Code and Standards Requirements For Acceptance Testing

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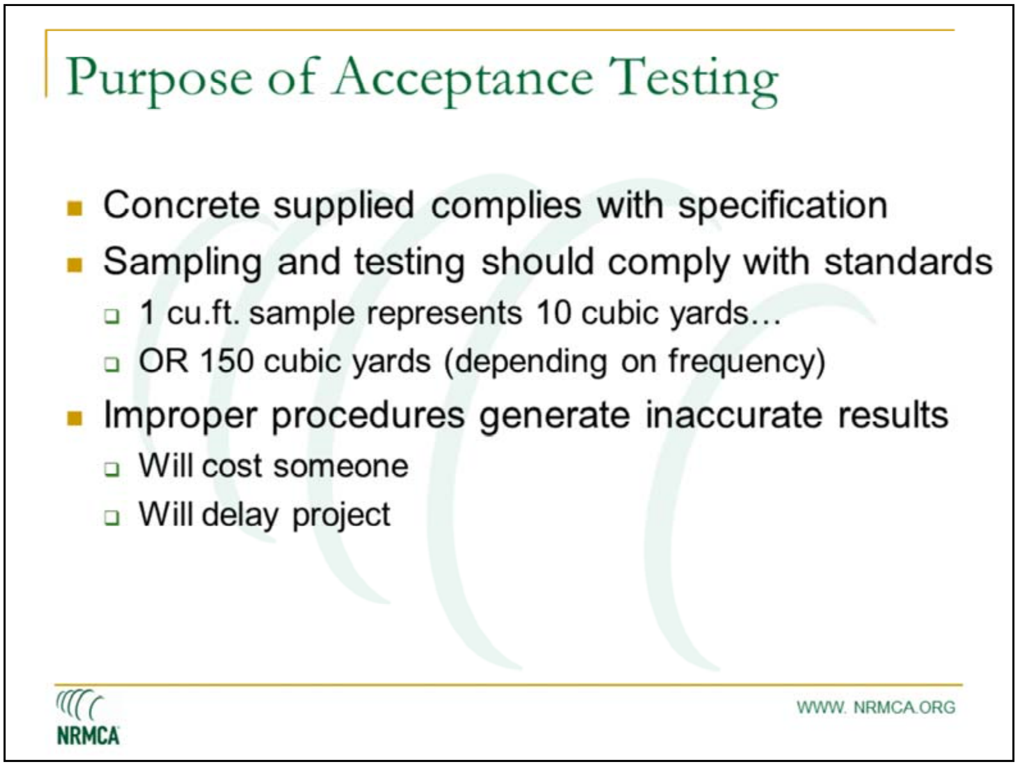
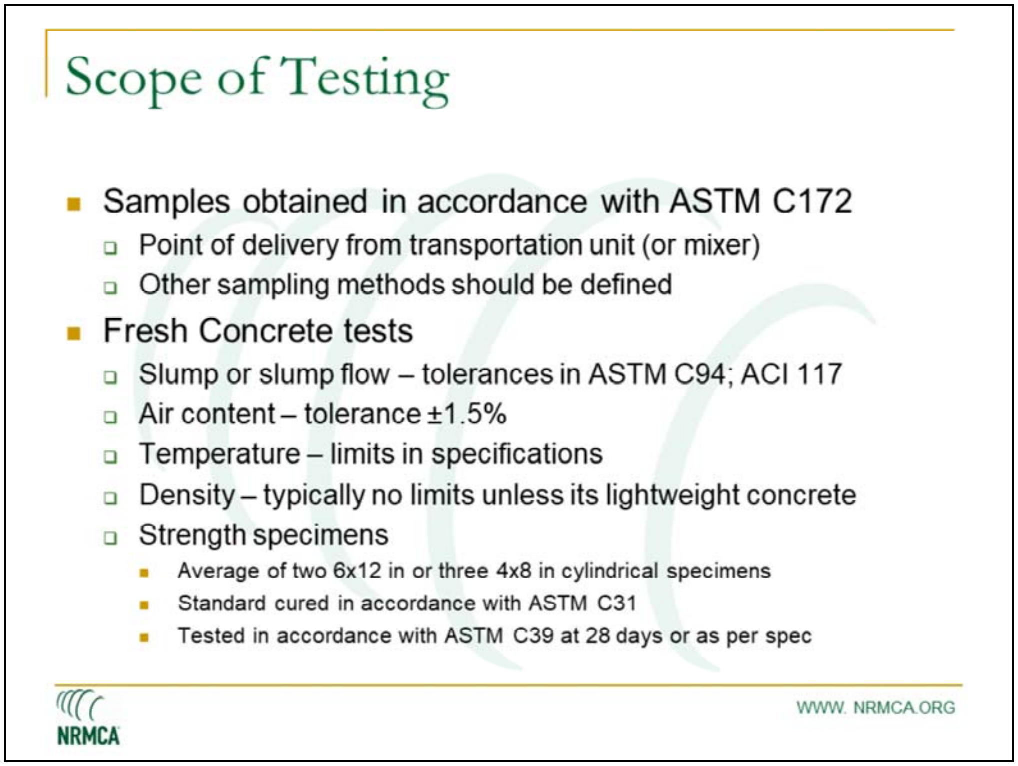
Disclaimer



Testing is performed on deliveries of concrete to determine whether the quality of concrete supplied meets the requirement of the specification. Any concrete structure that is built in accordance with the Building Code, state transportation or other public agencies will require that concrete be tested, typically by a third party testing agency that is hired by the owner or owner's representative.

The sample of concrete obtained is rather small compared to the volume of concrete represented. Typically a 1 cubic foot sample is obtained from a truck mixer that may contain 10 cubic yards (about 4% of the load). Typically one sample is taken for every 100 or 150 cubic yards – 10 or 15 loads of concrete. So the test results obtained from that 1 cubic foot sample will represent the quality of that volume of concrete. If the results do not meet the requirements of the specification, this renders that this volume of concrete might be of questionable quality. Some of it will be placed in the structure. The cost of concrete represented by a series of tests performed on one sample of concrete is between \$1000-2000 per load or between \$15,000 to \$30,000 for 15 loads.

It is important that the testing agencies performing tests on concrete comply with the procedures applicable in the standards. Any deviation from these procedures will generate erroneous results that might penalize acceptable concrete. This evaluation will incur significant costs to several entities and will delay the completion of the project – this causes revenue loss to the owner of the structure.

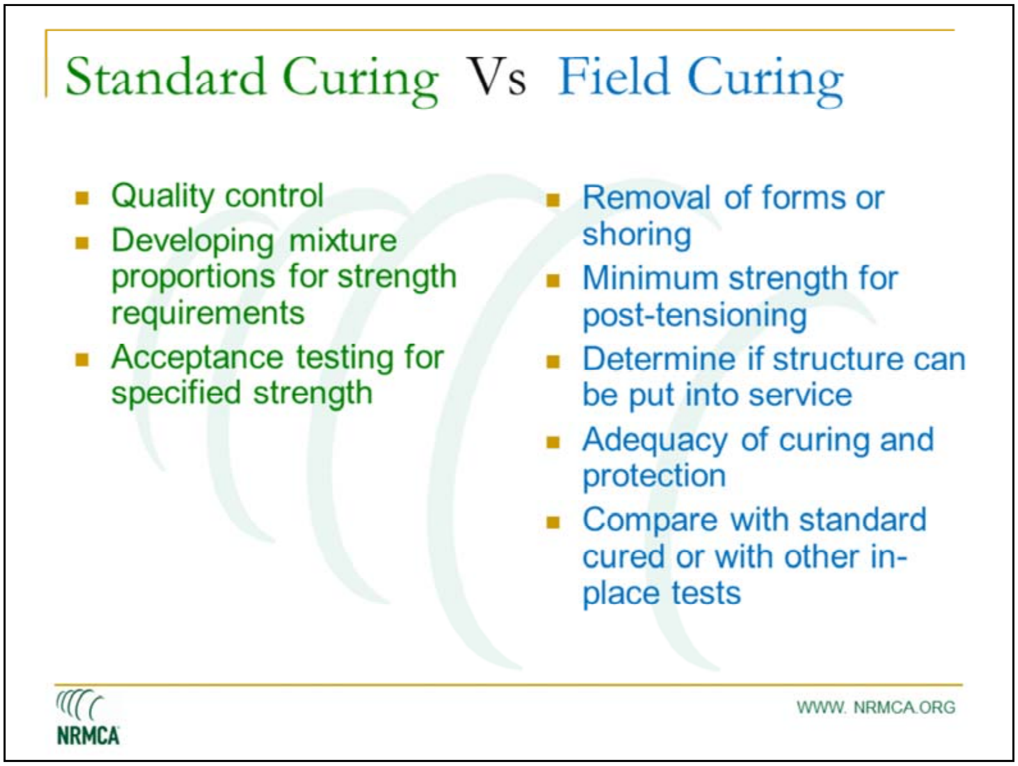


There are consistent details on how sampling and testing needs to be performed. These are addressed in the building code, reference and project specifications, specification for ready mixed concrete and in the contract with the testing agency.

Sampling is the first important step. The sample obtained must be representative of the load. This is assured when the procedure of obtaining a sample is in accordance with ASTM C172 – middle portion of the load with two or more portions of the discharged concrete mixed together to create a composite sample. ASTM C172 only describes sampling from the transportation unit. Often, project specifications will require tests to be performed on samples obtained at the point of placement in the structure – at the end of a bucket, pump, etc. Sampling at this location is not described in ASTM C172, so the procedure has to be clear. The problem is that the characteristics of the concrete can change by the procedure used to convey it from the truck discharge to the point of placement. The concrete supplier has no control on this process, cannot anticipate the types of changes that might occur and thereby cannot be responsible for tests results at the point of placement. These issues should be discussed at a pre-construction conference. More information about this can be found at http://www.nrmca.org/research_engineering/RMC_Specs_Guide.htm.

