)

STEP 4: CONCRETE TESTING

- Compressive Strength (ASTM C39)
  - 3, 7, 28 days
- Split Tensile (ASTM C496)
  - 7, 28 days
- Durability (ASTM C1260)
  - Fresh, 3, 7, 21, 28 days

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Where are we in the study?

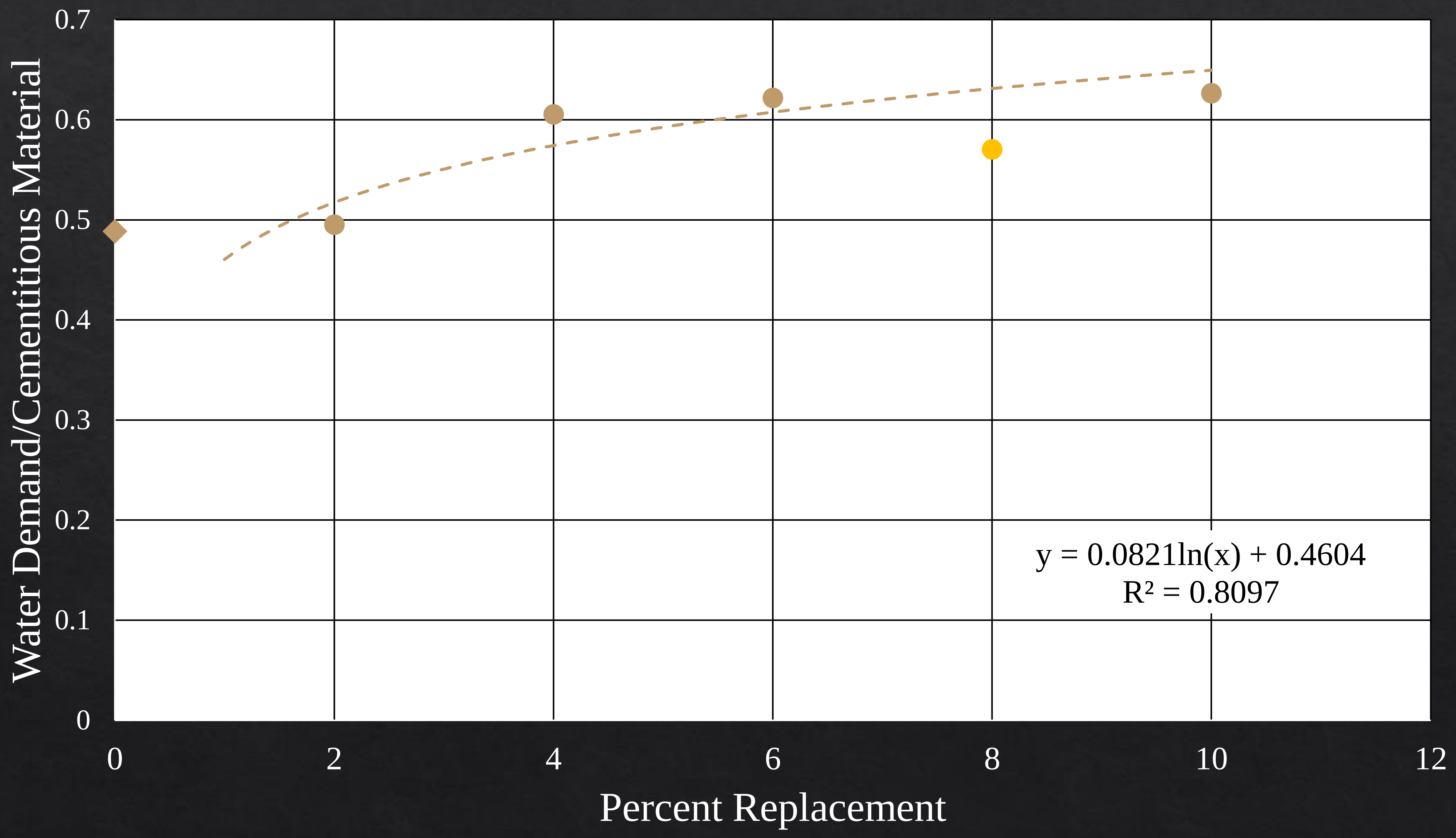
Current Mixes

- Control
- Silica Fume
  - 2%, 4%, 6%, 8%, 10% Replacement
- Fly Ash (Future)
  - 5%, 10%, 20%, 30%, 40%

