Votorantim Cimentos

High Strength Concrete and Modulus of Elasticity: Addressing Increasingly Complex Projects

February 1, 2018

Overview

- **Introduction**
  - What is high strength concrete?
  - Performance requirements
- **Commonly Used Constituents**
- **Production and Delivery**
- **Quality Control and Testing**
- **Modulus of Elasticity**

High Strength Concrete: An Introduction

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What is high strength concrete?

Wanda Vista

Design

Current View

What is high strength concrete?

35th Street Bridge Chicago

A vast range

- ACI defines high strength concrete as a mix with a specified compressive strength over 8000psi
- Throughout much of the United States, concrete producers in urban areas are capable of producing 14000 psi mixes
- A few projects have successfully placed mixes specified to achieve 19000 psi

The unanswerable question

- **High Strength concrete is a relative term**
  - Locally available materials
  - Construction practices

- **Stakeholders determine the definition of High Strength Concrete**

- **"The reason for such diversity is twofold: need and ability… need to the type of construction and the initiative of the designer, and the commitment of the concrete producer and quality of locally available materials."**

(Albinger, 1988)

- **Even after determining a specified strength, high strength concrete must often meet many other requirements to satisfy stakeholders**

  - **Design**
    - Modulus of Elasticity
    - Durability
    - Set Time
    - Early Strength
    - Consistency
  - **Constructability**
    - Workability retention
    - Placeability
    - Finishability
    - Form Stripping
    - Post-tensioning

- **High strength concrete differs from conventional concrete in that a high strength bonding system is weaker aggregate filler**

Communication

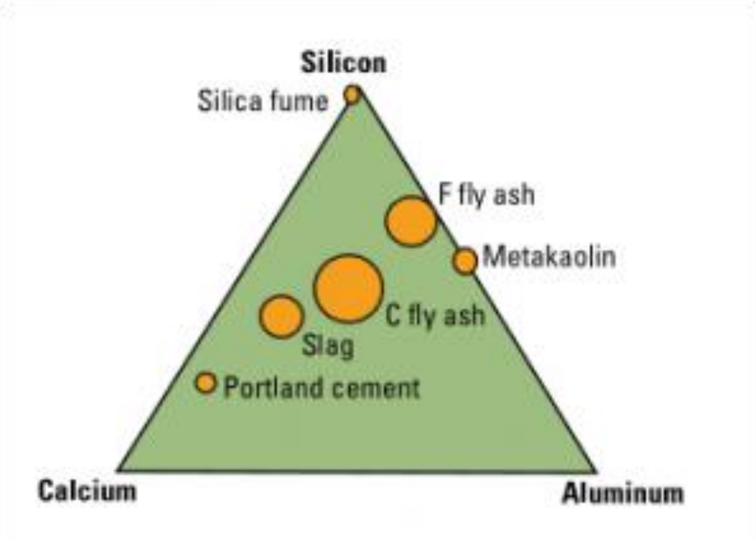
- **The importance of good communication between all parties cannot be stressed enough for high strength concrete jobs**

Constituents

Cementitious materials

- **Unlike traditional concrete, the paste for high strength concrete is the strongest portion of the mix**

- **The following material are normally used to produce a robust paste:**
  - Cement (Type I/II)
  - Fly Ash (C or F)
  - Slag (Grade 100 or 120)
  - Silica Fume