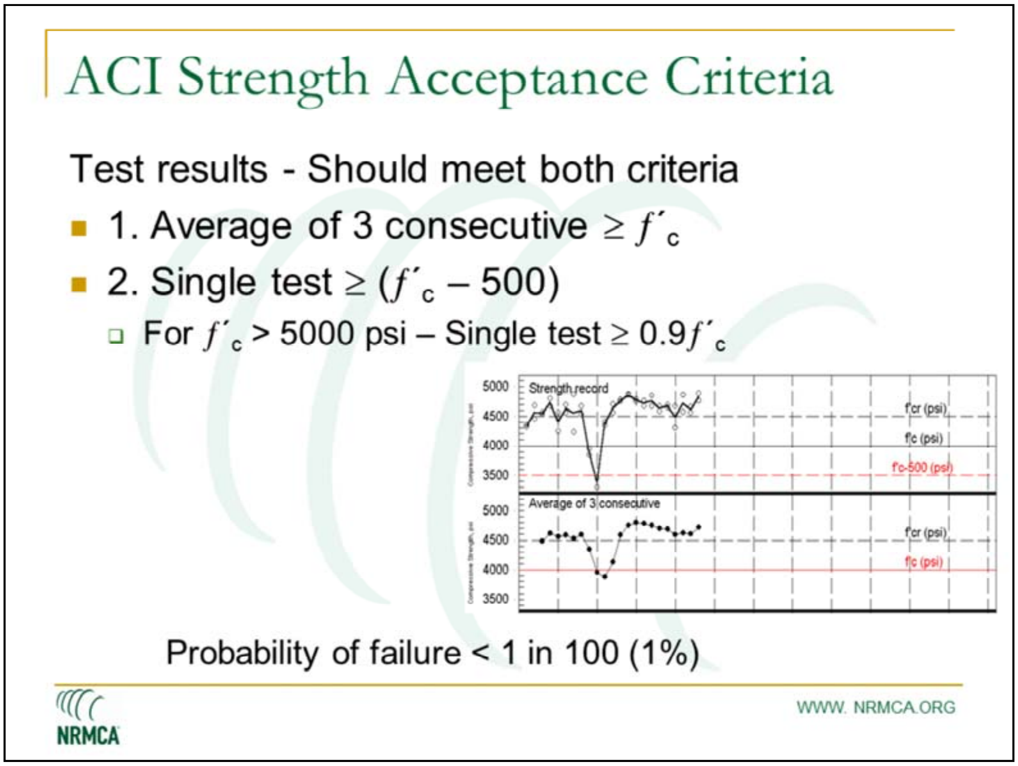
Typically several fresh concrete tests are performed as listed on the slide. Most of these tests have specification criteria that should be met, with stated or industry-established tolerances.

Additionally specimens for tests on hardened concrete are also prepared, typically strength tests. There are detailed requirements on making and curing these specimens up to the point they are tested.



Specimens for strength testing are prepared and cured in accordance with ASTM C31. There are two distinct curing procedures described in ASTM C31 – standard curing and field curing. These different curing methods are used depending on the purpose of the test results. These reasons are shown on the screen as summarized from C31.

Specimens for strength tests to determine the quality of concrete supplied to a project should follow the standard curing procedure. This is clear in the industry standards. There is a misconception, even by practicing engineers that the purpose of the tests are to determine the strength of concrete in the structure and thereby specimens should be field-cured. This is incorrect.

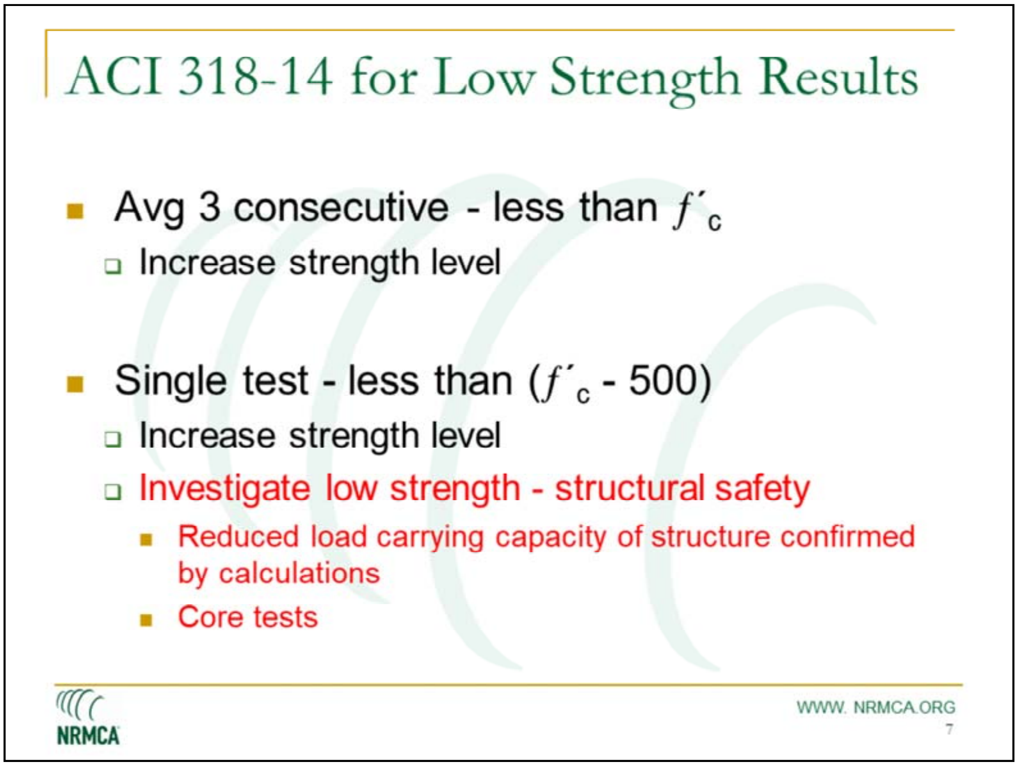


To reiterate, acceptance of concrete is based on samples of concrete obtained in accordance with ASTM C 172, test specimens prepared and cured in accordance with ASTM C 31, and tested in accordance with ASTM C 39. The test age for cylinder strengths is 28 days or as required by the job specification. Once the mix is approved and the job has started, the tests of laboratory-cured specimens made from the job concrete must satisfy both of the following requirements before the concrete is considered acceptable:

1. The average of all sets of three consecutive strength tests equal or exceed the specified strength (f'_c).

2. No single strength test (average of 2 cylinders) falls below the specified strength (f'_c) by more than 500 psi [3.5 MPa] or 10% of f'_c when the specified strength exceeds 5000 psi (35 MPa).

These acceptance criteria are established at a confidence level of 99% - meaning there is a 1% probability that strength test results can fail these criteria.



If either of the criteria are not met, the code indicates that steps should be taken to increase the level of subsequent test results. The commentary recommends these measures:

•Increase the cementitious materials content

•Change the mixture proportions

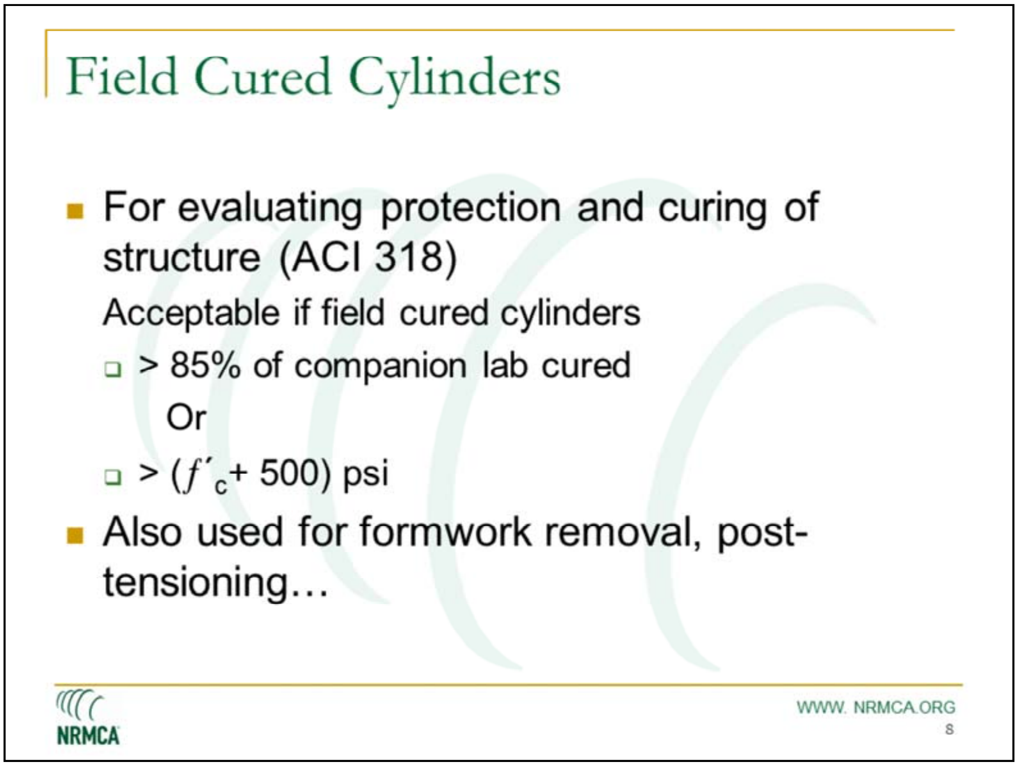
•Reduce or have better control on the slump level supplied

•Shorten the delivery time

•Closer attention to the air content

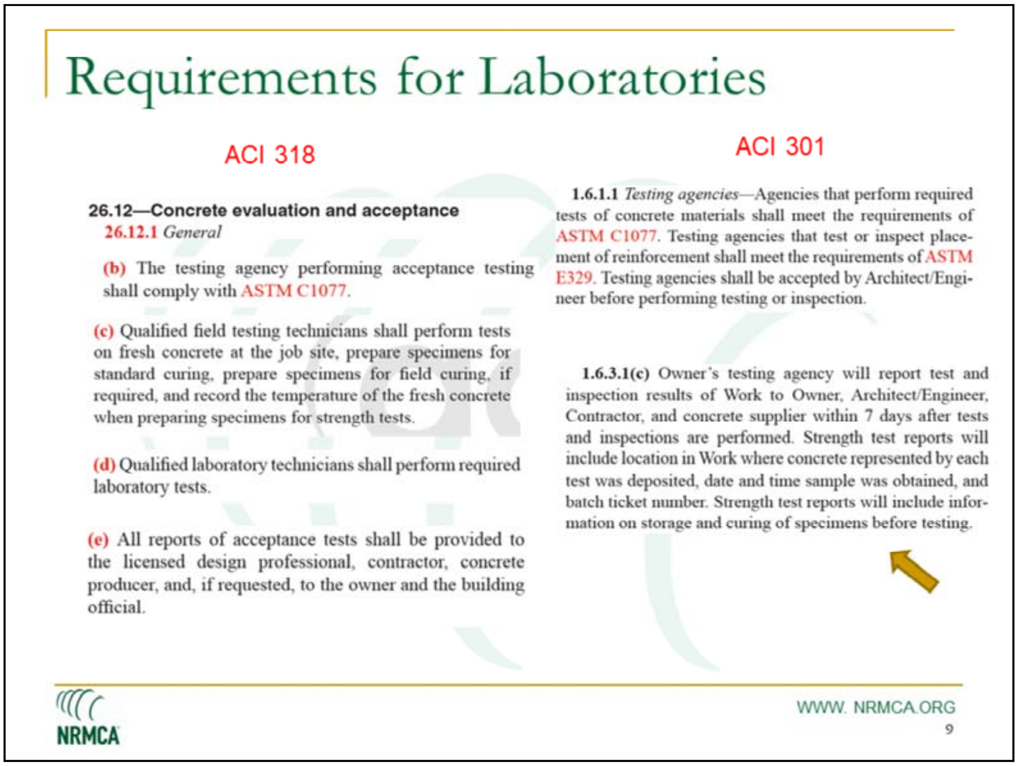
•Evaluate the quality of testing to ensure that the standards are being complied with.

