Slag cement in high performance concrete

Slag Cement School

4/29/24

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Introduction

- What is high performance concrete?
- Performance requirements

Use of slag cement

Production and delivery

Quality control and testing

Questions

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High Performance Concrete

An Introduction

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What is high performance concrete?

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What is high performance?

- **High Performance concrete can be unified as having extended or set lifecycle requirements**
  - 20 years
  - 50 years
  - 100 years
- **Historically, high performance concrete was synonymous with high strength concrete**
  - 6000+
  - 8000+
  - 10000+
- **High performance means different things to each designer, owner, and engineer**

What is high performance?

- **High performance concrete is a relative term**
  - Locally available materials
  - Construction practices
- **Stakeholders determine the definition of high-performance 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.”**

Performance Requirements

- **Even after determining a defined lifecycle and specified strength, high performance concrete must often meet many other requirements to satisfy stakeholders**
  - **Design**
  - Permeability
  - Durability
  - Set Time
  - Early Strength
  - Consistency
  - Modulus of Elasticity
  - **Constructability**
  - Workability retention
  - Placeability
  - Finishability
  - Form Stripping
  - Post-tensioning
- **High performance concrete differs from conventional concrete in that a high strength bonding system is paired with weaker aggregate filler**

Specification and Communication

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

High Performance Concrete

Slag Cement and high-performance constituents

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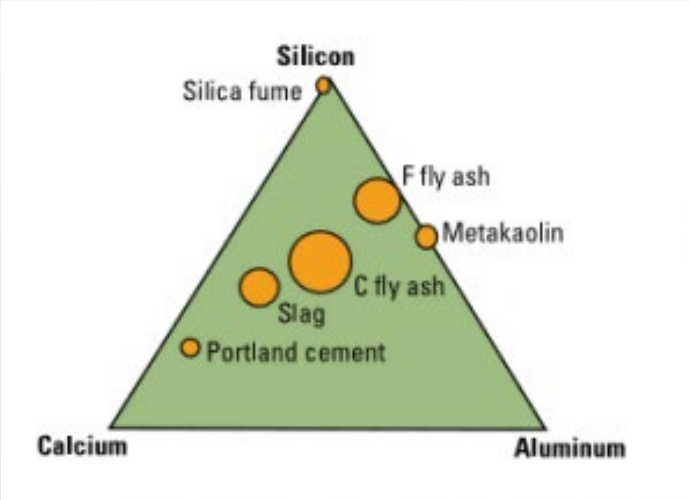
Cementitious materials

- **Unlike traditional concrete, the paste for high performance concrete is likely to be the strongest portion of the mix design**

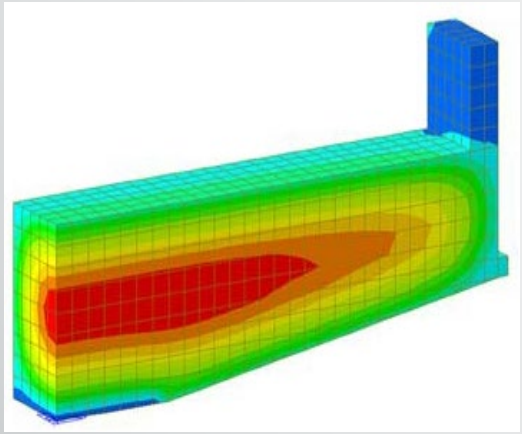
- **The following material are normally used to produce a robust paste:**
  - Cement (PLC or blended)
  - Slag (Grade 100 or 120)
  - Silica Fume
  - C/F ash



Selection of Cementitious Materials

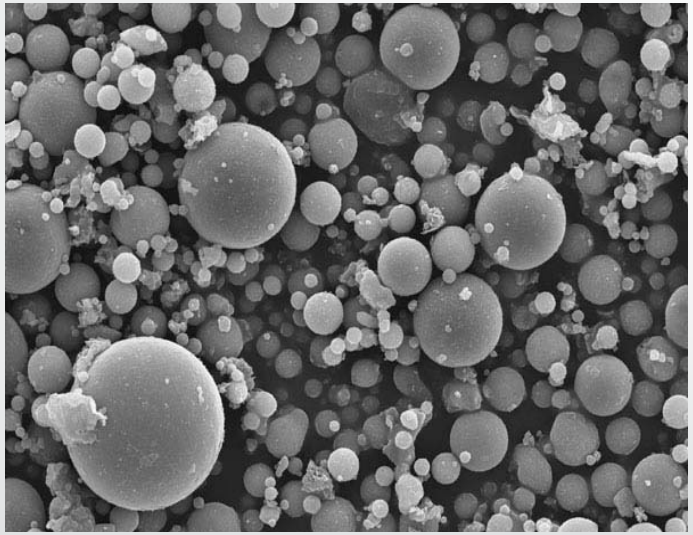
- **High Strength concrete can be produced with nearly limitless combinations of cementitious materials**