Particle Packing

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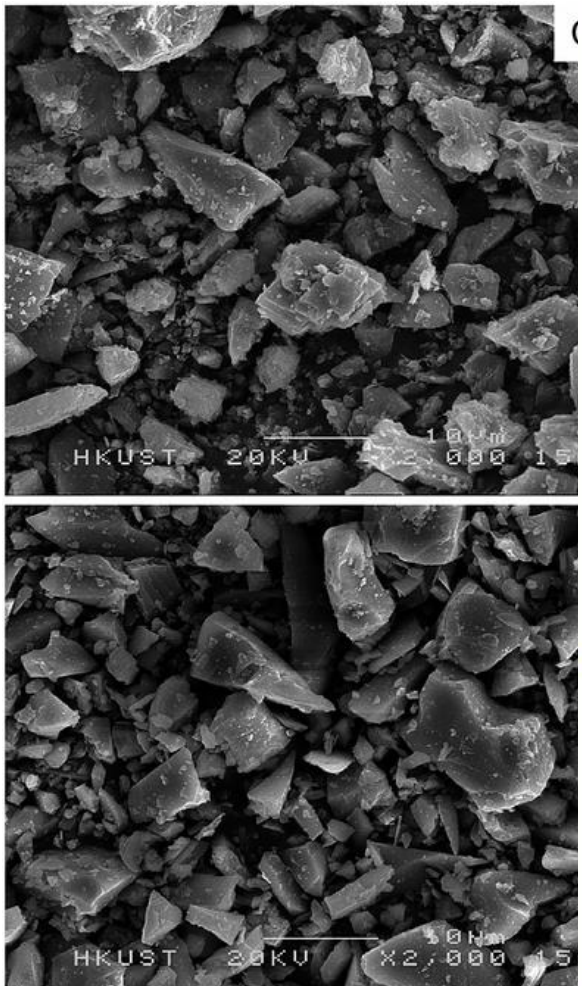
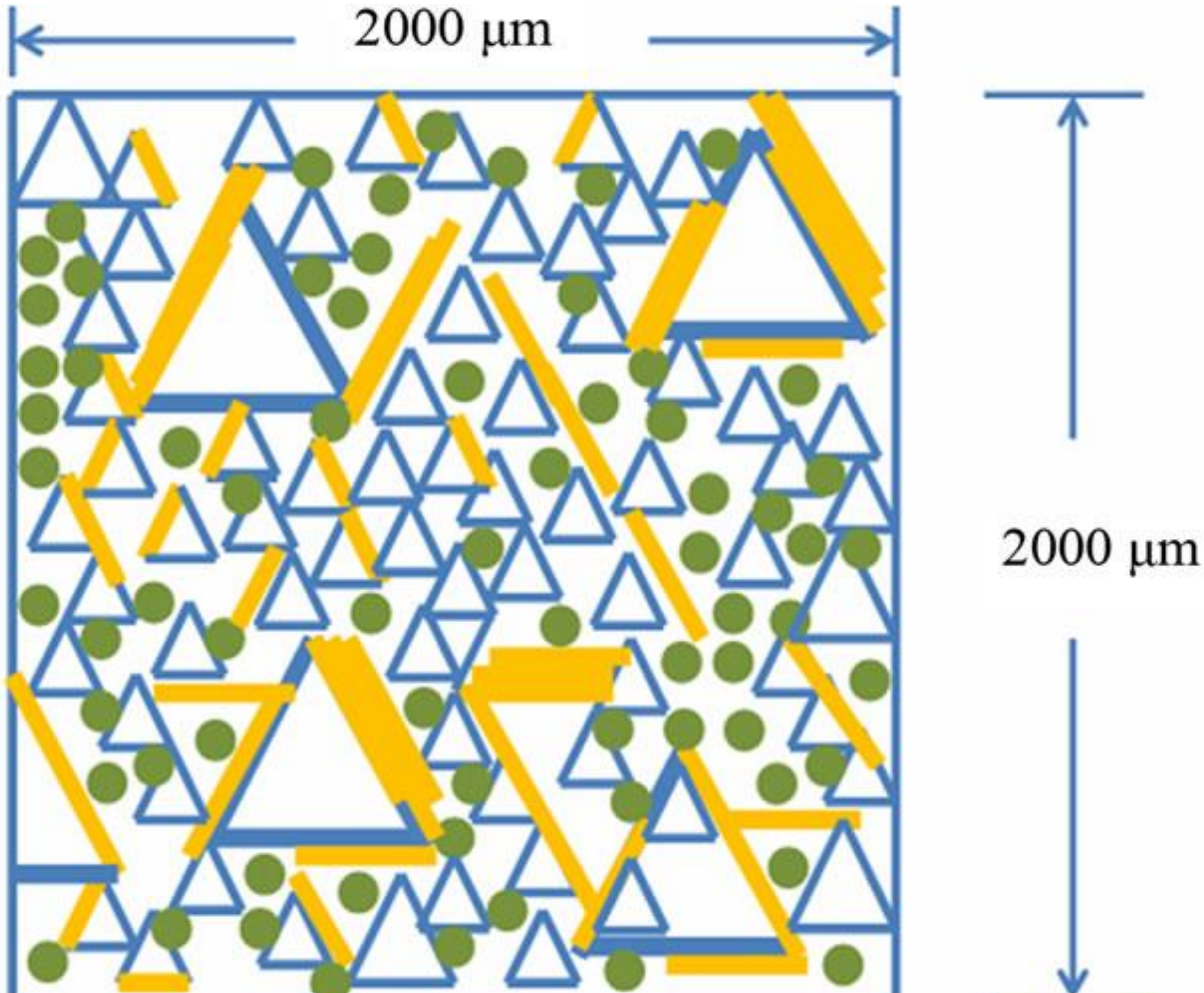
- **Arguably, the most important factor to achieving high strength concrete is development of a dense, multi-component paste**

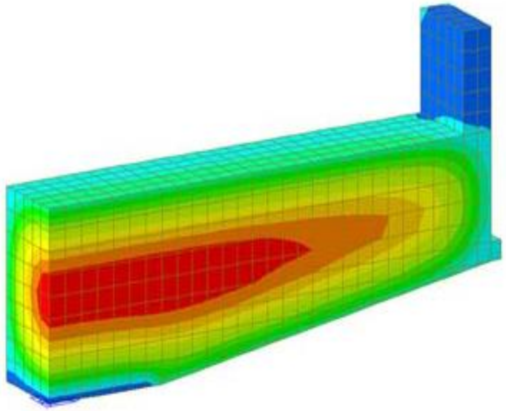




Selection of Cementitious Materials

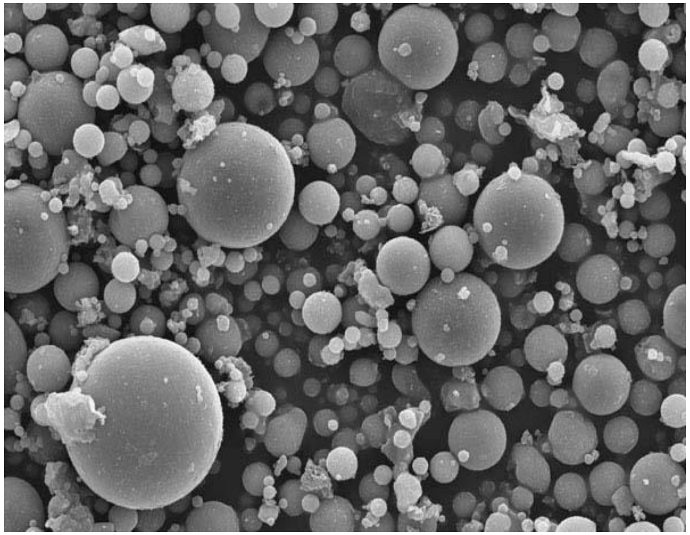
- **High Strength concrete can be produced with nearly limitless combinations of cementitious materials**