If the single test is more than 500 psi less than the specified strength (2nd criteria), the code also requires that an investigation of low strength test results be followed. The low strength result should be a cause for concern on whether the structural capacity of the region represented by the low strength is adequate. This is a public safety issue.



ACI 318 has a specific purpose for using strength test results from field-cured cylinders – for evaluating the protection and curing afforded to the structure. There are criteria for strength tests from field cured cylinders as indicated on the slide.

These tests are also used for other purposes to estimate the strength of concrete in the structure.

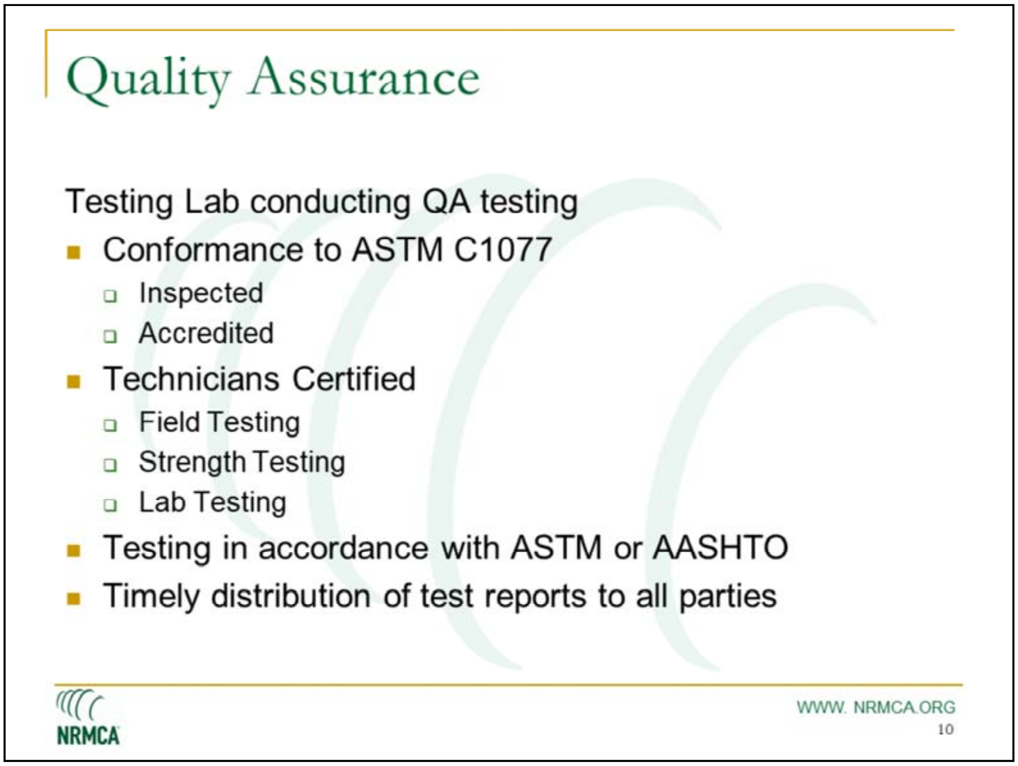


These are excerpts from ACI 318 and ACI 301 regarding requirements for testing agencies and technicians.

ASTM Standard Practice C1077 identifies and defines duties, responsibilities and minimum technical requirements of testing laboratories' personnel and minimum technical requirements for laboratory equipment utilized in testing concrete and concrete aggregates. The standard also provides criteria for the evaluation of capabilities of testing laboratory to perform ASTM test methods for accreditation purposes. This practice requires laboratories to have ACI certified or equivalent field testing technicians as well as certified strength testing technicians. Supervisory personnel must have at least three years of relevant experience and hold current certification.

ACI 318 states that labs should share test data with all stakeholders. ACI 301 Section 1.6.3.1.c states that labs should share test data within 7 days of completion of test.

ACI 301 also states that strength test reports should include information on storage and curing of test specimens before testing.



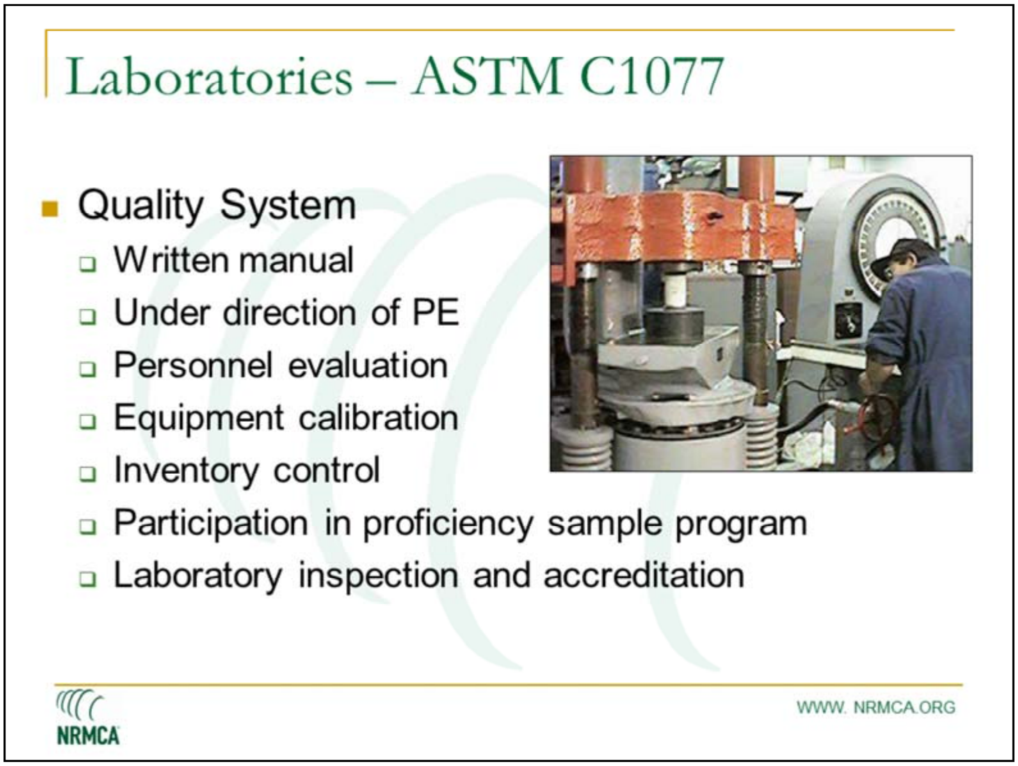
This slide summarizes the requirements for testing agencies.

Conform to ASTM C1077 – the labs may need to be accredited – which requires inspection and documentation of corrective action of deficiencies resulting from the inspection.

Technicians in the field and lab have to be certified.

Tests should be performed in accordance with the standards.

It is also important that all test reports be distributed to all parties that are impacted in a timely manner. Only if the producer is provided with all test results can he take action to avoid failing test results.



A laboratory testing concrete in accordance with ASTM C1077 must maintain a written Quality System. This internal quality assurance system requires laboratories to maintain and calibrate equipment on a regularly scheduled basis. The lab must have a system in place to address technical complaints. The laboratory must participate in a proficiency testing program such as CCRL Concrete Proficiency Sample Program or the AMRL Aggregate Proficiency Sample Program.

Factors Affecting Strength

NRMCA Publication No. 179

Review of Variables that Influence Measured Concrete Compressive Strength

By David N. Richardson

TABLE 1. Measured Strength Reduction by Nonstandard Conditions

Variable (1)	Strength loss (%) (2)	Lab (L) or field (F) (3)
Convex ends	up to 75	L
Insufficient consolidation	up to 61	F
Immediate freezing for 24 hours	up to 56	F
Rubber cap, no restraint	up to 53	L
Weak, soft capping compound	up to 43	L
Flat particle vertical orientation	up to 40	F
Concave ends	up to 30	L
Rough end before capping	up to 27	F
Seven days in field, warm temperature	up to 26	F
Reuse of plastic molds	up to 22	L
Cardboard mold	up to 21	F
Seven days in field at 73° F, no added moisture	up to 18	F
Plastic mold	up to 14	F
Rough end, air gaps under cap	up to 12	F
Convex end, capped	up to 12	F
Eccentric loading	up to 12	L
Out-of-round diameter	up to 10	F
Ends not perpendicular to axis	up to 8	F
Rough handling	up to 7	F
Three days at 37° F, mixed at 73° F	up to 7	F
One day at 37° F, mixed at 46° F	up to 7	F
Excessive tapping	up to 6	F
Thick cap	up to 6	L
Sloped end, leveled by cap	up to 5	F
Wet mix subjected to vibrations	up to 5	F
Chipped cap	up to 4	L
Rebar rodding	up to 2	F
Insufficient cap cure	up to 2	L
Slick end cap	up to 2	L
Slow loading rate	up to 2	L