- Thermal Concerns



Minimize cement
Maximize slag (30-70+%)

- Pumpability and placement



- Increase fly ash
- Addition of silica fume

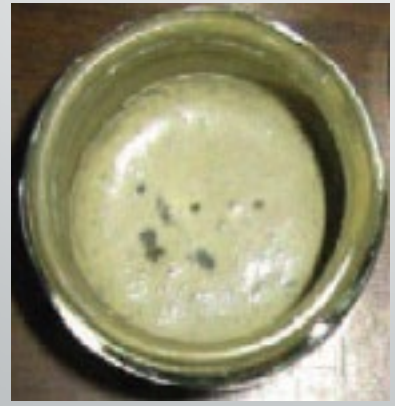
- Low Permeability

- Blend of multiple SCMs
- Silica fume 5 – 20%

Testing of Cementitious Materials

Design Phase

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



Production Phase

- **Monitor performance during product**
  - Mortar cubes (ASTM C 109 and 989)
  - Blaine
  - LOI, foam index, reactivity

Aggregate Selection

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

Aggregate Selection

- Key differences from conventional concrete
  - Coarse sands
    - Decrease surface area
  - Finishability
    - Not prioritized commonly
  - Fineness Modulus
    - May be specified indirectly through gradation requirements such as coarseness and workability specifications
  - Manufactured sands are beneficial due to lower ASR reactivity

Aggregate Testing

- Continuous evaluation of aggregates is needed to maintain performance
  - Weekly gradations
  - Monitor specific gravity and hardness particularly if mining location changes
  - Aggregate moisture needs to be tracked to provided effective water/cement control

Admixture Selection

- **The creation and widespread use of chemical admixtures have allowed more flexibility for the development of high-performance concrete**
  - High Range Water Reducers – modern polycarboxylates
    - Allow for W/CM ratios well below traditional concrete but still highly placeable
  - Hydration Stabilizers
    - Maintain control over set times and increase long-term strength
    - Helps control heat of hydration
  - Viscosity Modifying Admixtures
    - Reduce segregation
    - Reduce bleeding
    - Reduce friction and pressure in pump
  - Shrinkage reducing admixture
    - Manages shrinkage to prevent unwanted cracking and potential for chemical ingress

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Production and Delivery

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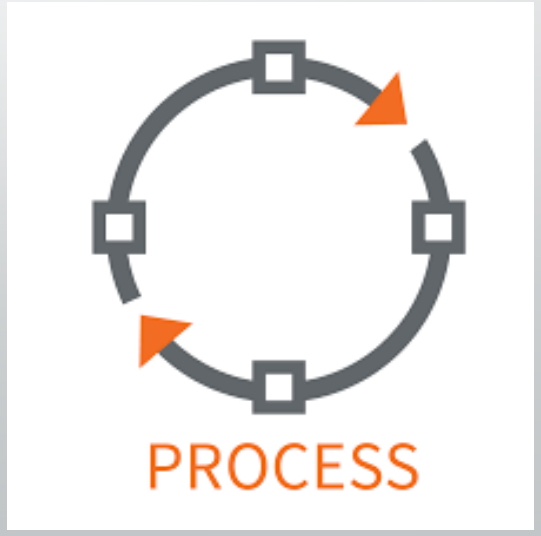
Design and Proportions

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

- Identify relevant requirements
- Selected desired consistency (slump or spread)
- Select nominal max aggregate size
- Estimate water content based on constituents
- Estimate W/CM ratio based on requirements
- Estimate amount and proportions of cementitious based on water content and W/CM ratio
- Estimate admixture dosage rates
- Estimate coarse aggregate volume
- Estimate fine aggregate volume
- Conduct lab trials
- Conduct field trials