- Thermal Concerns



- Minimize cement
- Maximize slag (50+%)

- Pumpability



- Increase fly ash
- Addition of silica fume

- Low Permeability

- Silica fume 5 – 20%

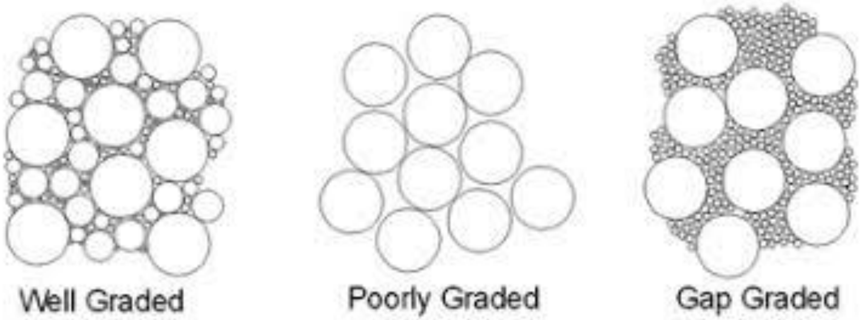
Design Phase

- **Evaluate cementitious materials before selection**
  - Mill certifications
  - ASTM C618-12a
  - ASR and Sulfate Resistance

Production Phas

- **Monitor performance during product**
  - Loss on ignition
  - Foam index
  - Mortar cubes (ASTM C 109 and 989)

- **Key differences from conventional concrete**
  - Smaller aggregate often preferred
    - More surface area
    - Crushing eliminates weak zones
  - Shape and face
    - Cubical shape
    - Rough texture
  - Well graded material
    - May require blending
  - Increased density
    - Higher specific gravities



- **Key differences from conventional concrete**
  - Coarse sands
    - Decrease surface area
  - Finishability
    - Not prioritized commonly
  - Fineness Modulus
    - FM of ≥3.0 optimal

- **Manufactured sand is often preferred**

Aggregate Testing

- **Constant evaluation of aggregates is needed to prevent performance changes**
  - Aggregates used in high strength concrete are subject to weekly gradations
  - Monitor the specific gravity and Mohr's hardness of coarse aggregate
  - Aggregate moisture should be carefully tracked to protect design W/CM ratio

Admixture Selection

- **The creation and widespread use of chemical admixtures have allowed for the development of high strength concrete**
  - High Range Water Reducers – modern polycarboxylates
    - Allow for W/CM ratios within .35 - .20 and workability
  - Hydration Stabilizers
    - Maintain control over set times and increase long-term strength
  - Viscosity Modifying Admixtures
    - Reduce segregation
    - Reduce bleeding
    - Reduce friction and pressure in pump
  - Air Detraining Admixtures
    - Provides low air contents to maintain design strength and permeability

Production and Delivery

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- **ACI 211.1 (proportioning normal weight concrete) is still applicable in designing high strength mixes**

1. Identify relevant requirements
2. Selected desired consistency (slump or spread)
3. Select nominal max aggregate size
4. Estimate water content based on constituents
5. Estimate W/CM ratio based on requirements
6. Estimate amount and proportions of cementitious based on water content and W/CM ratio
7. Estimate admixture dosage rates
8. Estimate coarse aggregate volume
9. Estimate fine aggregate volume
10. Conduct lab trials
11. Conduct field trials

- **Make necessary adjustments**

Producer Limitations

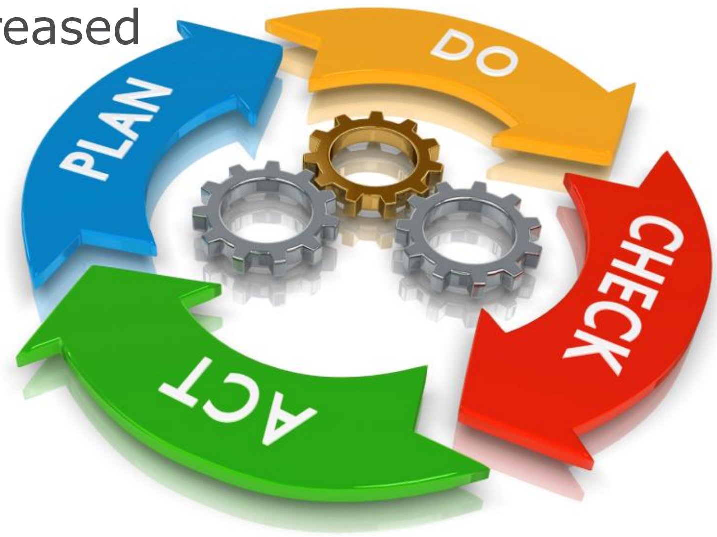
- **High strength concrete is often limited by the producers supply streams and equipment**
  - ➢ Determine if plant has adequate material storage systems
    - Aggregate bins and stockpiles
    - Cementitious siloes
    - Admixture tanks and lines
  - ➢ Central mix plants often produce more consistent concrete
    - One drum, one operator
  - ➢ Calibration and use of moisture probes
    - Maintain consistency and reduce aggregate testing burden
  - ➢ Consistent maintenance of equipment
    - Ensure adequate mixing action of all equipment

Order taking and Dispatching

- **Customer expectations and behavior may need modification from sales staff**
  - Establish appropriate order window and consistency
    - Ensure all materials are available
    - Slump or spread
  - Minimum loads size can help prevent excess variability
  - Appropriate truck staging and delivery rate
    - High strength concrete often requires more time to produce
  - Instruct drivers on proper high strength concrete procedures
    - Empty all water from drum prior to loading
    - Standardize wash time and volume
    - Provide minimum revolutions to drivers
    - Eliminate water additions