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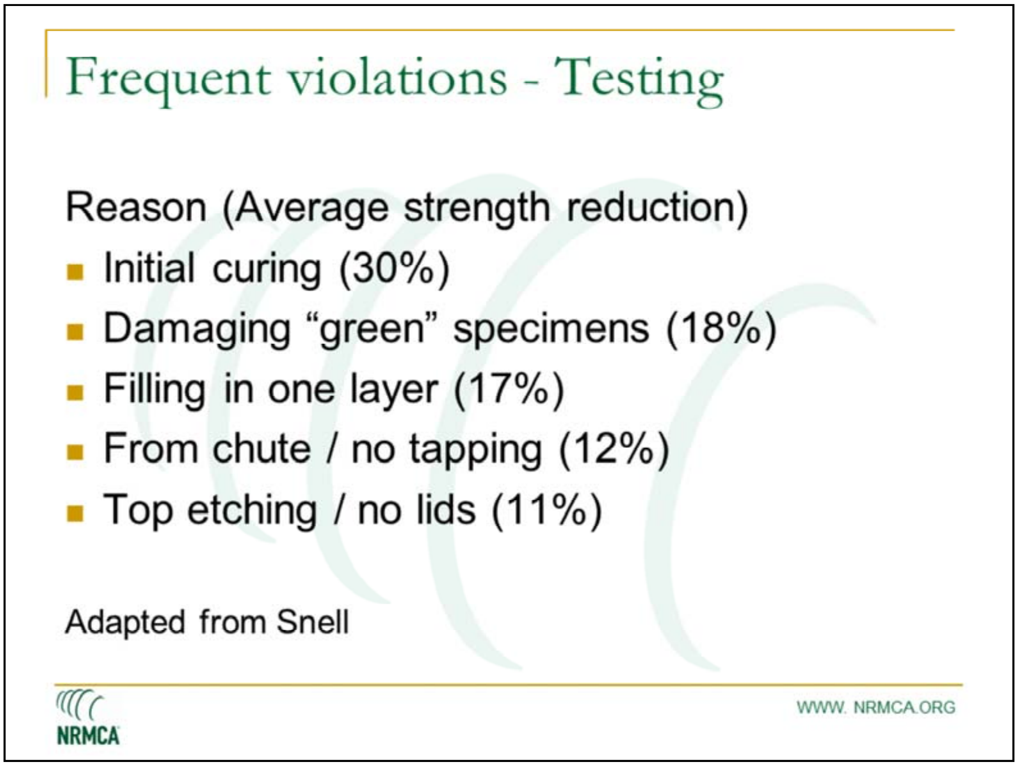
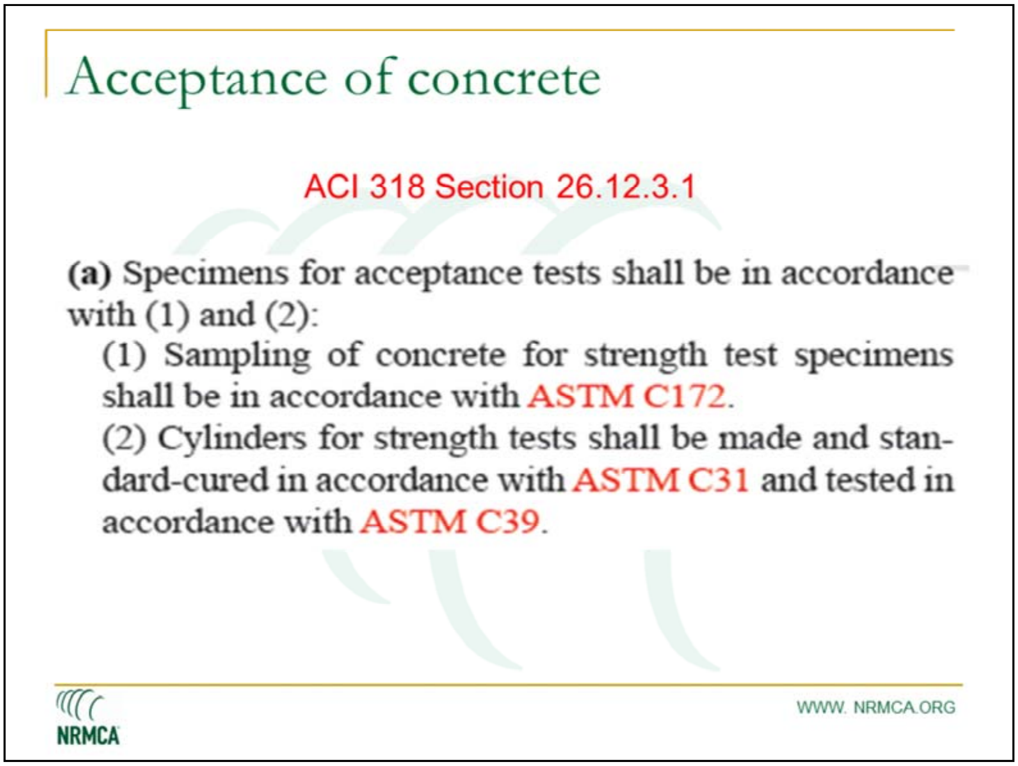
This comprehensive paper by Richardson quantifies various factors that will negatively impact the strength test results of concrete specimens – both for procedures in the laboratory and the field. All these factors are cumulative. This paper is available from the NRMCA.

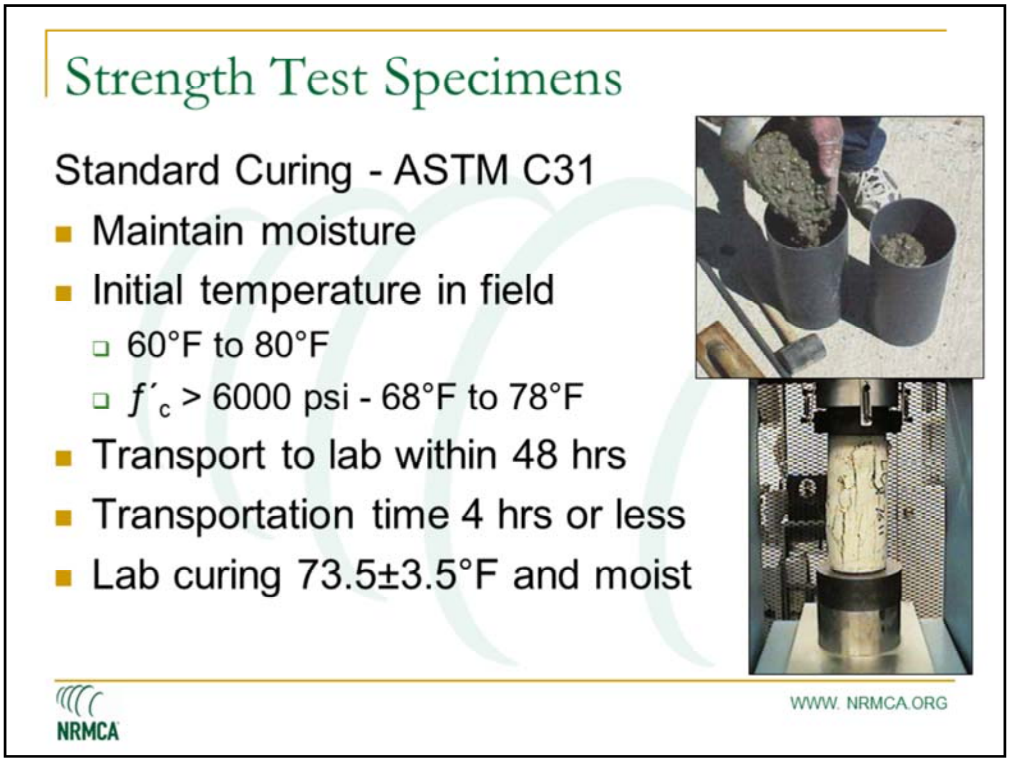


This is a summary of observations from Luke Snell on more common violations on specimen preparation and care at the jobsite – and the impact on strength reduction. Initial curing can amount to up to 30% reduction in strength by his assessment.

These are some images on jobsite issues – using a rebar, improper consolidation, improper filling the cylinder, not finishing the surface properly and improper initial curing at the jobsite.



ACI 318-14 clearly states that for acceptance of concrete supplied by the concrete producer, cylinders shall be standard cured in accordance with C31



This slide summarizes the details regarding standard curing of test specimens as stated in C31.

An important factor is the proper maintenance of moisture and temperature during the first 24-48 hours in the field. This tends to be the biggest observed violation that impacts strength test results used for acceptance of concrete.

ASTM C31 Note 8 – Standard Curing

Satisfactory moisture environment

- Immerse in water
- Store in wooden boxes or structures
- Place in damp sand
- Cover with removable lids
- Place inside plastic bags
- Cover with plastic sheets or plates – with damp burlap

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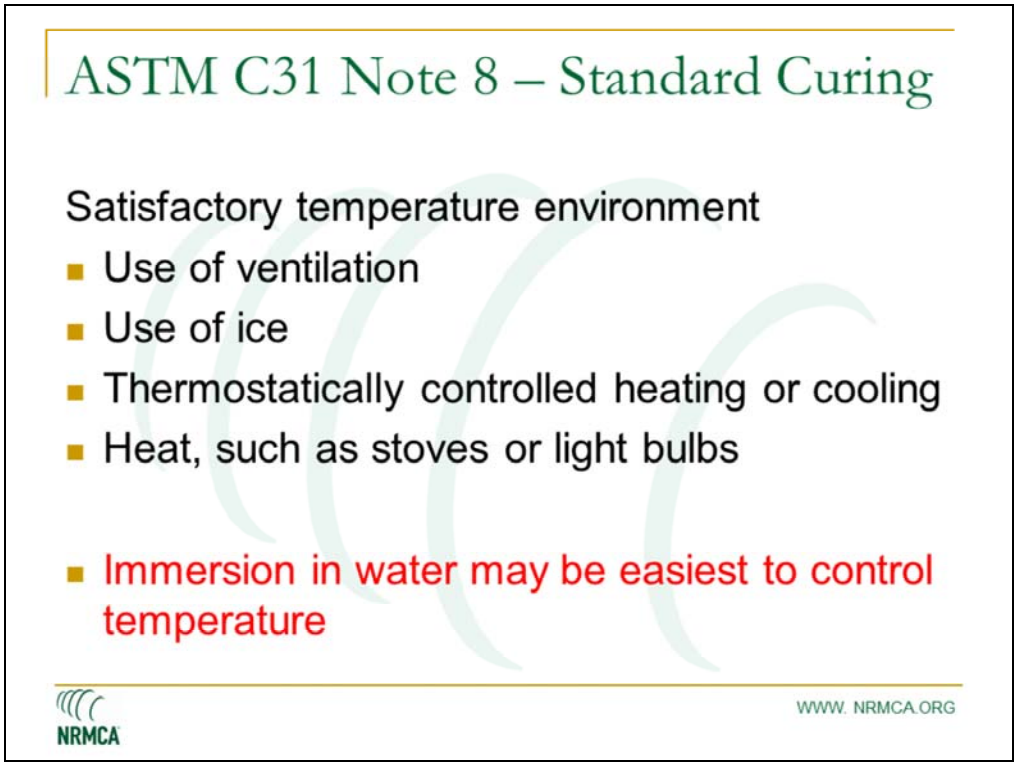
In Note 8, ASTM C31 provides some guidance on methods that can be used to maintain the moisture and temperature environment for the initial curing of test specimens

These are suggestions for maintaining a satisfactory moisture environment.



These are suggestions for maintaining a satisfactory temperature environment

It is suggested that the best way to maintain both temperature and moisture environment is to immerse the cylinders in water for the initial curing period. Studies have shown that this achieves the highest strength of concrete compared to other curing methods.