- **Make necessary adjustments**

Producer Limitations

- **High performance 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 excessive variability
  - Appropriate truck staging and delivery rate
    - High performance 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 performance**
  - Ensure concrete is thoroughly mixed
    - Superplasticizer
    - Multiple cementitious
    - 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

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Quality Control and Testing

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High Strength Specimens and testing

- **While high performance specimens follow many of the same testing procedures as conventional concrete, they are inherently more sensitive to poor testing practices**
  - As cementitious content increases, specimens become increasingly brittle, prone to drying, and potentially slower initial strength gain
- **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 performance concrete can have a consistency between conventional slump and self-consolidating concrete due to constructability requirements**
  - Rebar congestion
  - Pumping distance
  - Architectural finishes
- **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

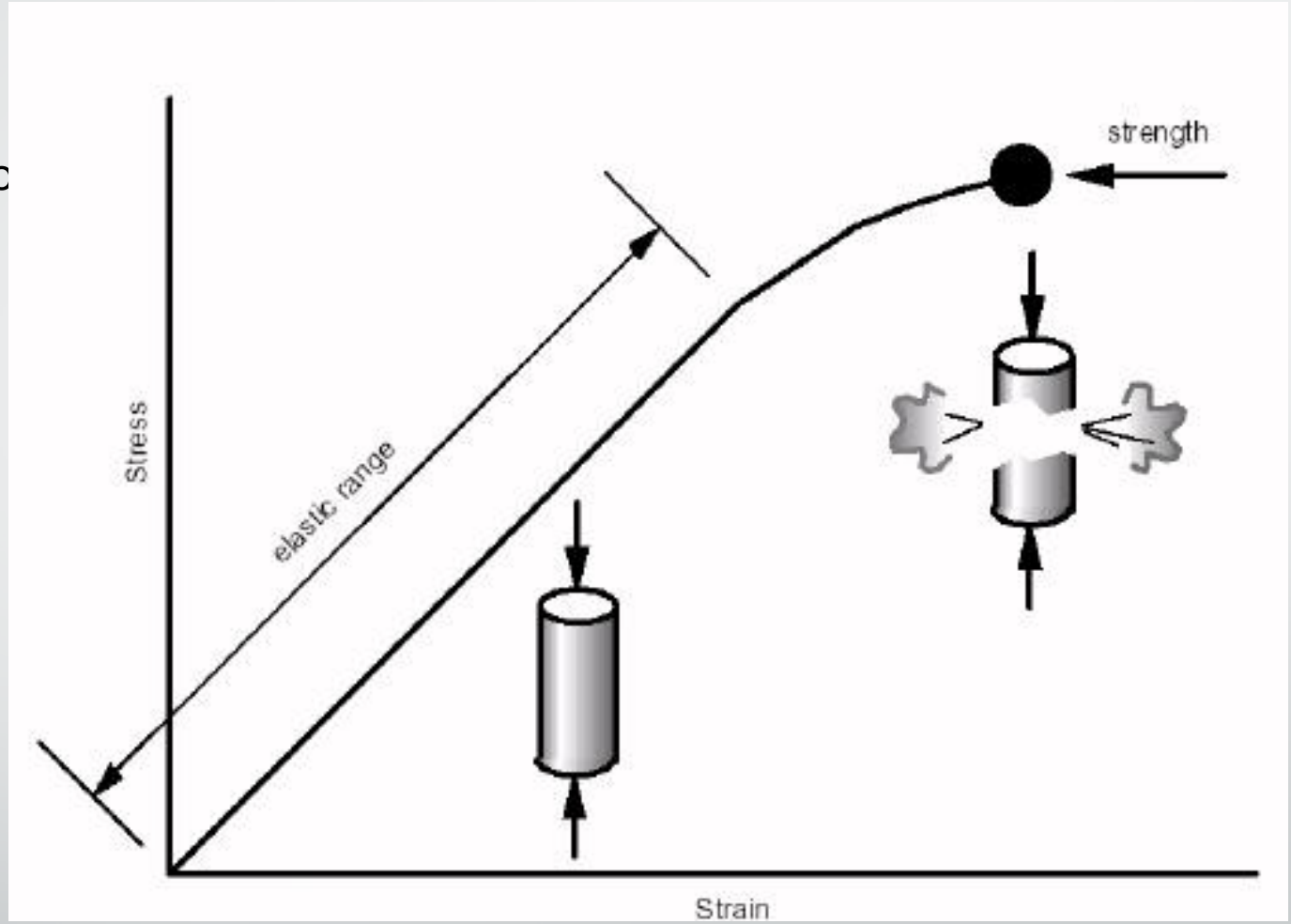
- **Because of their size, high performance specimens are strongly influenced by changes in temperature and moisture during curing periods**
  - Both initial and final curing should ensure the specimens do not lose moisture
    - Saturated lime water storage
    - Moist Room storage
  - Insulated and 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 performance 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)