Mixing and Production

- **ASTM C 94 outlines production of concrete and applies to high strength**
  - Ensure concrete is thoroughly mixed
    - Superplasticizer
    - Silica fume
  - Try to avoid shrink mixing if using a central mix plant
  - Reduce batch size to accommodate increased cementitious material
    - 5-15% reduction
  - Protect your W/CM ratio – ensure no additional water is added!
    - Drivers
    - Customers



Quality Control and Testing

High Strength Specimens and testing

- **While high strength specimens follow many of the same testing procedures as conventional concrete, they are inherently more sensitive to poor testing practices**
  - As material strength increases, specimens become increasingly brittle

- **To ensure consistency, personnel must have proper knowledge, performance, and equipment**

- **Communication between producer, concrete contractor, and independent testing lab will help greatly**

Slump and Spread

- **High strength concrete can have a consistency between conventional slump and self-consolidating concrete due to constructability requirements**
  - Rebar congestion
  - Pumping distance
- **This unique trait can lead to confusion over the type of consistency measurement**
  - Align consistency measure for each high strength mix with all parties based on submitted design

Specimen handling and storage

- **Because of their size, high strength specimens are strongly influenced by changes in temperature and moisture during curing periods**
  - ➢ Both initial and final curing should ensure the specimens do not lose moisture
    - Saturated lime water storage
    - Moist Room storage
  - ➢ Insulated and heated storage boxes ensure ambient temperatures minimally affect mix performance
  - ➢ The use of elevated SCM proportions and hydration stabilizer can leave specimens more susceptible to early age transport damage

Compressive Strength Testing

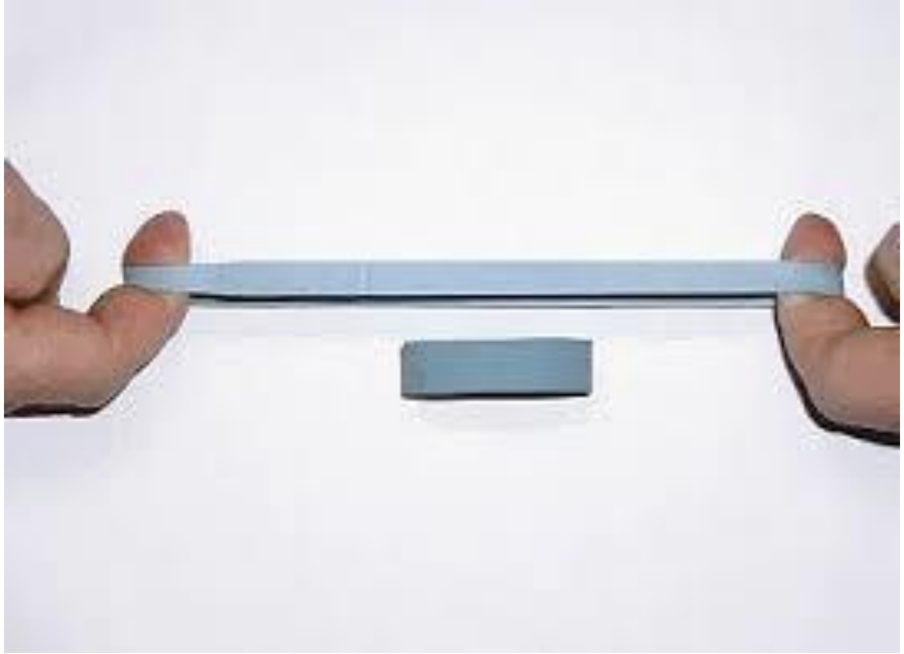
- **AASHTO or CCRL accredited labs must be used for evaluation of high strength concrete specimens**
  - Specimen storage
  - Preparation of specimens (capping or grinding)

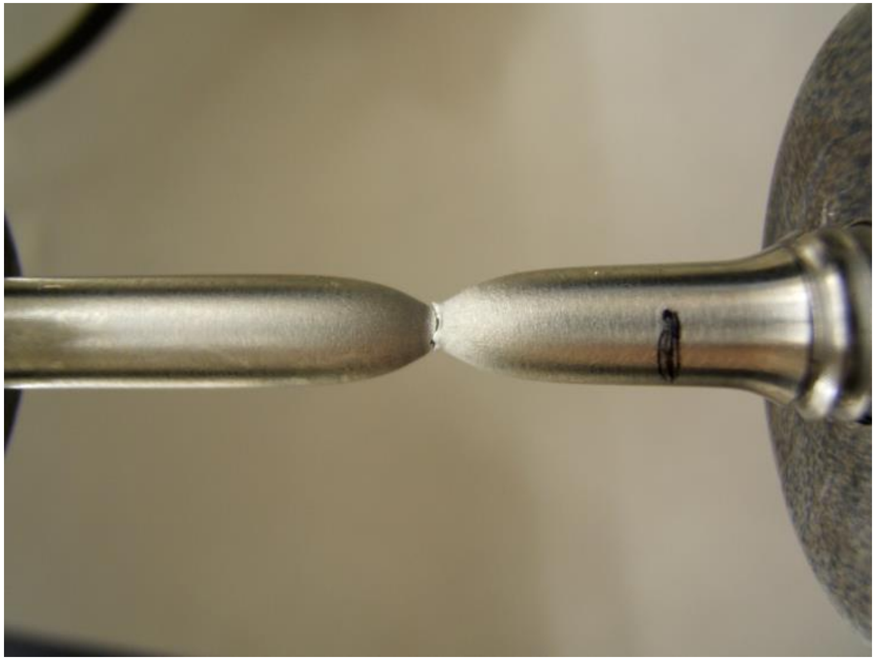
- **Not all labs may have the necessary equipment or certification to process high strength concrete specimens**
  - Compression machines may need 600,000 lbs total load capacity
  - Load rates consistent with conventional concrete of 20 to 50 psi/sec (ASTM C 39)