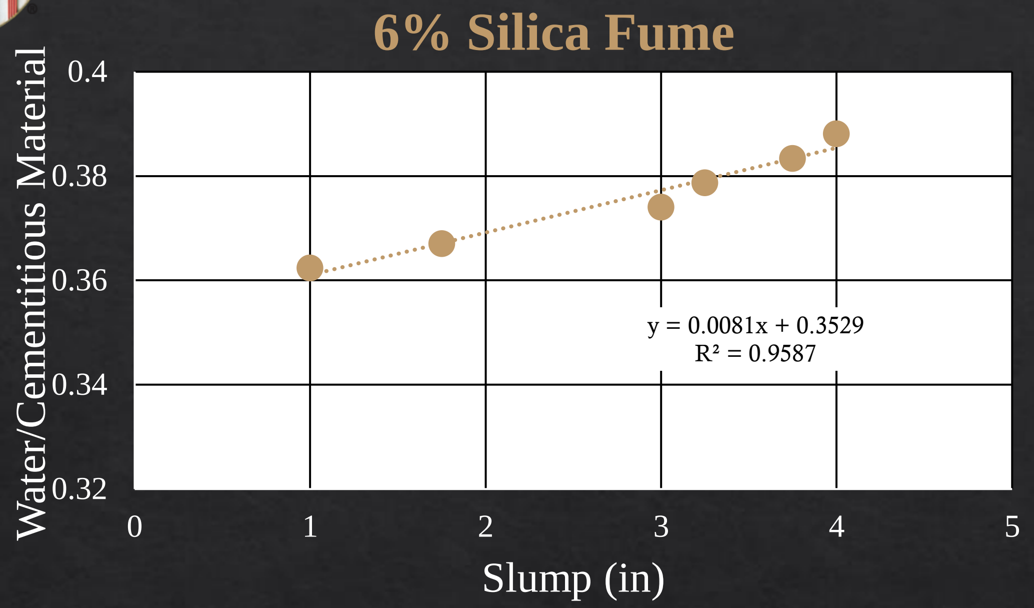
Testing Completed & In-Progress

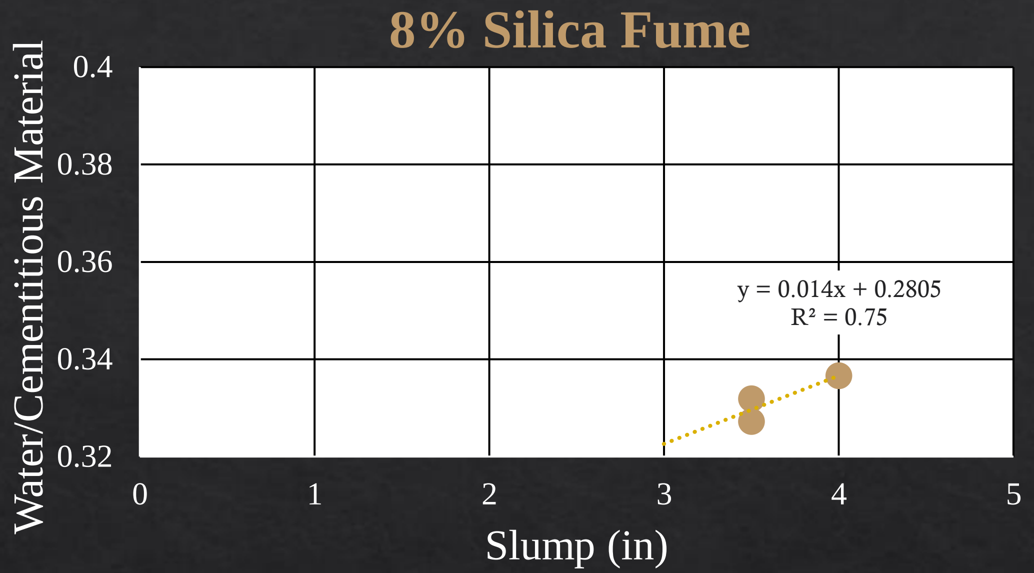
- Control and Silica Fume Mixes
- Pending 28-Day Testing
  - Compressive, Split-Tensile, Durability