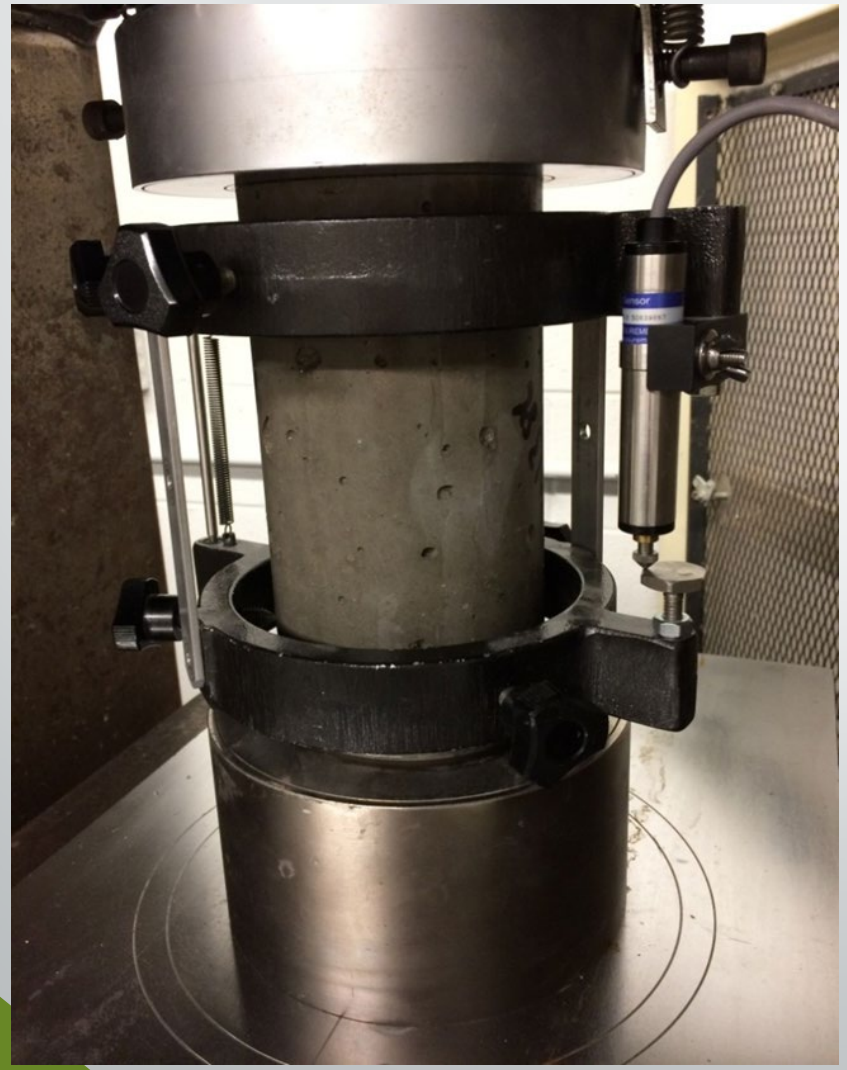
Modulus of Elasticity (Young's Method)

- 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.