Modulus of Elasticity

▪ Young's Modulus:

- Measure of the stiffness of a solid material
- Defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material

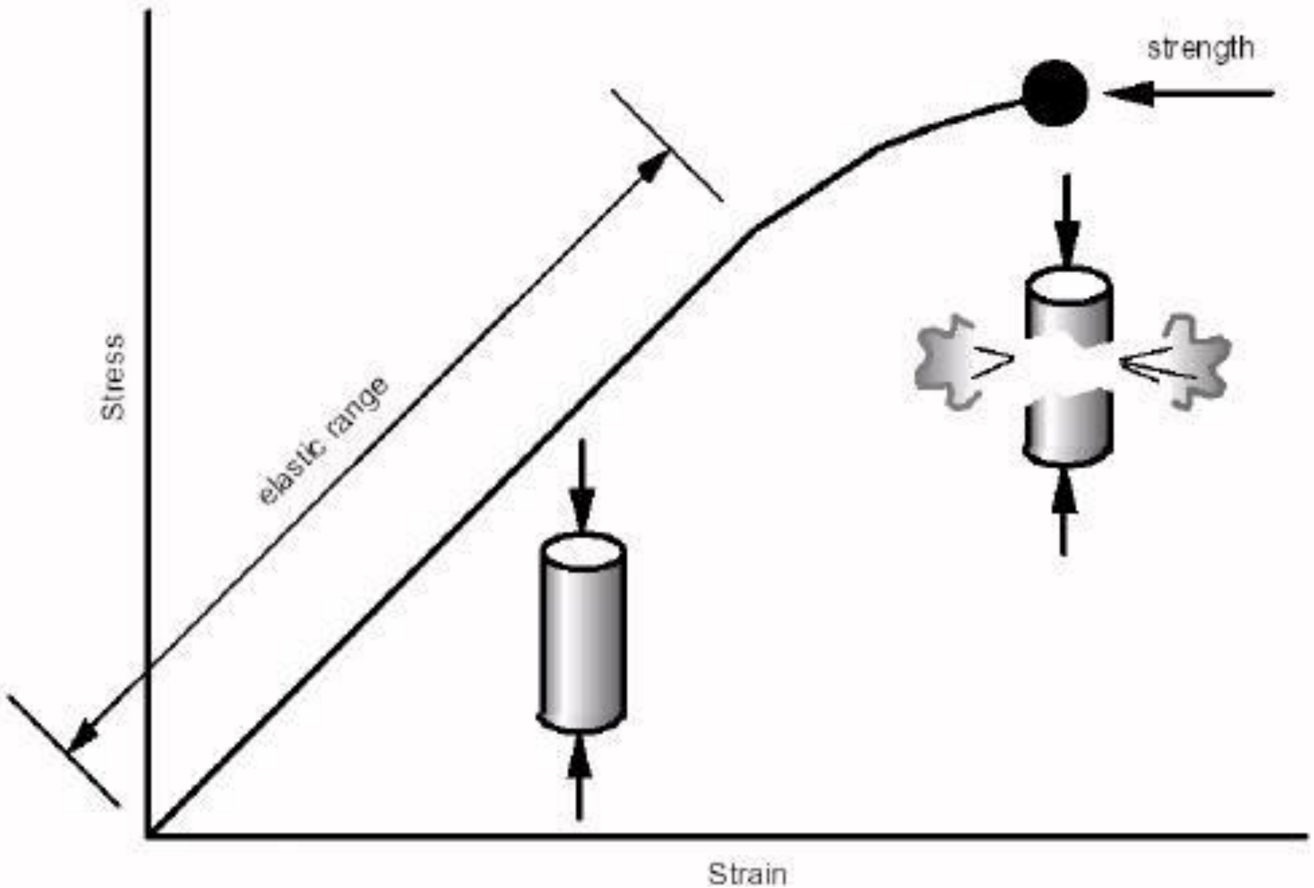




Modulus of Elasticity (Young's Method)

- A solid material will deform when a load is applied to it. If it returns to its original shape after the load is removed, this is elastic deformation.

- In the range where the ratio between load and deformation remains constant, the stress-strain curve is linear.



- **Samples over 12,000psi must be ground before compression and modulus testing (ASTM C1231)**

Specimen Prep Cont.

Air voids and moisture

- **Voids within the specimen can produce skewed results**
- **Both mix design and specimen casting practices impact final surface**
- **Specimen moisture must be kept constant**