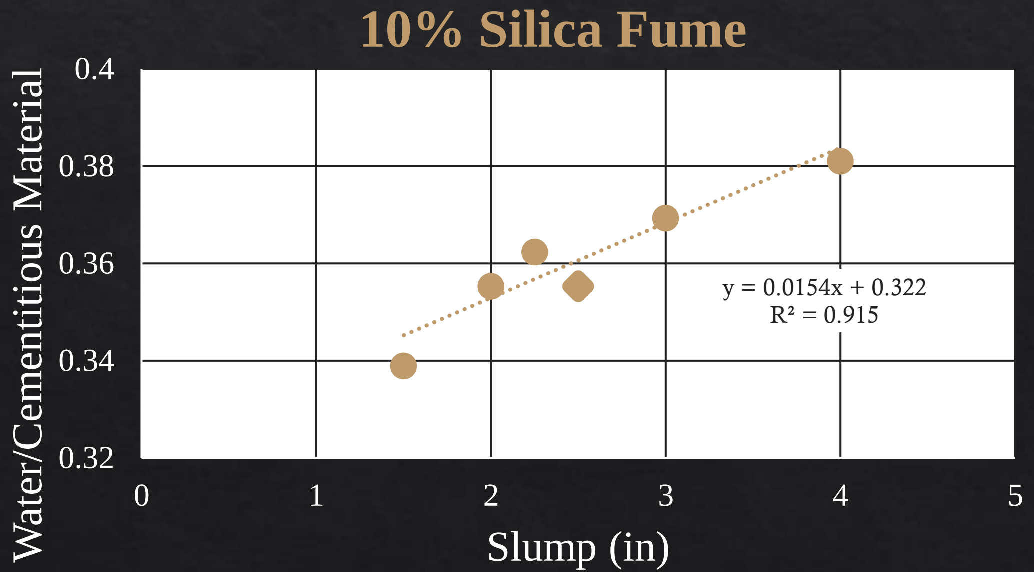
Water Demand vs Percent Replacement



W/CM vs Slump







Initial Empirical Findings

Linear Relationship between Slump and W/CM Ratio

$$y = mx + b$$

m ≈ 0.0125 (Average Slope for SF)