Violation of standard procedures

- Initial Curing is the most frequent problem

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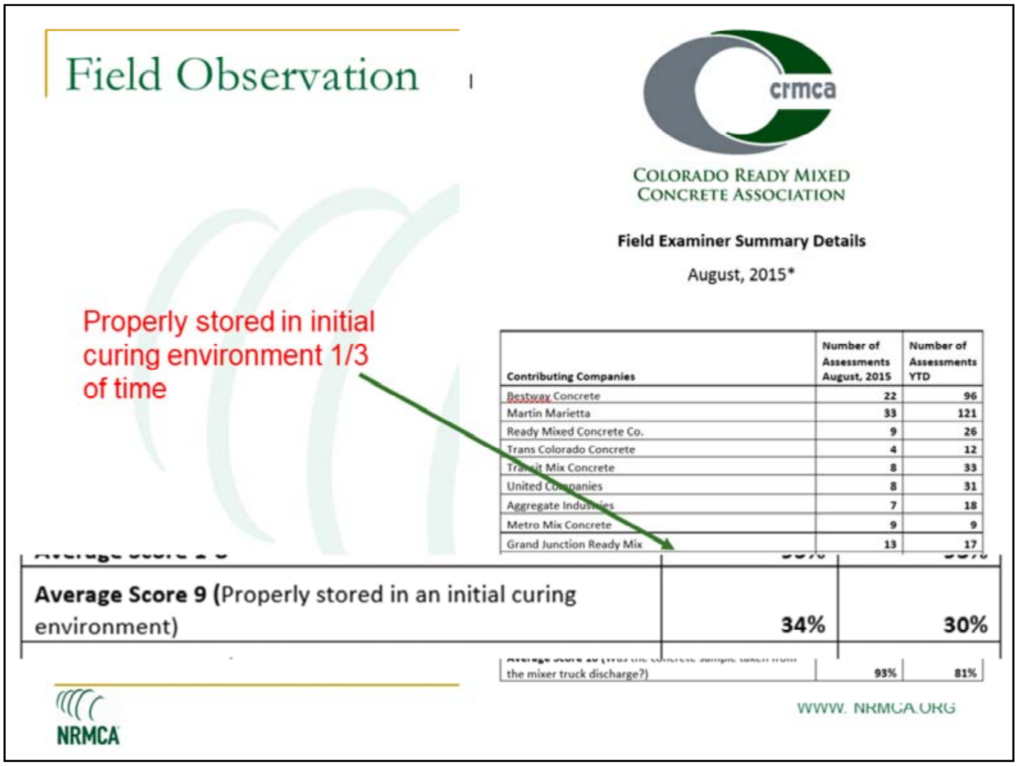
Some examples of unacceptable initial curing procedures in the field



Contributing Companies	Number of Assessments August, 2015	Number of Assessments YTD
Bestway Concrete	22	96
Martin Marietta	33	121
Ready Mixed Concrete Co.	9	26
Trans Colorado Concrete	4	12
Transit Mix Concrete	8	33
United Companies	8	31
Aggregate Industries	7	18
Metro Mix Concrete	9	9
Grand Junction Ready Mix	13	17

The Colorado Ready Mixed Concrete Association initiated a program whereby individuals would observe various details on compliance with testing procedures at project sites. This summary for August and through August indicate that only about one-third of the time was initial curing of test specimens done correctly.

Some of the means used for initial curing of jobsites – from 5-gallon buckets, larger water containers, wooden curing boxes, coolers, and temperature-controlled curing boxes. The temperature should be monitored in enclosed spaces. Temperatures can get very high in wooden curing boxes and coolers. Water immersion is the preferred method

Using Sand

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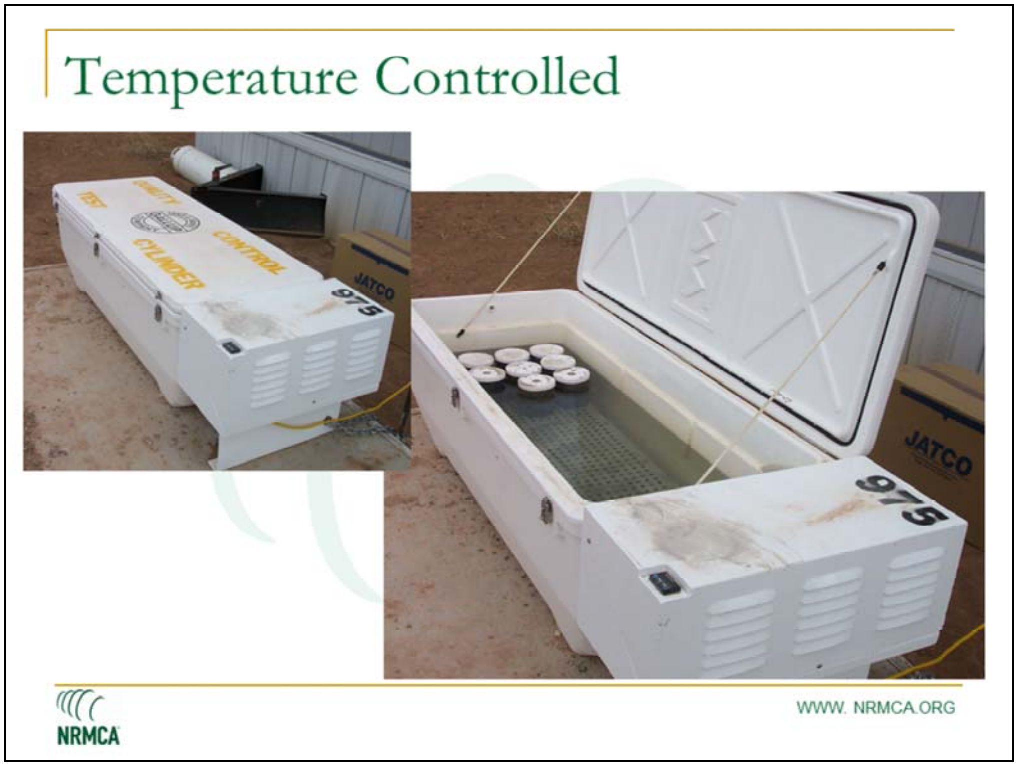
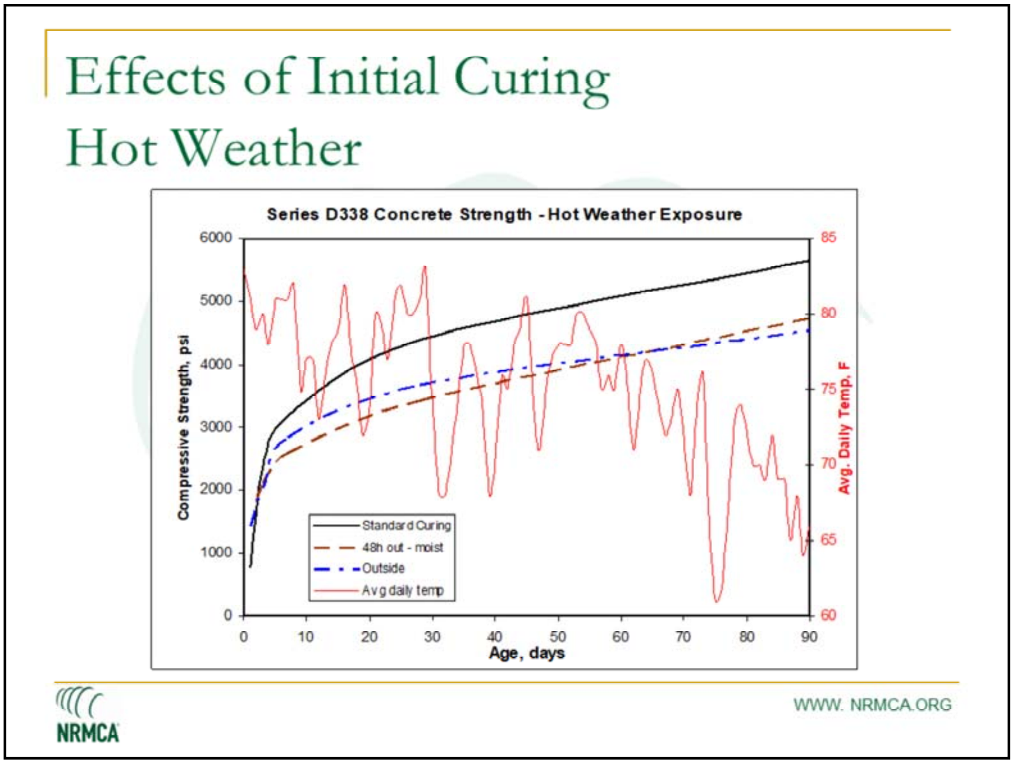
Some use sand. The test cylinders are placed in a bucket, the bucket is filled with sand. The sand is soaked with water and the bucket is kept in a location away from sunlight and potential disturbance.

Some examples of immersion in water and use of a cooler. Ice can be used to control temperature in hot weather – more easier to do this when cylinders are immersed in water.



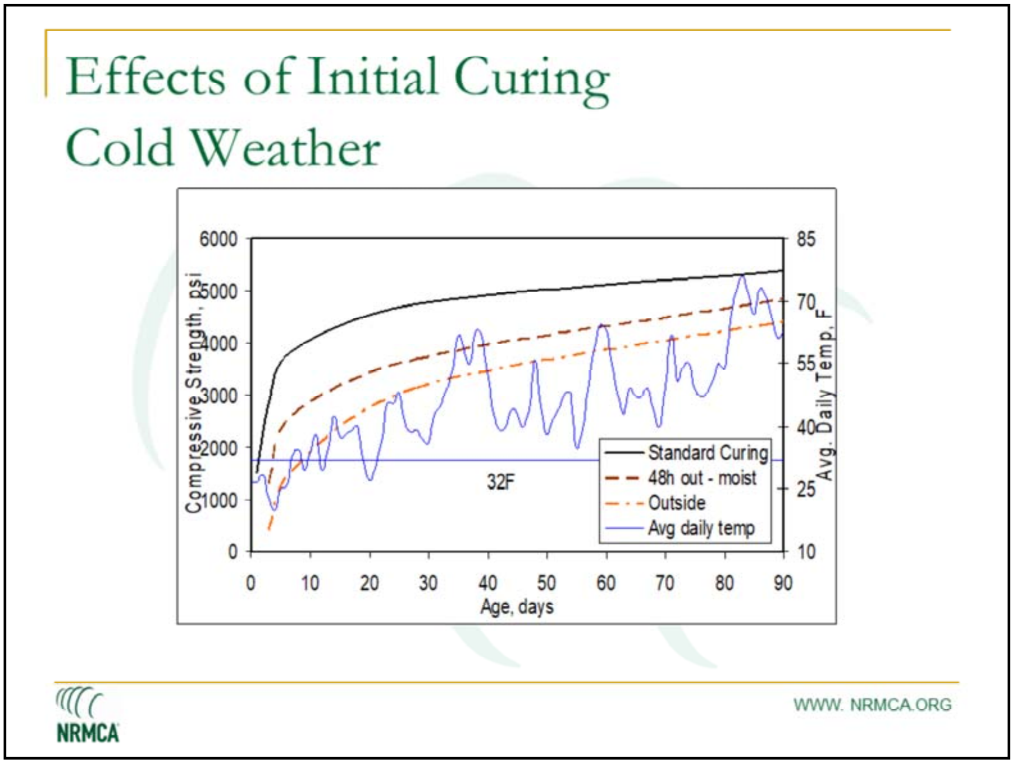
Some testing agencies use these temperature controlled coolers. These cost more but provide the required temperature and moisture control. One concern is the potential for theft and vandalism as these systems can be expensive.



