

# Concrete in Practice

What, why & how?



## CIP 35 - Testing Compressive Strength of Concrete

### WHAT is the Compressive 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 attribute used by the engineer when designing structures. Compressive strength is measured by breaking cylindrical concrete specimens in a compression-testing machine. 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) or megapascals (MPa). Concrete compressive strength can vary from 2500 psi (17 MPa) for residential concrete to 4000 psi (28 MPa) and higher in commercial structures. Some applications use higher strengths, greater than 10,000 psi (70 MPa).

### WHY is Compressive Strength Determined?

Compressive strength results are used to ensure 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, for estimating the strength in a structure, or for evaluating the adequacy of curing and protection afforded to the structure. Standard-cured cylinders are tested for acceptance and quality control. Field-cured cylinders are tested for estimating the in-place concrete strength. Procedures for standard-curing and field-curing are described in ASTM C31. Cylindrical specimens are tested in accordance with ASTM C39. Standard sizes of test specimens are 4×8 in. (100×200 mm) or 6×12 in. (150×300 mm) concrete cylinders. The smaller specimens tend to be easier to make and handle in the field and the laboratory.

A strength test result is the average of at least two 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 use the specified strength  $f'_c$  to design concrete members. The specified strength is stated in project specifications. The concrete mixture is designed to produce an average strength,  $f'_{cr}$ , higher than the specified strength so that the possibility of strength tests failing the acceptance criteria is very low. Historical strength test records from a similar concrete are used to establish the target average strength of concrete mixtures. TIP 2 discusses the process of establishing the required average strength for concrete mixtures.



Fractured Test Specimen at Failure

To comply with the strength requirements of a 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 (3.5 MPa); or by more than 0.10  $f'_c$  when  $f'_c$  is more than 5000 psi (35 MPa)

The same strength acceptance criteria are applicable for either cylinder size. It is important to understand that an individual test falling below  $f'_c$  does not constitute non-compliance with the strength acceptance criteria. The probability of not complying with these acceptance criteria is about 1% and that for an individual strength tests to be less than the specified strength is about 10%. This is based on the assumption that the average of strength tests are around the required average strength,  $f'_{cr}$  at the same level of variability of the assumed standard deviation

When strength test results indicate that the concrete delivered fails to comply with the acceptance criteria, it is possible that the failure may be in the testing, and 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.

## HOW to Test the Strength of Concrete?

- Requirements for strength testing machines are stated in ASTM C39.
- 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 weight of the specimens before testing provides useful information in case of disputes.
- To provide for a uniform load distribution when testing, cylinders are capped with sulfur mortar (ASTM C617) or neoprene pad caps (ASTM C1231). 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 12,000 psi (10 to 80 MPa). Durometer hardness requirements for neoprene pads vary from 50 to 70 depending on the strength level tested. Pads should be replaced after 100 uses; 50 when testing strength between 7000 and 12,000 psi (50 and 80 MPa). TIP 5 discusses capping concrete specimens.
- Cylinders should not be allowed to dry 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  $0.5^\circ$  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 28 to 42 psi/s (0.20 to 0.30 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 as seen in the figure.
- The concrete strength is calculated by dividing the maximum load at failure by the average cross-sectional area. C39 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)
- Information to be included in the report include the specimen identification, average measured diameter, cross-sectional area, test age, maximum load applied, compressive strength, type of fracture, any defects in the cylinders or caps and, when determined, the density to the nearest  $1 \text{ lb/ft}^3$  ( $10 \text{ kg/m}^3$ ). Information required by C31 should be available—location of concrete in the structure represented by test specimens; date, time and individual molding cylinders; slump, air content, temperature and density measured on the concrete sample used to make test specimens; maximum and minimum temperatures during initial curing for standard cured specimens, or details of field curing.
- Most deviations from standard procedures for making, curing and testing concrete test specimens will result in a lower measured strength.
- The coefficient of variation between companion cylinders tested at the same age should be about 2 to 3%. If the difference between companion cylinders exceeds 8% for two or 9.5% for three more than 1 time in 20, the testing procedures should be evaluated and rectified.
- Strength test results made by different labs on the same concrete sample should not differ by more than about 14% of the average.
- 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, possibly for petrographic examination. This provides an opportunity to correct a problem. In some cases additional reserve cylinders are made and can be tested if one cylinder of a set breaks 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.
- ACI 318, ACI 301 and ASTM C1077 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 of all strength tests should be forwarded to the concrete producer, contractor and the owner's representative as expeditiously as possible.

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### References

1. ASTM C 31, C 39, C 617, C 1077, C 1231, Annual Book of ASTM Standards, Volume 04.02, ASTM, West Conshohocken, PA, [www.astm.org](http://www.astm.org)
2. CIP 9, *Low Concrete Cylinder Strength*, Concrete in Practice Series, NRMCA, Silver Spring, MD, [www.nrmca.org](http://www.nrmca.org)
3. TIP 2 and 5, *Technology in Practice Series*, NRMCA, Silver Spring, MD.
4. *In-Place Strength Evaluation - A Recommended Practice*, NRMCA Publication 133, NRMCA RES Committee, NRMCA, Silver Spring, MD
5. *NRMCA/ASCC Checklist for Concrete Pre-Construction Conference*, NRMCA, Silver Spring, MD
6. *Review of Variables That Influence Measured Concrete Compressive Strength*, David N. Richardson, NRMCA Publication 179, NRMCA, Silver Spring, MD
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2003, 2014