Apparatus and Setup

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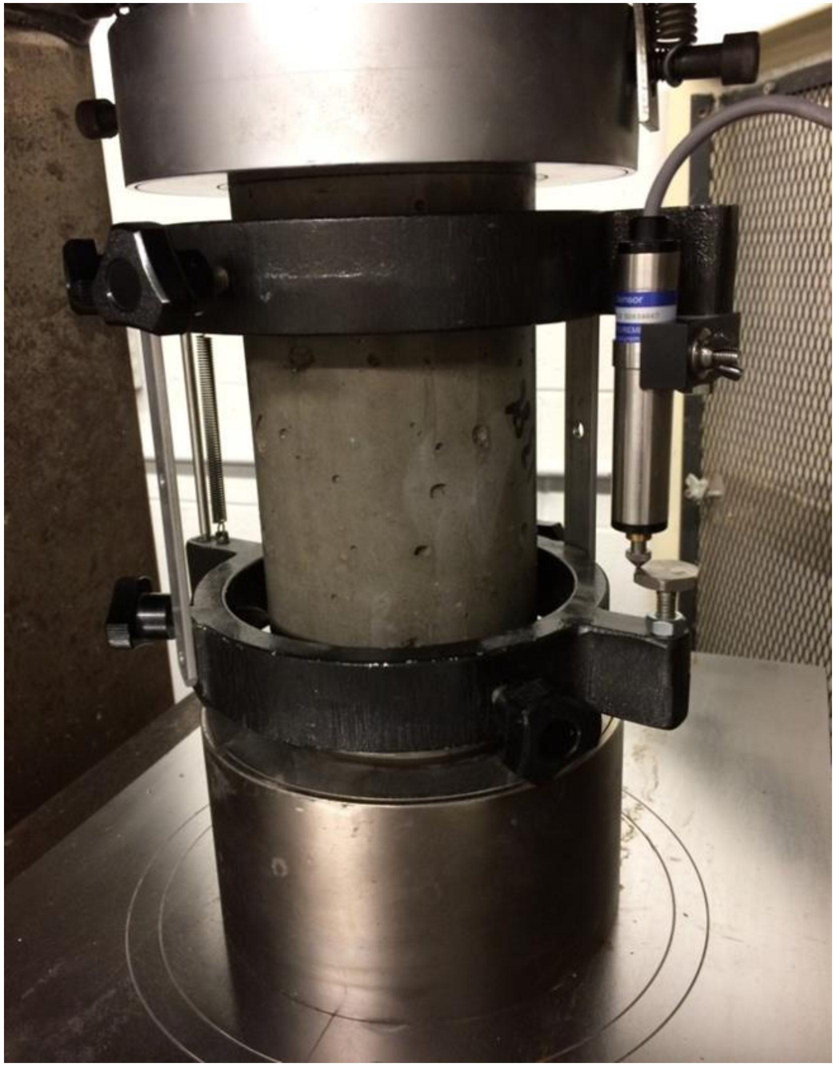
MoE Rig