This is an NRMCA study of exposure of test specimens to higher temperature in hot weather. The red line is a plot of the variation of ambient temperature during this period – the temperature scale is on the right. It is not a very hot period as might be observed in many southern states in summer.

The solid line represents strength gain of cylinders that were standard cured in accordance with ASTM C31 – these cylinders were immersed in water. The dash line are for cylinders that were kept out exposed to the ambient temperatures for 48 hours followed by moist curing. The dash-dot line are for cylinders that were kept outside for the duration until tested.

As can be seen, at 28 days there is a reduced strength of about 1000 psi or 25% compared to the properly cured cylinders.



This is another NRMCA study of exposure of test specimens in cold weather. The blue line is a plot of the variation of ambient temperature during this period – the temperature scale is on the right. Temperatures were below freezing during the initial period when the cylinders were cured in the field.

The solid line represents strength gain of cylinders that were standard cured in accordance with ASTM C31. The dash line are for cylinders that were kept out exposed to the ambient temperatures for 48 hours followed by moist curing. The dash-dot line are for cylinders that were kept outside for the duration until tested.

The strength loss for cylinders exposed to freezing temperatures during the initial curing period is between 25 and 40%.

Effects of Initial Curing

Importance of temperature and duration of initial curing on 28-day compressive strength

Initial curing conditions	Relative 28-day strength, %*		
Temperature	37°F at 100% RH	73°F at 60% RH	100°F at 25% RH
1 day in air	100	92	88
3 days in air	93	89	78

**In comparison with compressive strength of 5590 psi determined for specimens moist cured at 73°F and 100% RH*

NRMCA Pub 53; Delmar L. Bloem, 1954

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This is a portion of a larger NRMCA study conducted in the 1950s. The data shown are for a concrete mixture proportioned with ordinary portland cement at 517 lb/yd^3 (307 kg/m^3), *w/c* of 0.57, and a 3 to 4 in. (75 to 100 mm) slump.

The comparison is based on cylinders that were moist cured soon after casting (representing the 100% strength of 5590 psi)

6x12 in. Specimens were molded at 73°F, subjected to initial curing conditions in air at temp and RH, age as stated, and transferred to standard moist room at 73°F for curing until test age of 28 days.

Specimens initially cured in air for 1 day at 37, 73, and 100°F achieved 100, 92, and 88%, respectively, of the strength of specimens that were moist cured at 73°F from the time of molding until testing (5590 psi or 38.5 MPa). Specimens initially cured in air for 3 days at 37, 73, and 100°F achieved 93, 89, and 78% of the strength of specimens that were moist cured at 73°F from the time of molding until testing, respectively.

While there was no apparent strength reduction associated with initial curing in air at 37°F (3°C) Bloem[5] noted that low initial curing temperatures in the field could be accompanied by a lower RH than was present in the reported study, which could be expected to reduce the 28-day strength.

Effects of Initial Curing

Importance of temperature and moisture during first 24 hours of initial curing – on 28-day compressive strength

Type of 1-day initial curing	Temp. range, °F	Relative strength, %	
Outdoor exposure: curing box with thermostatic control; in water	71 – 76	100	4860 psi
Laboratory: immersed in lime water (control)	76 – 82	100	
Laboratory: in air	78 – 82	88	
Outdoor exposure to sunlight: not protected	71 – 107	85	
Outdoor exposure: covered with wet burlap and plastic	94 - 140	83	

Specimens molded at 86°F at the jobsite and subjected to the initial curing condition for 24 h

NRMCA Montoya – New Mexico, 1995 WWW. NRMCA.ORG

Study done by the NM ready mixed association in 1995

In this case the importance of ensuring that the cylinders are kept moist during the initial curing period is also illustrated.

Concrete was mixed in a truck and had a slump of 3-3/4 in. (95 mm), air content of 5.8%, and fresh concrete temperature of 86°F (30°C).

Cylindrical specimens (6 by 12 in.) were molded and stored initially for 24 h under five different conditions as shown in Table 3. Specimens were covered with plastic lids.

At the end of the initial curing period, specimens were transferred to a standard moist room at 73°F until the test age of 28 days.

Cylinders that were kept in air in a lab environment but not immersed in water had a 12% lower strength.

specimens immersed in water inside a thermostatically controlled curing box on site attained strengths comparable to control specimens immersed in water in the laboratory (see Fig. 3).

They also show that specimens exposed to ambient conditions without temperature control exhibited strength reductions of 15 and 17% relative to control specimens.

Montoya[7] questioned whether any initial curing method that does not involve immersion in water would be acceptable in all RH conditions.

Effects of Initial Curing

Initial curing for 24 hours - Within limits of ASTM C31

Initial curing condition†	Relative 28-day strength, %	
	Cement A	Cement B
60°F in water	100% (6080 psi)	100% (6090 psi)
60°F in air	92	97
80°F in water	89	93
80°F in air	81	88

Specimens molded at 73°F, subjected to initial curing condition for 22 h, and transferred to standard moist room at 73°F for curing until test age of 28 days

Both temperature limits and moisture provision matter

Average Effect:	
Water vs. Air	+6.6%
60°F vs. 80°F	+9.2%
60°F water vs. 80°F air	+16%

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NRMCA study: Meininger, ASTM Cement Concrete & Aggregates, 1983

This is an NRMCA study published by Rick Meininger in 1983. It illustrates the difference in strengths even when cylinders are maintained within the temperature and moisture conditions applicable to ASTM C31.

The concrete mixture was proportioned with ordinary portland cement from two different sources (cement A and B) at 580 lb/yd^3 (344 kg/m^3), *w/c* of 0.51, and a 3 to 5 in. (75 to 125 mm) slump.

Cylindrical specimens (6 by 12 in.) were molded at room temperature (70 to 72°F [21 to 22°C]) and initially cured as shown for 22 hours.

The specimens stored in air were placed in plastic bags and sealed with rubber bands, while the water-immersed specimens were not covered.

At the end of the initial curing period, specimens were transferred to a standard moist room at 73°F until the test age of 28 days. B

Both 60°F and 80°F initial curing for 22 hours in air resulted in 3 to 8% (avg. 6.6%) lower strengths compared with initial curing under water.

Initial curing at 80°F resulted in 7 to 11% (avg. 9.2%) lower strengths compared with initial curing at 60°F as long as the moisture conditions were not varied.

Initial curing at 80°F in air resulted in 12 to 19% (avg. 16%) lower strength compared with initial curing at 60°F in water.

The specimens cured initially under water had a lower temperature rise compared with the specimens stored initially in air. This was also observed in the 1954 study. For specimens initially stored in air, the temperature increase for specimens made with cement A was greater than for specimens made with cement B. This explains the greater strength reductions in the specimens made with cement A. Meininger[6] also found that specimens with 2 days of initial curing exhibited strength reductions that were nearly the same as specimens with 1 day of initial curing.

These studies show that both temperature limits and ensuring that cylinders are immersed in water matter to the strength.

ASTM C31 – Report

12. Report

Report the following information to the laboratory that will test the specimens:

Identification number,

Location of concrete represented by the samples,

Date, time and name of individual molding specimens,

Slump or slump flow, air content, and concrete temperature, test results and results of any other tests on the fresh concrete, and any deviations from referenced standard test methods, and

Curing method. For standard curing method, report the initial curing method with maximum and minimum tem- peratures and final curing method. For field curing method, report the location where stored, manner of protection from the elements, temperature and moisture environment, and time of removal from molds.

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These are the reporting requirements in ASTM C31.

The reporting section of ASTM C31 states that for standard curing, the initial curing method with maximum and minimum temperatures should be reported to the entity testing the cylinders. However, this is seldom, if ever, seen on a strength test report (which complies with the reporting requirements of ASTM C39).

Most reports will have some statement that the making and curing of specimens complied with ASTM C31 with no detail.

Statements in Laboratory Reports

Molded to C-31 - Yes
Initially Cured to ASTM C-31 - Unknown
Cured & Tested in Lab to ASTM C-31 & C-39 - Yes

5 - Concrete specimen cured in accordance with ASTM C-31 after being received in laboratory.

Cylinders molded to ASTM C-31 & lab cured/tested to ASTM C-31 & ASTM C-39.

2.Specimen(s) Prepared to ASTM C 31

Obtain samples of fresh concrete at the placement locations (ASTM C-172), perfor
field tests and cast, cure, and test compressive strength samples (ASTM C-31, C-3

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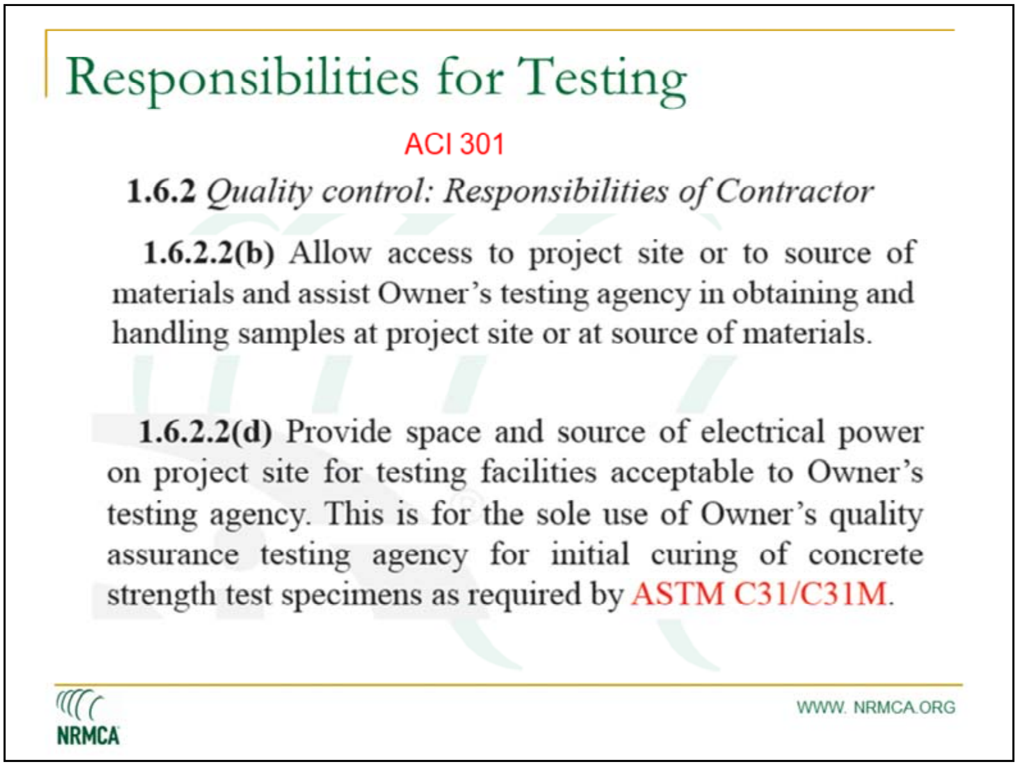
These are typical statements regarding conformance with ASTM C31 extracted from different strength test reports. There is no information about the max and min temperatures during the initial curing in the field



So the question often arises is who is reponsible for various factors associated with care of test specimens.