b → Varies based on SCM Replacement

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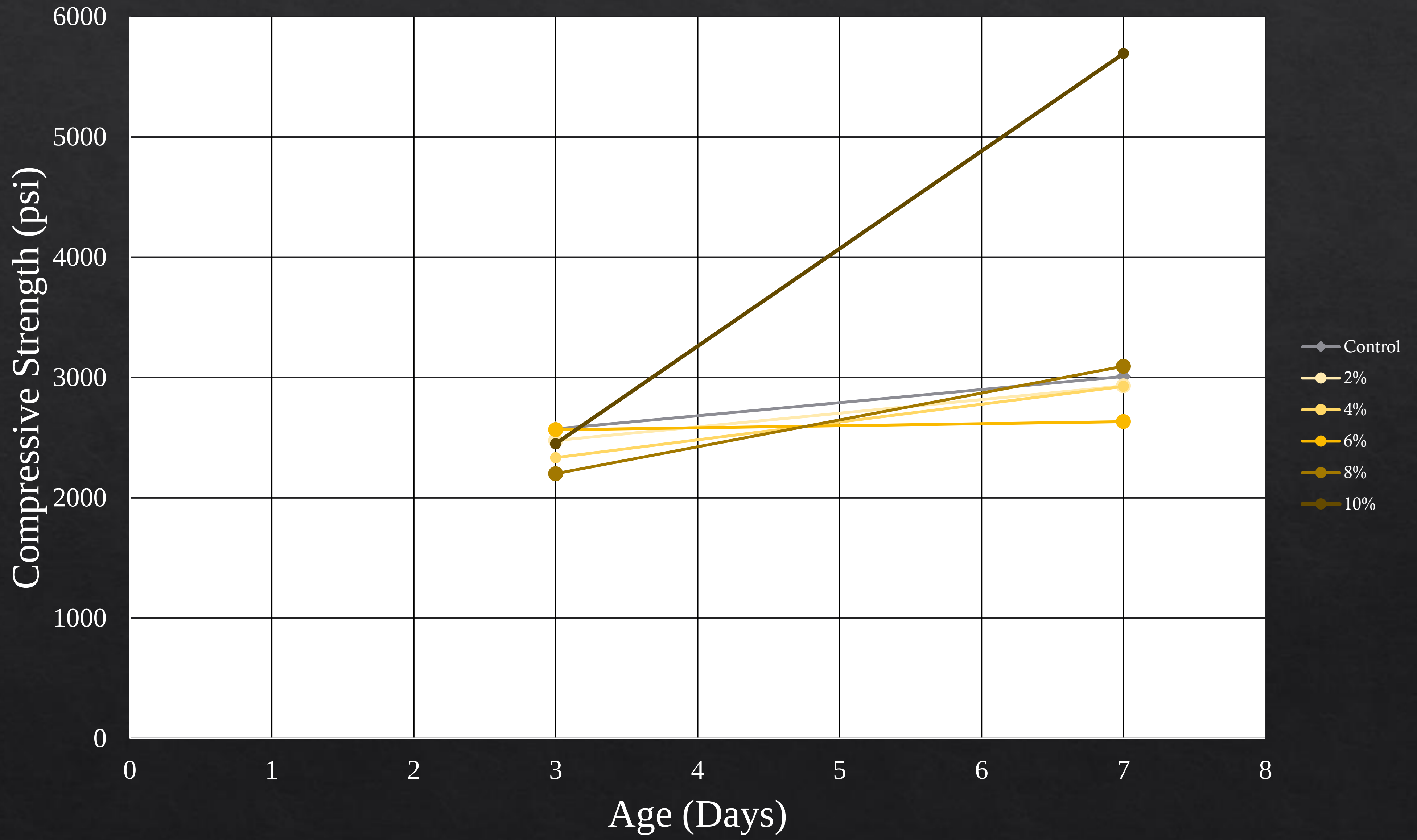
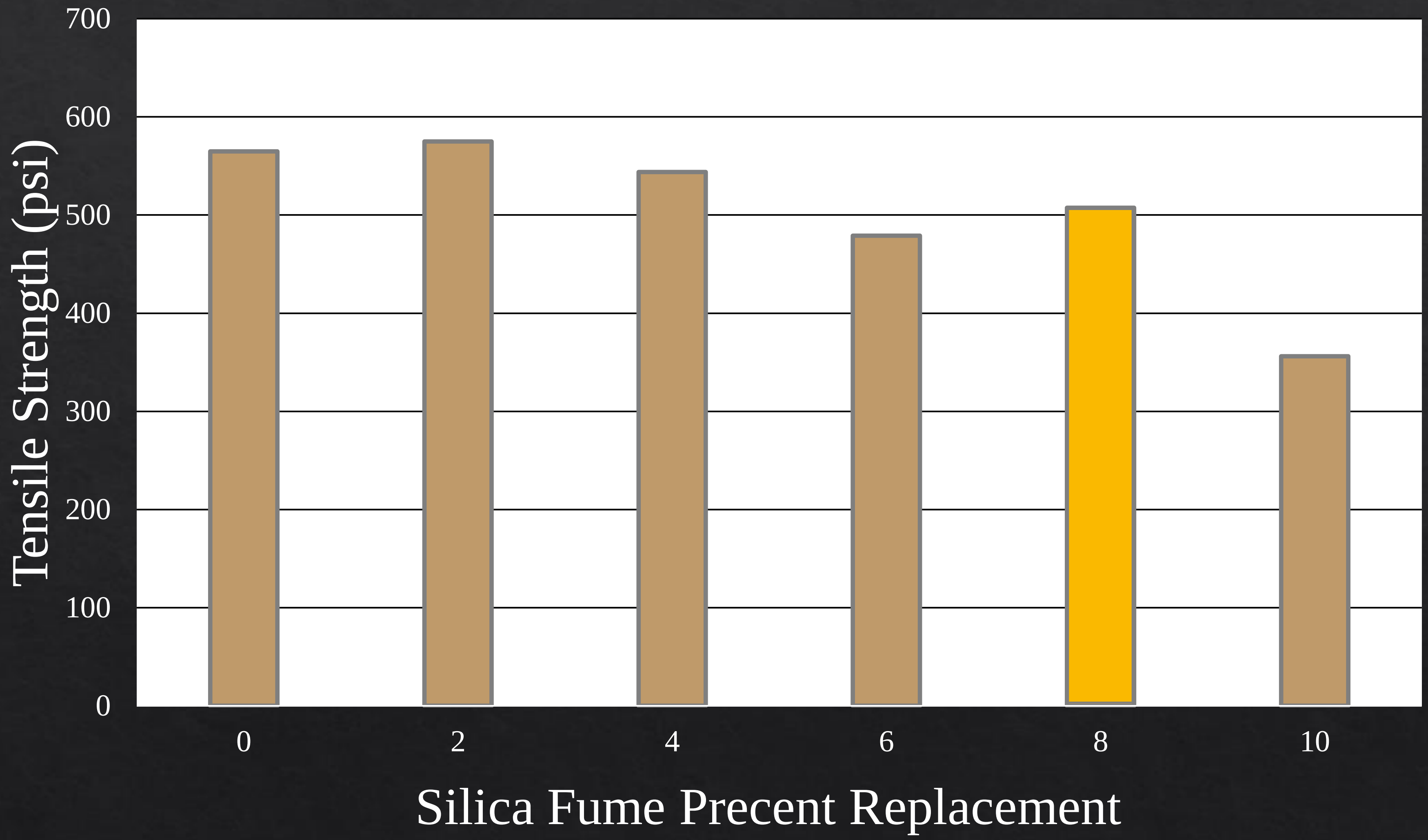
Compressive Strength vs Age



