Concrete in Practice

What, why & how?

NRMCA

CIP 33 - High Strength Concrete

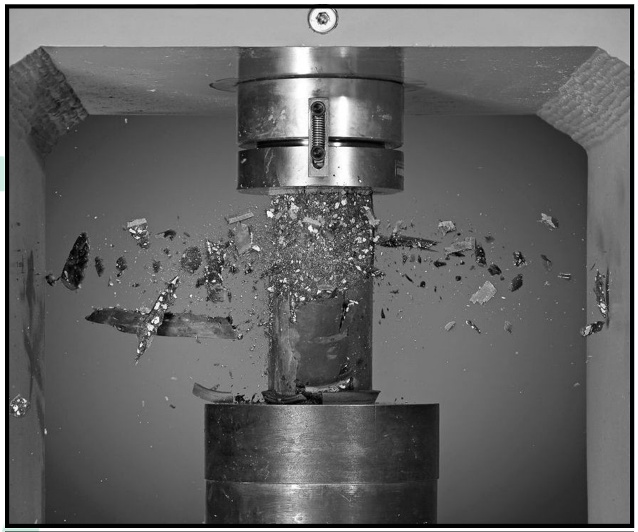
WHAT is High Strength Concrete

It is a type of high performance concrete generally with a specified compressive strength of 8,000 psi (55 MPa) or greater. Today compressive strengths exceeding 20,000 psi (140 MPa) have been used in cast-in-place buildings. While the unit cost of high strength concrete is higher, significant cost savings are possible with optimized design of structural members for the same structural capacity.

The compressive strength is measured on 6 × 12 inch (150 × 300 mm) or 4 × 8 inch (100 × 200 mm) test cylinders generally at 56 or 90-days or some other specified age depending upon the application. Special attention and expertise is required for development, quality control, and production of high strength concrete. More attention to detail is essential for testing high strength concrete. For high strength concrete design details and empirical relationships between mechanical properties may differ from those assumed for conventional concrete. When critical to the design, these should be established from research references or developed by additional testing.

WHY Use High Strength Concrete

a. To put the concrete into service at an earlier age, for example opening the pavement to traffic or for post-tensioned members.
b. To reduce size and reinforcement in structural members, such as columns, and increase useable space, especially in high-rise buildings.
c. To build the superstructure of long-span bridges and to enhance the durability of bridge structures.
d. To achieve special properties for some applications such as abrasion resistance, modulus of elasticity, and flexural strength. Applications include dams, grandstand roofs, marine foundations, parking garages, and heavy duty industrial floors. Special properties may only be achieved with high strength concrete, which allows for more efficient structural design. High strength does not assure durable concrete. Specific requirements should address requirements for durability based on the exposure conditions.



HOW are Mixtures Developed

Developing high strength concrete mixtures involves selecting the right materials and optimizing the mixture proportions. Considerable testing and evaluation may be required to achieve the required workability and strength and other hardened concrete properties required by the designer of the structure. The limitations of concrete materials to produce high strength concrete should be recognized. Occasionally the use of some locally available materials may be precluded. It is imperative that the specification clearly state the performance requirements that can be measured by available standard test methods and clearly defined acceptance criteria. Prescriptive details that constrain the use of materials or optimizing mixture proportions should be avoided.

Some of the basic concepts that need to be understood for high strength concrete are:

1. Aggregates should be strong and durable. They need not necessarily be of high strength but need to be compatible, in terms of stiffness and strength, with the cementitious paste. Generally smaller maximum size coarse aggregate is used for higher strength concretes. Sand may have to be coarser requirements in ASTM C33 (fineness modulus greater that 3.2) because of the high fines content from the cementitious materials.

2. High strength concrete mixtures will contain a higher quantity of cementitious materials content. One or more supplementary cementitious materials, such as fly ash, slag cement, silica fume, metakaolin or natural pozzolans, will be required. The total cementitious material content will be in the range of 700 to 1000 lbs/yd^3 (400 to 600 kg/m^3). This can increases the heat of hydration and may result in higher shrinkage leading to the increased potential for cracking.
3. High strength concrete mixtures generally need to have a low water-cementitious materials ratio (w/cm) in the range of 0.23 to 0.35. These low w/cm ratios are only attainable with higher than typical dosage of high range water reducing admixtures (or superplasticizers) conforming to ASTM C494, Type F or G. A Type A water reducer may be used in combination. Other admixtures that modify the rheology of fresh concrete and retain workability for difficult placements may be necessary.
4. Air entrainment in high strength concrete will greatly reduce the strength potential, more so than in conventional concrete.

Additional lead time may be necessary for mixture development and evaluation, especially if the specification sets limits for other concrete properties such as creep, shrinkage, and modulus of elasticity. Some of these tests are specialized and can only be performed by a few testing agencies. The testing for evaluation can be more expensive than traditional tests on concrete. The engineer may choose to assume values on these properties based on published empirical relationships for the design of the structure.

Lower creep and shrinkage and high modulus of elasticity can be achieved by increasing the volume of aggregate and minimizing the paste volume in the mixture. This would typically entail using the largest size aggregate possible and medium to coarsely graded fine aggregate. Smaller maximum size aggregate are typically used to produce very high compressive strength. This increases the paste volume and make it difficult to achieve required properties like creep, shrinkage, and modulus of elasticity. Adding more cementitious material to increase strength levels is typically not appropriate or effective. Factors such as deleterious materials in aggregates, aggregate coatings, coarse aggregate fracture faces, shape and texture, and testing limitations may prevent higher strength from being achieved. Concrete mixtures developed in the laboratory are often validated by test production batches.

The production, transportation, placement and finishing of high-strength concrete can differ significantly from procedures used for conventional concrete. For projects requiring a larger volume of high strength concrete it is highly recommended that a trial pour and evaluation be conducted and included as a pay item in the contract. Pre-bid and pre-construction meetings are very important to ensure the success of projects using high strength concrete. During construction special measures should be taken to protect against plastic shrinkage and thermal cracking in thicker sections. Longer time may be needed for shoring and formwork removal.

High strength concrete test cylinders should be carefully molded, cured, and tested. Extra care and attention should be paid to handling test cylinder specimens for initial curing in the field. Some high strength concrete mixtures may set slower than conventional concrete. ASTM standards have specific procedures for testing high strength concrete. Specimen size is typically 4 x 8 in. (100 x 200 mm) cylinders. Temperature during initial curing should be maintained in the range of 68 to 78°F (20 to 26°C). Transporting cylinders from the jobsite to the laboratory may need to be delayed if the mixture takes longer to set. Unbonded caps are not permitted to test cylinders if the specified strength exceeds 12,000 psi. (85 MPa). Ends of cylindrical specimens should be capped with high strength sulfur mortar or ground to the required planeness. The testing machine should have adequate load capacity and test specimens should be tested to complete failure. Improper procedures when testing high strength concrete will have significant financial implications and will delay project schedules.

References

1. *Report on High Strength Concrete*, ACI 363R, ACI, Farmington Hills, MI, www.concrete.org.
2. *Guide to Quality Control and Assurance of High Strength Concrete*, ACI 363.2R, ACI, Farmington Hills, MI.
3. *Getting Started with High-strength Concrete*, Ron Burg, The Concrete Producer, November 1993.
4. *Effects of Testing Variables on the Measured Compressive Strength of High Strength (90 MPa) Concrete*, N.J. Carino, et al., NISTIR 5405, October 1994, NIST, Gaithesburg, MD, *www.nist.gov.*
5. *10,000 psi Concrete*, James E. Cook, ACI Concrete International, October 1989, ACI, Farmington Hills, MI.

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