ACI 301 clearly states the contractor responsibility is to provide space and power for the initial curing of test specimens and this makes sense because the contractor has responsibility over the construction site.

Responsibilities for Testing

ACI 301

1.6.3 *Quality assurance: Duties and responsibilities of Owner's testing agency*

Sampled concrete used to mold strength test specimens (ASTM C31/C31M) will be tested for slump (ASTM C143/C143M), air content (ASTM C231/C231M or ASTM C173/C173M), temperature (ASTM C1064/C1064M), and density (ASTM C138/C138M).

1.6.3.2(e) Owner's testing agency will conduct concrete strength tests by making and standard curing test specimens in accordance with ASTM C31/C31M and testing them according to ASTM C39/C39M. Unless otherwise specified, concrete strengths for acceptance shall be tested at 28 days.

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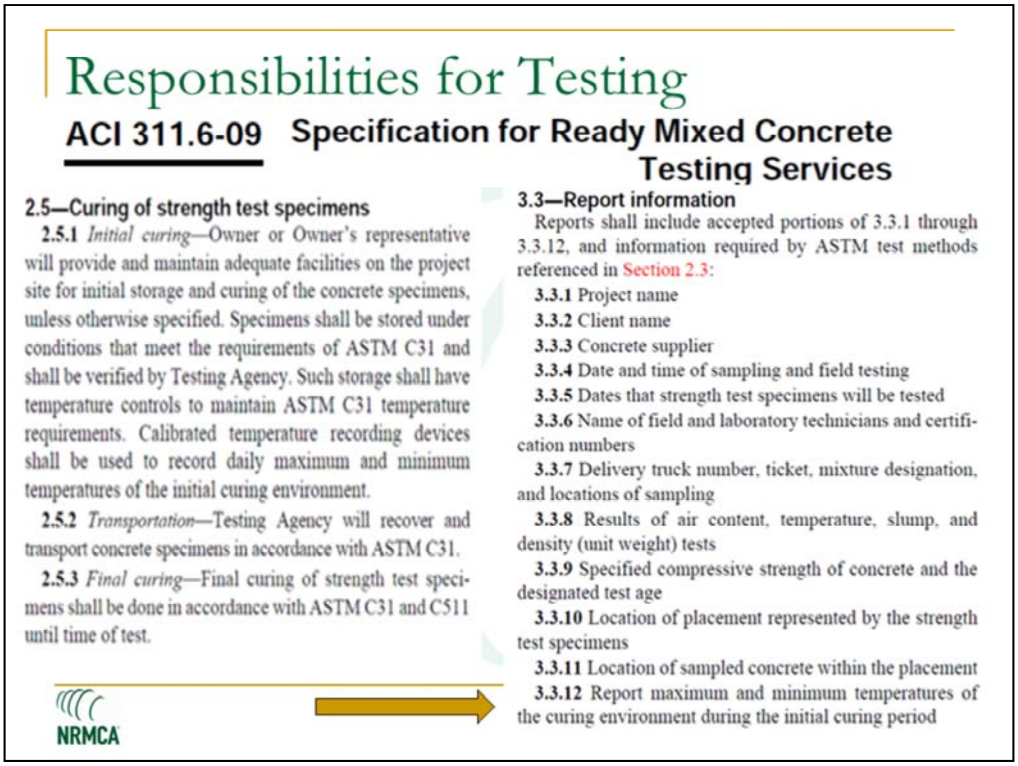
In ACI 301, several responsibilities of the testing agency are addressed. It indicates that several fresh concrete tests should be performed when strength test specimens are made. This is useful background information. It also indicates that density of fresh concrete should be measured. This is also stated in ASTM C94. Density is a useful test that can provide additional information to evaluate low strength test results – such as excessive air or water in the concrete.

ACI 301 also indicates that it is responsibility of the testing agency to test cylinders in accordance with C31. This means that they are responsible to ensure specimens are maintained within the temperature and moisture requirements of standard curing during the initial curing period in C31. Some concrete producers, testing agencies, and contractors partner to build a curing shed or box. Improper testing can lead to low break investigations, and coring that can cause delays and increase project costs. This is not in the best interests of any of the stakeholders including the owners.



Responsibilities for Testing

ACI 311.6-09 Specification for Ready Mixed Concrete Testing Services

2.5—Curing of strength test specimens

2.5.1 *Initial curing*—Owner or Owner's representative will provide and maintain adequate facilities on the project site for initial storage and curing of the concrete specimens, unless otherwise specified. Specimens shall be stored under conditions that meet the requirements of ASTM C31 and shall be verified by Testing Agency. Such storage shall have temperature controls to maintain ASTM C31 temperature requirements. Calibrated temperature recording devices shall be used to record daily maximum and minimum temperatures of the initial curing environment.

2.5.2 *Transportation*—Testing Agency will recover and transport concrete specimens in accordance with ASTM C31.

2.5.3 *Final curing*—Final curing of strength test specimens shall be done in accordance with ASTM C31 and C511 until time of test.

3.3—Report information

Reports shall include accepted portions of 3.3.1 through 3.3.12, and information required by ASTM test methods referenced in Section 2.3:

3.3.1 Project name

3.3.2 Client name

3.3.3 Concrete supplier

3.3.4 Date and time of sampling and field testing

3.3.5 Dates that strength test specimens will be tested

3.3.6 Name of field and laboratory technicians and certification numbers

3.3.7 Delivery truck number, ticket, mixture designation, and locations of sampling

3.3.8 Results of air content, temperature, slump, and density (unit weight) tests

3.3.9 Specified compressive strength of concrete and the designated test age

3.3.10 Location of placement represented by the strength test specimens

3.3.11 Location of sampled concrete within the placement

3.3.12 Report maximum and minimum temperatures of the curing environment during the initial curing period

NRMCA

ACI 311 is a specification for testing services. It says similar things like in ACI 301 and 318. But it seems to suggest that the owner has to provide the facilities for curing of test specimens and the agency will only verify that requirements of C31 were met. This differs from ACI 301.

The report section of this specification does state that the max/min temps during the initial curing period should be reported.

This specification also indicates that the distribution of reports should to all stakeholders.

ACI requirements on initial curing

Requirement	ACI 318-14[1]	ACI 301-16[13]	ACI 311.6-09[14]
Standard cured in accordance with ASTM C31/C31M	Stated	Stated	Stated
Concrete test report shall include information about the initial curing period	NA	Stated	Testing Agency to provide all project stakeholders maximum and minimum temperatures during initial curing
Provide space and electrical power for initial curing	NA	Contractor to provide	NA
Verify standard curing is according to ASTM C31	NA	NA	Testing agency to verify
Who is responsible for supplying the curing facility on site?	NA	Implied that Testing Agency is responsible	Owner or Owner's representative to provide this. Owner's representative is not defined explicitly

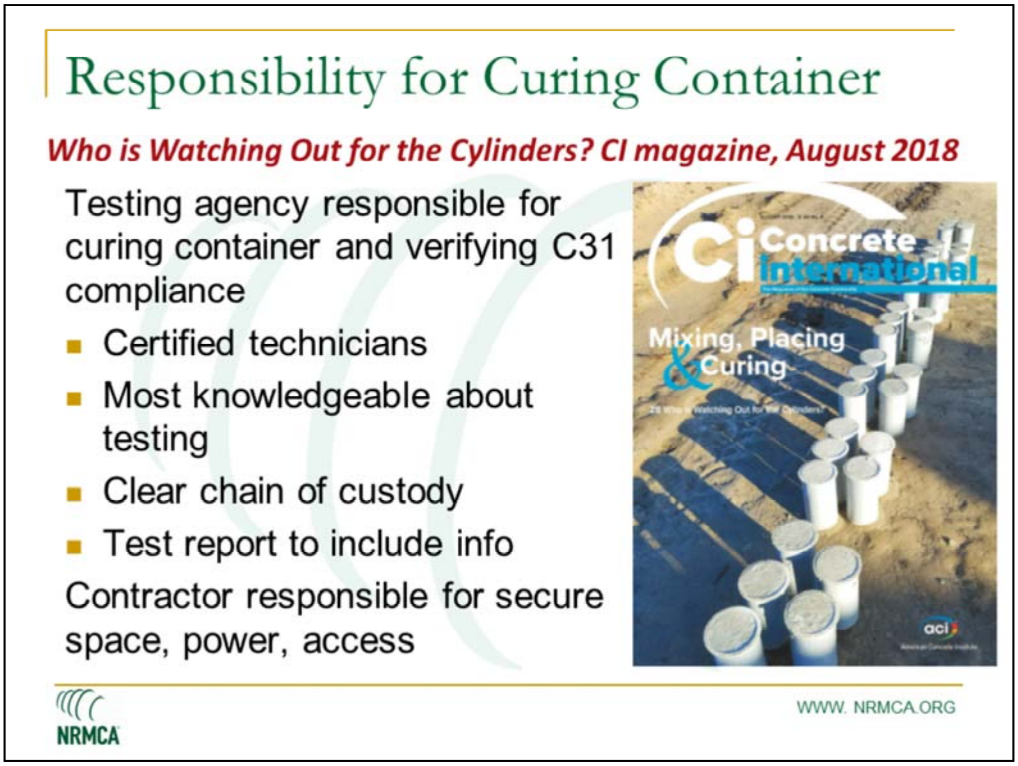
ACI 318-14, Provision 26.12.3.1; 301-16, Provision 1.6.3.2(e)[13]; and 311.6-09, Provision 2.5.1[14], all require that specimens for acceptance testing be standard-cured in accordance with ASTM C31/C31M.

The reporting section of ASTM C31/C31M requires the agency making the specimens to report the maximum and minimum temperatures of the surrounding environment and the curing method used during initial curing. ACI 301, Provision 1.6.3.1(c), requires that the concrete strength test report includes information on storage and curing of specimens before testing, while ACI 311.6, Provision 3.3.12, requires the Testing Agency to report the maximum and minimum temperatures of the curing environment during the initial curing period to all the parties listed in the test report distribution list.