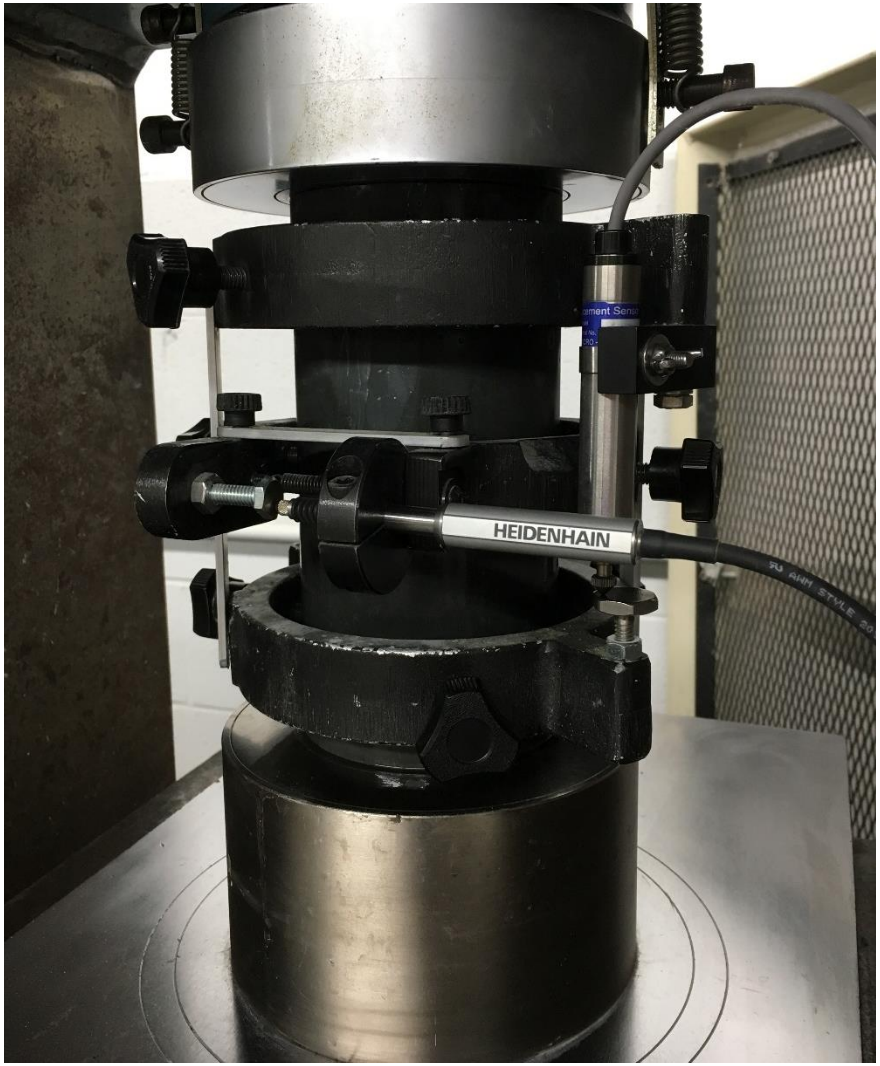
Rig with Cylinder

Testing MoE

Young’s Modulus setup

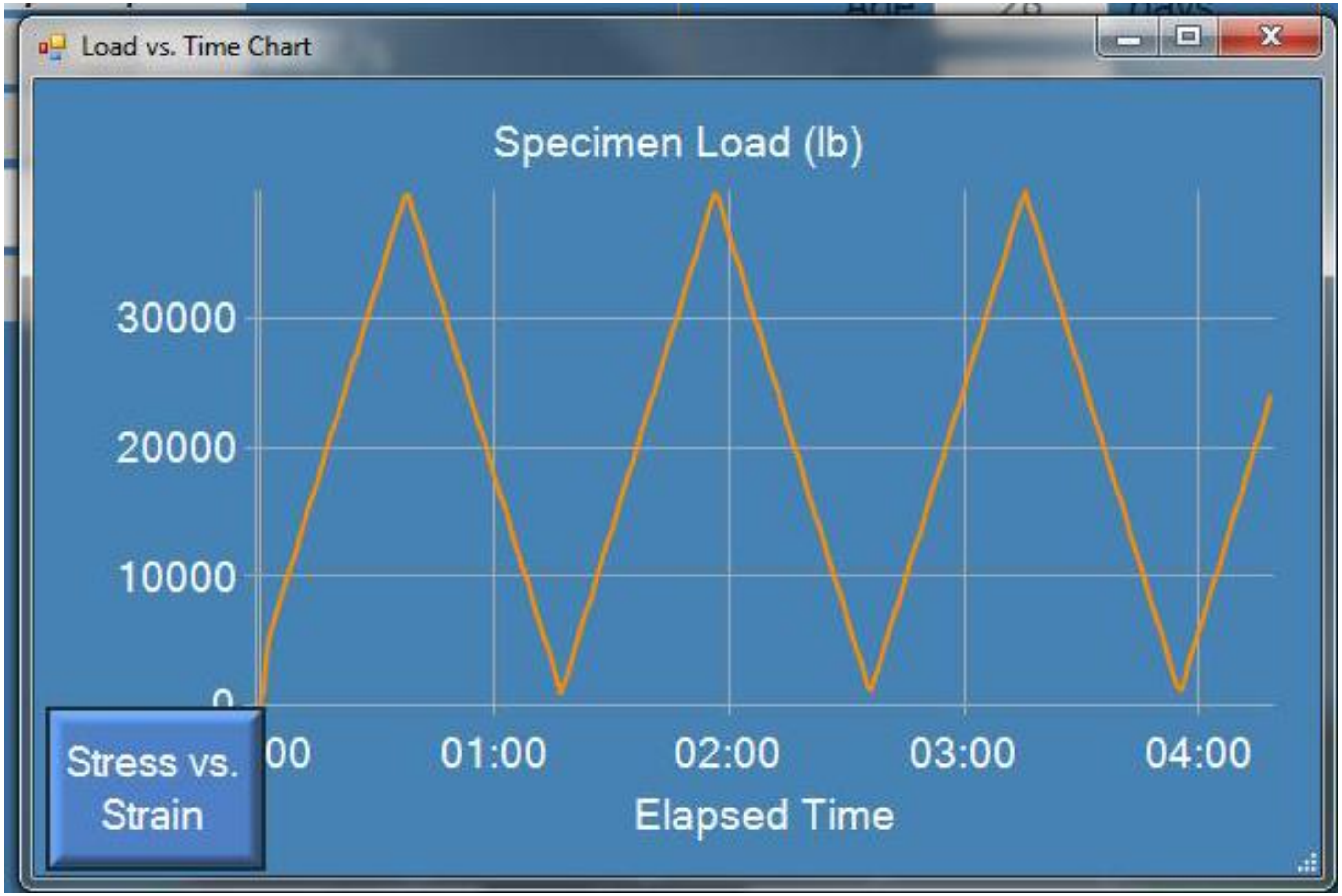


Poisson’s Ratio setup



MoE Loading Curve

- **ASTM C469 requires a specimen to be loaded to at least 40% of its compressive strength and then unloaded in a controlled manner three times**



MoE Report and Graph

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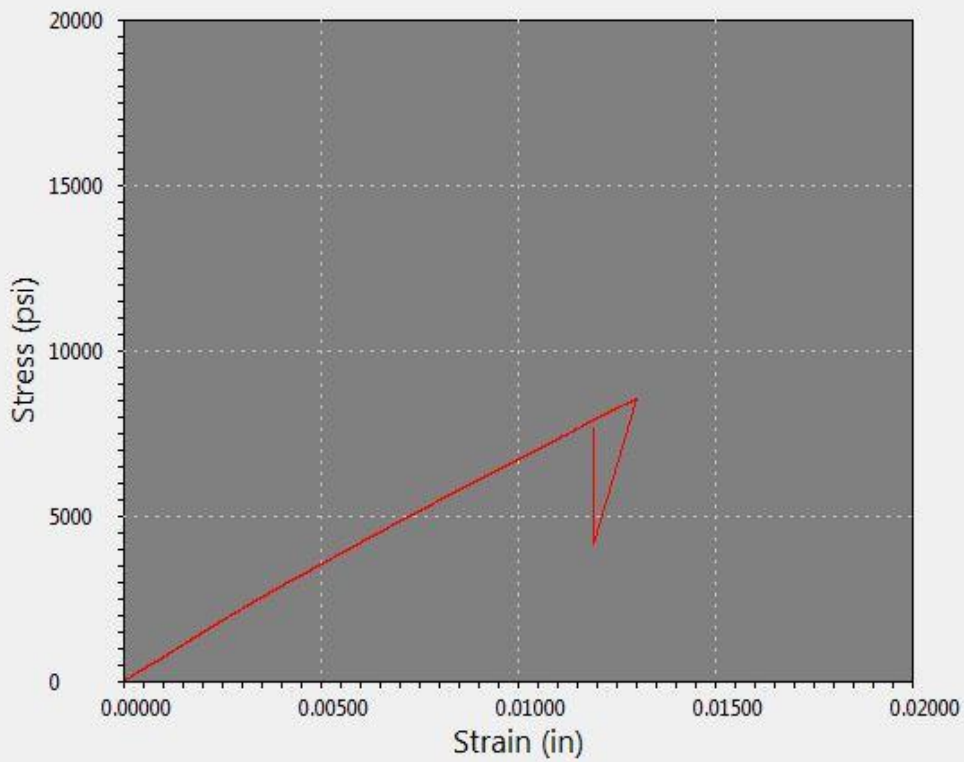
MainView | CalibrationView | SetupView | TestDataView | ChannelsView | ReportView

