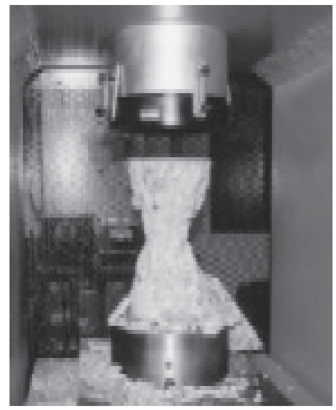
Concrete in Practice

What, why & how?

NRMCA

CIP 35 - Testing Compressive Strength of Concrete



WHAT is the Compression Strength of Concrete?

Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete is the most common performance measure used by the engineer in designing buildings and other structures. The compressive strength is measured by breaking cylindrical concrete specimens in a compression-testing machine. The compressive strength is calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of pound-force per square inch (psi) in US Customary units or megapascals (MPa) in SI units. Concrete compressive strength requirements can vary from 2500 psi (17 MPa) for residential concrete to 4000 psi (28 MPa) and higher in commercial structures. Higher strengths up to and exceeding 10,000 psi (70 MPa) are specified for certain applications.

WHY is Compressive Strength Determined?

Compressive strength test results are primarily used to determine that the concrete mixture as delivered meets the requirements of the specified strength, f'_c, in the job specification.

Strength test results from cast cylinders may be used for quality control, acceptance of concrete, or for estimating the concrete strength in a structure for the purpose of scheduling construction operations such as form removal or for evaluating the adequacy of curing and protection afforded to the structure. Cylinders tested for acceptance and quality control are made and cured in accordance with procedures described for *standard-cured* specimens in ASTM C 31 *Standard Practice for Making and Curing Concrete Test Specimens in the Field.* For estimating the in-place concrete strength, ASTM C 31 provides procedures for *field-cured* specimens. Cylindrical specimens are tested in accordance with ASTM C 39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.*

A test result is the average of at least two *standard-cured* strength specimens made from the same concrete sample and tested at the same age. In most cases strength requirements for concrete are at an age of 28 days.

Design engineers us the specified strength f'_c to design structural elements. This specified strength is incorporated in the job contract documents. The concrete mixture is designed to produce an average strength, f'_{cr}, higher than the specified strength such that the risk of not complying with the strength specification is minimized. To comply with the strength requirements of a job specification both the following acceptance criteria apply:

- The average of 3 consecutive tests should equal or exceed the specified strength, f'_c
- No single strength test should fall below f'_c by more than 500 psi (3.45 MPa); or by more than 0.10 f'_c when f'_c is more than 5000 psi (35 MPa)

It is important to understand that an individual test falling below f'_c does not necessarily constitute a failure to meet specification requirements. When the average of strength tests on a job are at the required average strength, f'_{cr}, the probability that individual strength tests will be less than the specified strength is about 10% and this is accounted for in the acceptance criteria.

When strength test results indicate that the concrete delivered fails to meet the requirements of the specification, it is important to recognize that the failure may be in the testing, not the concrete. This is especially true if the fabrication, handling, curing and testing of the cylinders are not conducted in accordance with standard procedures. *See CIP 9, Low Concrete Cylinder Strength.*

Historical strength test records are used by the concrete producer to establish the target average strength of concrete mixtures for future work.

HOW to Test the Strength of Concrete?

- Cylindrical specimens for acceptance testing should be 6 x 12 inch (150 x 300 mm) size or 4 x 8 inch (100 x 200 mm) when specified. The smaller specimens tend to be easier to make and handle in the field and the laboratory. The diameter of the cylinder used should be at least 3 times the nominal maximum size of the coarse aggregate used in the concrete.
- Recording the mass of the specimen before capping provides useful information in case of disputes.
- To provide for a uniform load distribution when testing, cylinders are capped generally with sulfur mortar (ASTM C 617) or neoprene pad caps (ASTM C 1231). Sulfur caps should be applied at least two hours and preferably one day before testing. Neoprene pad caps can be used to measure concrete strengths between 1500 and 7000 psi (10 to 50 MPa). For higher strengths upto 12,000 psi, neoprene pad caps are permitted to be used if they are qualified by companion testing with sulfur caps. Durometer hardness requirements for neoprene pads vary from 50 to 70 depending on the strength level tested. Pads should be replaced if there is excessive wear.
- Cylinders should not be allowed to dry out prior to testing.
- The cylinder diameter should be measured in two locations at right angles to each other at mid-height of the specimen and averaged to calculate the cross-sectional area. If the two measured diameters differ by more than 2%, the cylinder should not be tested.
- The ends of the specimens should not depart from perpendicularity with the cylinder axis by more than 0.5º and the ends should be plane to within 0.002 inches (0.05 mm).
- Cylinders should be centered in the compression-testing machine and loaded to complete failure. The loading rate on a hydraulic machine should be maintained in a range of 20 to 50 psi/s (0.15 to 0.35 MPa/s) during the latter half of the loading phase. The type of break should be recorded. A common break pattern is a conical fracture (*see figure*).
- The concrete strength is calculated by dividing the maximum load at failure by the average cross-sectional area. C 39 has correction factors if the length-to-diameter ratio of the cylinder is between 1.75 and 1.00, which is rare. At least two cylinders are tested at the same age and the average strength is reported as the test result to the nearest 10 psi (0.1 MPa)
- The technician carrying out the test should record the date they were received at the lab, the test date, specimen identification, cylinder diameter, test age, maximum load applied, compressive strength, type of fracture, and any defects in the cylinders or caps. If measured, the mass of the cylinders should also be noted.
- Most deviations from standard procedures for making, curing and testing concrete test specimens will result in a lower measured strength.
- The range between companion cylinders from the same set and tested at the same age should be, on average, about 2 to 3% of the average strength. If the difference between two companion cylinders exceeds 8% too often, or 9.5% for three companion cylinders, the testing procedures at the laboratory should be evaluated and rectified.
- Results of tests made by different labs on the same concrete sample should not differ by more than about 13% of the average of the two test results.
- If one or both of a set of cylinders break at strength below f'_c, evaluate the cylinders for obvious problems and *hold the tested cylinders* for later examination. Frequently the cause of a failed test can be readily seen in the cylinder, either immediately or by petrographic examination. If it is thrown away an easy opportunity to correct the problem may be lost. In some cases additional reserve cylinders are made and can be tested if one cylinder of a set broke at a lower strength.
- A 3 or 7-day test may help detect potential problems with concrete quality or testing procedures at the lab but is not a basis for rejecting concrete, with a requirement for 28-day or other age strength.
- ASTM C 1077 requires that laboratory technicians involved in testing concrete must be certified.
- Reports of compressive strength tests provide valuable information to the project team for the current and future projects. The reports should be forwarded to the concrete producer, contractor and the owner's representative as expeditiously as possible.

References

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