7-Day Split-Tensile Strength

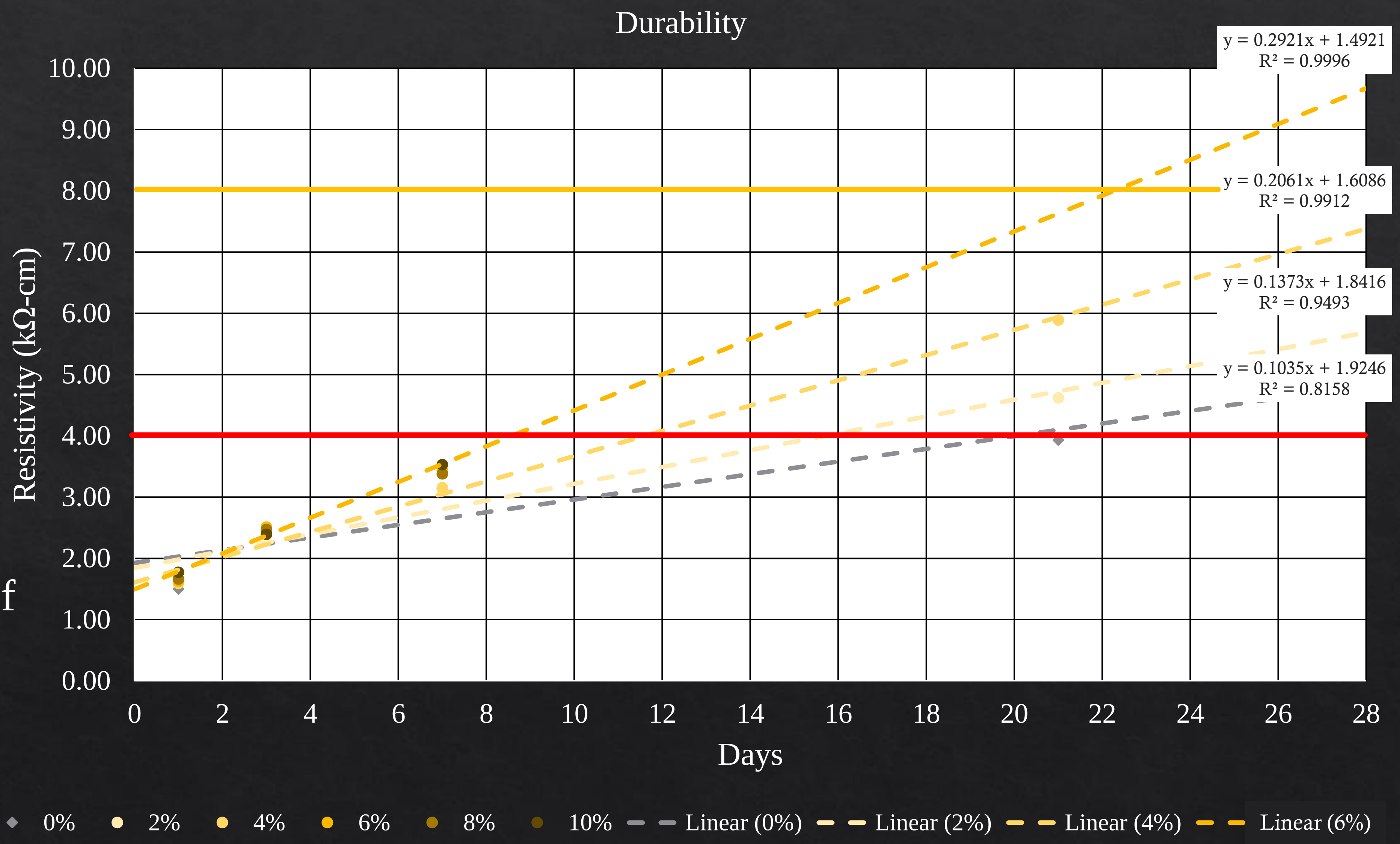


Durability via Electrical Resistivity

Chloride Penetration:

High: <4 kΩ-cm
Moderate: 4-8 kΩ-cm
Low: 8-16 kΩ-cm
Very Low: 16-190 kΩ-cm
Negligible: >190 kΩ-cm

This test examines the connectivity and volume of the pore space in the concrete samples.



Conclusion

Preliminary Findings

- Preliminary data aligns with expected behavior
  - Silica Fume increased the water demand
  - Higher replacement mixes were qualitatively less workable
  - Increased resistivity in higher replacements
    - Increased durability
  - Initial Empirical Slump to w/cm relationship
    - $\boldsymbol{y = 0.0125x + b}$
- Preliminary data leads to unexpected results
  - Decrease in compressive & tensile strength with increased silica fume
    - Not getting early strength gain

Future Research

Silica Fume:

- Retest the outlier – 8% Silica Fume
- Use collected data on water demand change in a mortar
  - Vicat Test – Initial and Final Set Time (ASTM C191)
  - Flow Test – Mortar Workability (ASTM C1437)

Fly Ash:

- Conduct the same procedures with Fly Ash
  - Fly Ash replacement of Portland Cement
    - 5%, 10%, 20%, 30%, 40%,

Ternary Blend:

- After understanding the impact of water demand at known replacement percentages on binary blends
- Begin to experiment and quantify the impact of water demand at known replacement percentages of both fly ash and silica fume combined

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