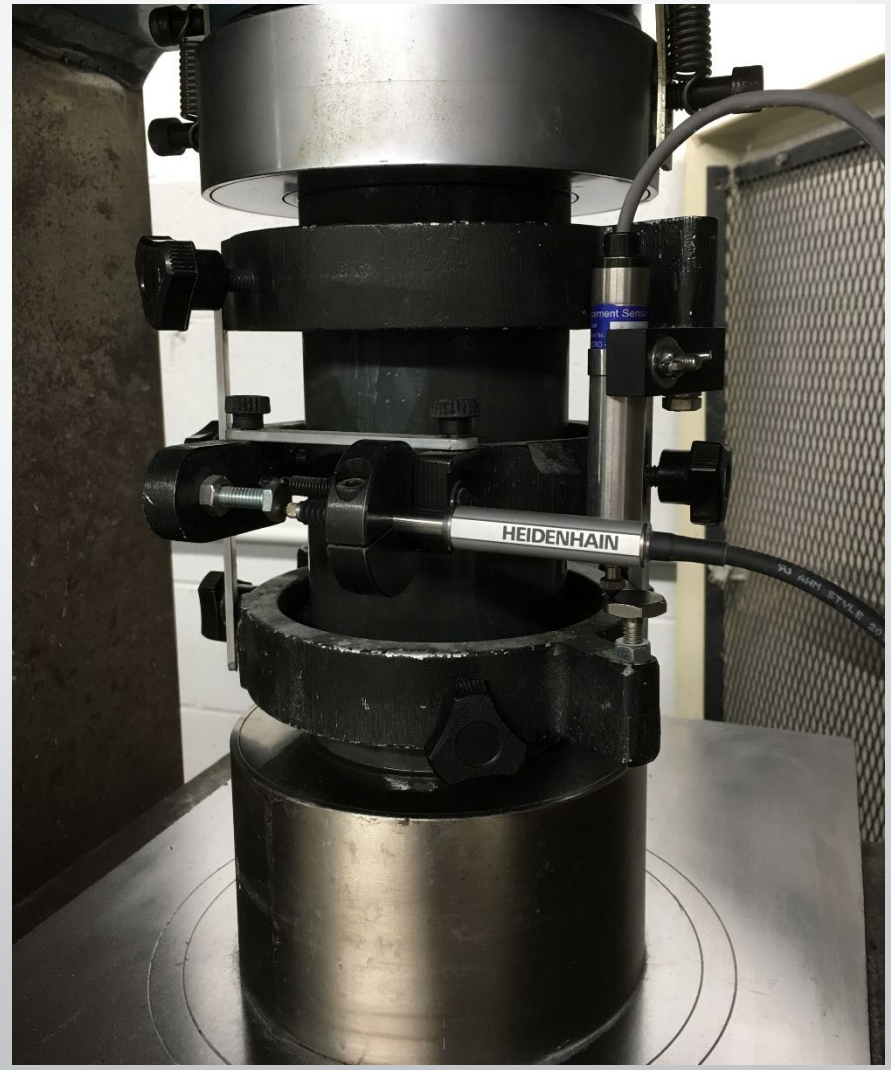


Testing MoE

Young's Modulus setup



Poisson's Ratio setup

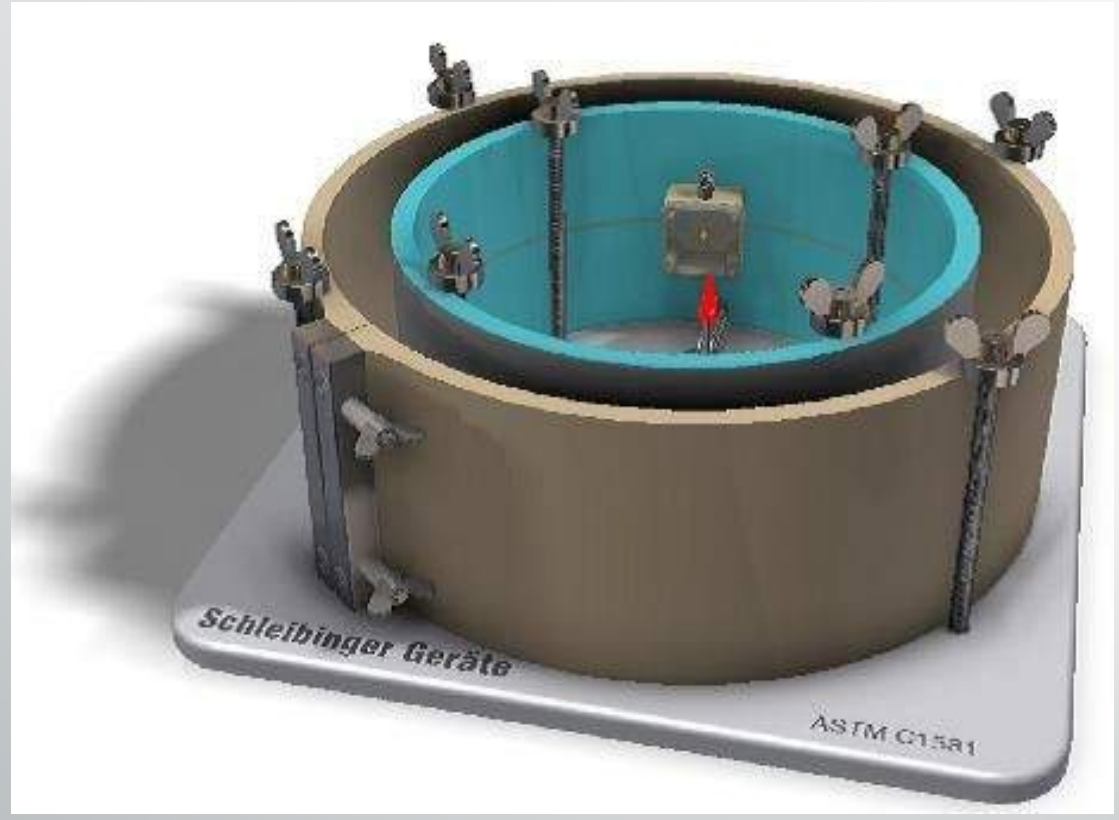


Lifecycle Testing