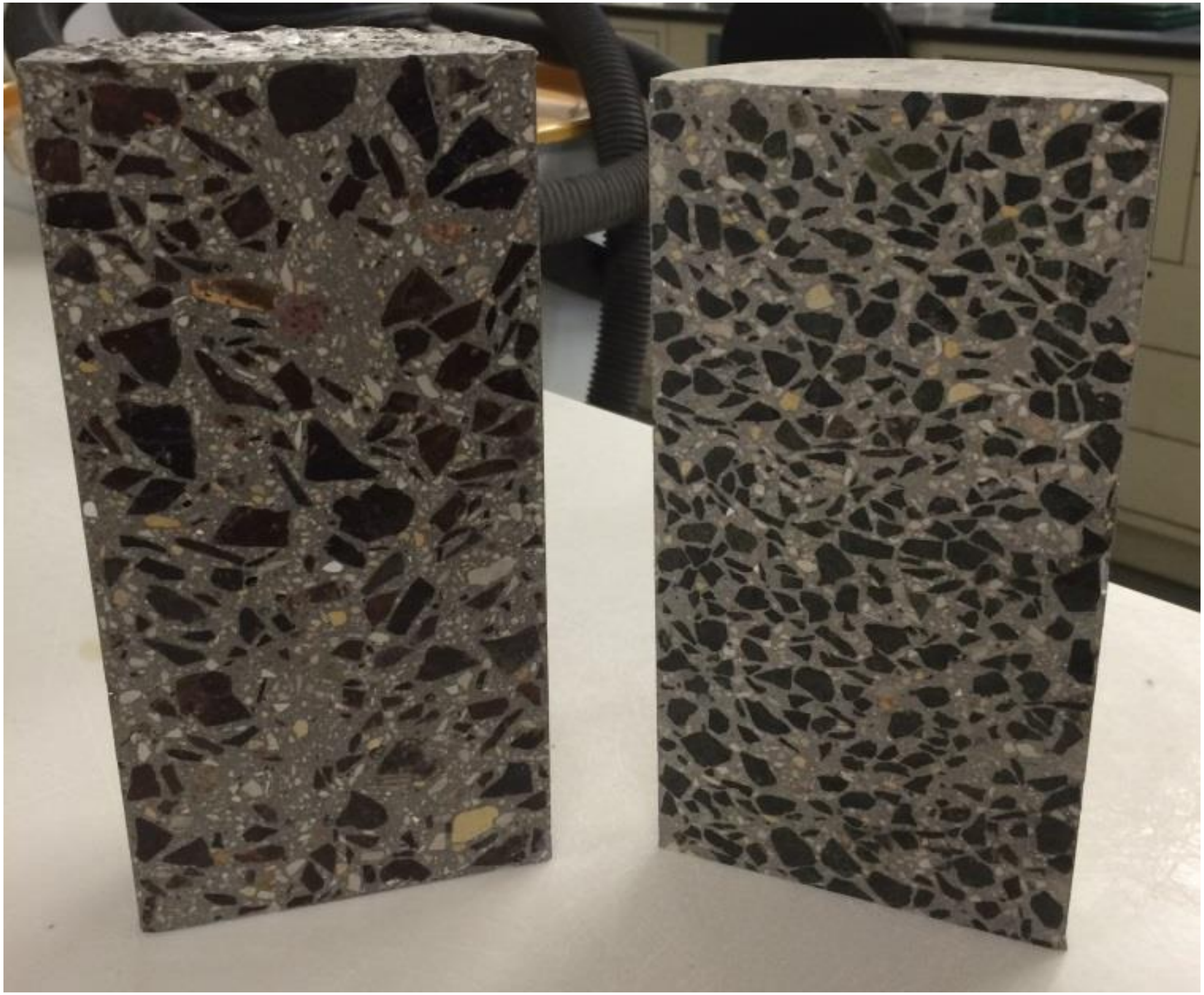


RESULTS

Date:	01/10/18
Time:	12:53:10
Specimen ID#:	101187
Specimen Type:	CYLINDER
Specimen Length (in):	7.780
Specimen Area (sqin):	12.629
Specimen Age:	91 days
Specimen Weight(Lb):	8.90
Cylinder Cap Type:	GROUND
C469 Modulus (psi):	7371223
Maximum Load (Lb):	107700
Maximum Stress (psi):	8527
Rate (Lb/s):	425.0
Rate (psi/s):	34.4

Specimen Evaluation

- **Examine cut specimens for voids, segregation, or other abnormalities**



High Strength Concrete References

- **Design and Control of Concrete Mixtures – 16th Edition**
  - Published by PCA
- **ACI 363R-10 Report on High-Strength Concrete**
  - Published by ACI
- **High-Strength Concrete: A Practical Guide**
  - Michael A. Caldarone
- **ACI 211.4R-08: Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement & Other Cementitious Material**
  - Published by ACI

Thank You