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

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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
What is high strength concrete?

Wanda Vista

Design

Current View
What is high strength concrete?

35th Street Bridge Chicago
ACI defines high strength concrete as a mix with a specified compressive strength over 8000 psi.

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)
Performance Requirements
The more subtle requirements

• 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
The importance of good communication between all parties cannot be stressed enough for high strength concrete jobs.
Constituents
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
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%
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
  - 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
Aggregated 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
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
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
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
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
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
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
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.
Specimen Preparation

End Grinding

- 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

MoE Rig

Rig with Cylinder
Testing MoE

Young’s Modulus setup

Poisson’s Ratio setup
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

RESULTS

Date: 01/10/18
Time: 12:33:10
Specimen ID#: 101187
Specimen Type: CYLINDER
Specimen Length (in): 7.780
Specimen Area (sqin): 12.829
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