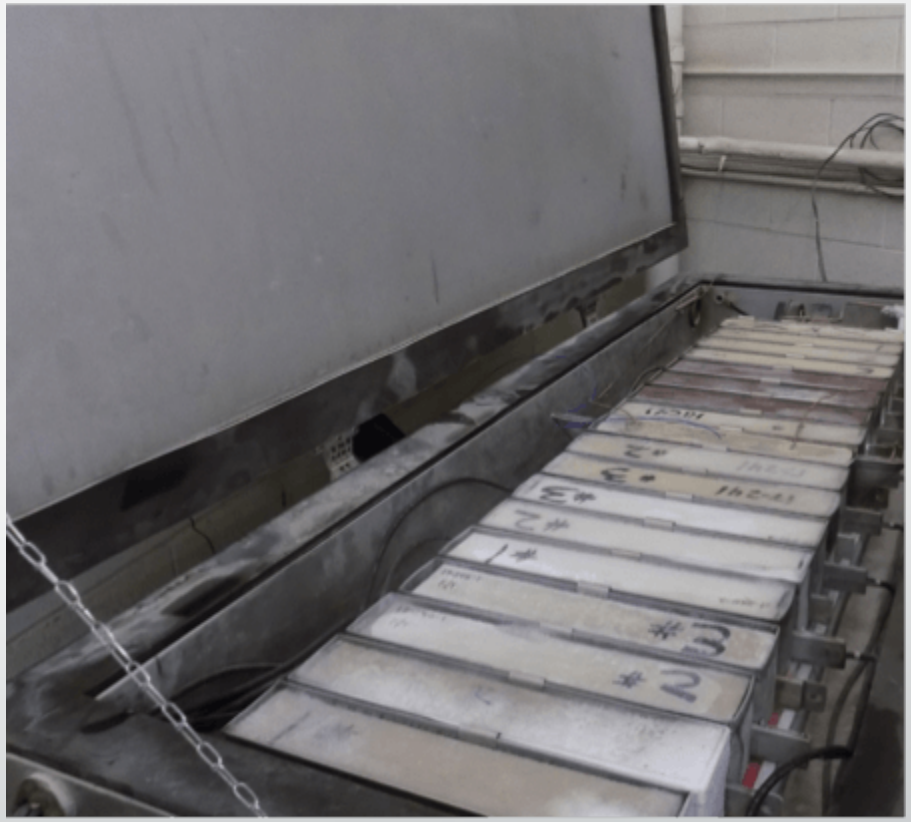
C 1760

C 1556

Restrained Shrinkage Testing



Freeze Thaw Durability C-666



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Thank You