ACI 301, Provision 1.6.2.2(d), states that the Contractor is to: "Provide space and source of electrical power on project site for testing facilities acceptable to Owner's testing agency. This is for the sole use of Owner's quality assurance testing agency for initial curing of concrete strength test specimens as required by ASTM C31/C31M." This implies that the Owner's testing agency will be responsible for initial curing. ACI 301, Provision 1.6.2.2(b), also states that it is the Contractor's responsibility to allow the Owner's testing agency access to the project site for obtaining samples to make test specimens. ACI 301 defines the Contractor as "the person, firm, or entity under contract for construction of the Work."

ACI 311.6, Section 2.5.1, states that the Testing Agency is responsible for verifying that the cylinders are maintained in accordance with ASTM C31/C31M. ACI 318, ACI 301, and ACI 311.6 require that field technicians, who prepare test specimens, must have an ACI Field testing Technician Grade I certification or acceptable equivalent. Thus, it is clear that the agency making test specimens is responsible for verifying conformance to the initial curing requirements.

The controversial topic is: "Who is responsible for supplying the curing facility on site?" ACI 301, Provision 1.6.3.2(e), under the duties and responsibilities of the Owner's testing agency, states: "Owner's testing agency will make and standard cure the specimens in accordance with ASTM C31/C31M…" Note that this statement is provided as information to the Contractor because ACI 301 is written to the Contractor and not the Testing Agency. This explains why the word "will" is used rather than "shall". Nevertheless, this provision implies that the testing agency is responsible for the initial curing and is also responsible for providing equipment needed to comply with the temperature requirements in ASTM C31/C31M. ACI 311.6, Section 2.5.1, which is written to the Testing Agency, states: "Owner or Owner's representative will provide and maintain adequate facilities on the project site for initial storage and curing of the concrete specimens, unless otherwise specified." Unfortunately, there is ambiguity in this provision because the specification does not define the "Owner's representative." Some have interpreted the Owner's representative to be the Architect/Engineer, while others have interpreted it to include the Testing Agency. According to the International Building Code (IBC)[15], the Owner is responsible for hiring the Testing Agency that conducts acceptance testing. In many jurisdictions, it is considered a conflict of interest for the Contractor to hire the Testing Agency that conducts acceptance testing.



The CI article concluded that

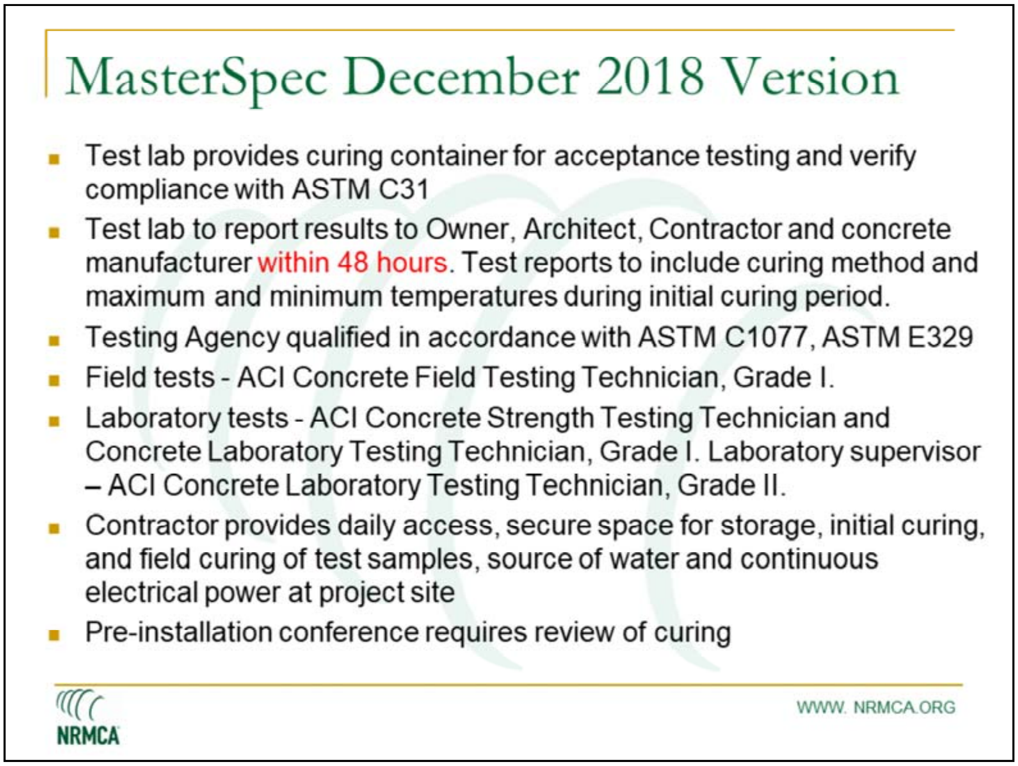
ACI 311.6, ACI 132R, AIA MasterSpec and project specifications should state explicitly that the Testing Agency is responsible for providing the on-site curing facility (container) and verifying that test specimens are maintained in accordance with ASTM C31/C31M at the jobsite.

Discussion: ACI 311.6 states that the Testing Agency is responsible for verifying that the specimens are stored under conditions in accordance with ASTM C31/C31M. ACI 318, ACI 301, and ACI 311.6 require that field technicians be certified. Among the project stakeholders, the Testing Agency is expected to have the most knowledge of the requirements for preparing and curing test specimens. This requirement will ensure an unambiguous chain of custody of standard-cured test specimens. This requirement should not preclude the Testing Agency from procuring the facility from the Contractor, but the Testing Agency is responsible for ensuring that test specimens are stored at temperatures conforming to ASTM C31/C31M.

ACI 301 and 311.6 require that the concrete test report includes information about the initial curing period, such as maximum and minimum temperatures of the medium surrounding the specimens. Specifiers should insist on receiving documentation of initial curing conditions. Producers can also request permission to place continuous temperature monitoring devices within the initial curing facility for independent measurements.

The AIA MasterSpec and project specifications should state explicitly that the Contractor is responsible for providing secured space, electrical power, and access for initial curing of test specimens.

Discussion: ACI 301 requires the Contractor to provide space and electrical power for initial curing by the Owner's Testing Agency.



Testing agency shall be responsible for providing curing container for composite samples on Site and verifying that field-cured composite samples are cured in accordance with ASTM C31//C31M.

Testing agency shall immediately report to Architect, Contractor and concrete manufacturer any failure of Work to comply with Contract Documents.

Testing agency shall report results of tests and inspections, in writing, to Owner, Architect, Contractor and concrete manufacturer within 48 hours of inspections and tests. Test reports shall include reporting requirements of ASTM C31/C31M, ASTM C39 and ACI 301, including the following as applicable to each test and inspection:

Information on storage and curing of samples before testing, including curing method and maximum and minimum temperatures during initial curing period.

Personnel performing laboratory tests shall be an ACI-certified Concrete Strength Testing Technician and Concrete Laboratory Testing Technician, Grade I. Testing agency laboratory supervisor shall be an ACI-certified Concrete Laboratory Testing Technician, Grade II.

Field Quality Control Testing Agency Qualifications: An independent agency qualified in accordance with ASTM C1077 and ASTM E329 for testing indicated.

Personnel conducting field tests shall be qualified as an ACI Concrete Field Testing Technician, Grade I, in accordance with ACI CPP 610.1 or an equivalent certification program.

Instructions to Contractor: Provide reasonable auxiliary services to accommodate field testing and inspections, acceptable to testing agency, including the following:

Daily access to the Work

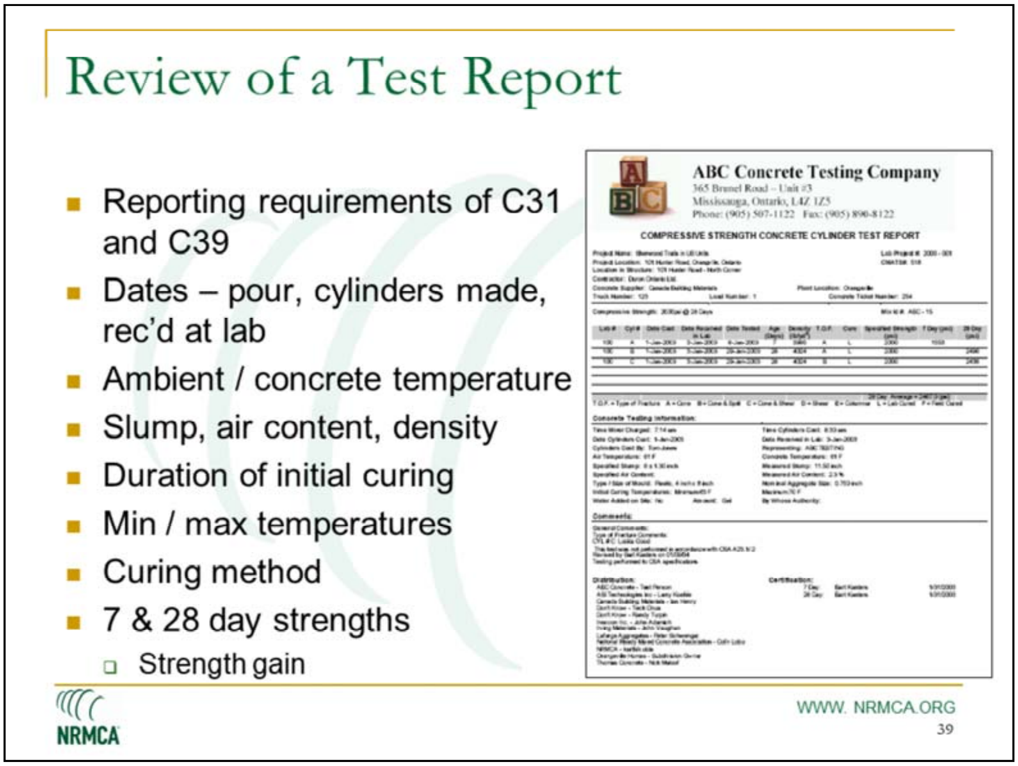
Incidental labor and facilities necessary to facilitate tests and inspections

Secure space for storage, initial curing, and field curing of test samples, including source of water and continuous electrical power at project site during site curing period for test samples

Security and protection for test samples and for testing and inspection equipment at Project site

Pre-installation conference now requires the review of the initial curing and field curing of field test cylinders (ASTM C31/C31M)

In some projects, the concrete producer has obtained permission to place continuous temperature monitoring devices within the on-site initial-curing facility. These temperature monitoring devices are low cost, can be reused, and allow wireless data transfer to a cell phone, tablet, or computer. Producers have reported acceptable initial curing practices on those projects.



Attention to details is extremely important when reviewing a test report of compression test results. A concrete producer should maintain a record of test results in the sequence of the date made and record all the pertinent information relative to these results.

Ensure that all reports have a date of pour. Often, test cylinder information is misleading due to improper reporting of the date.

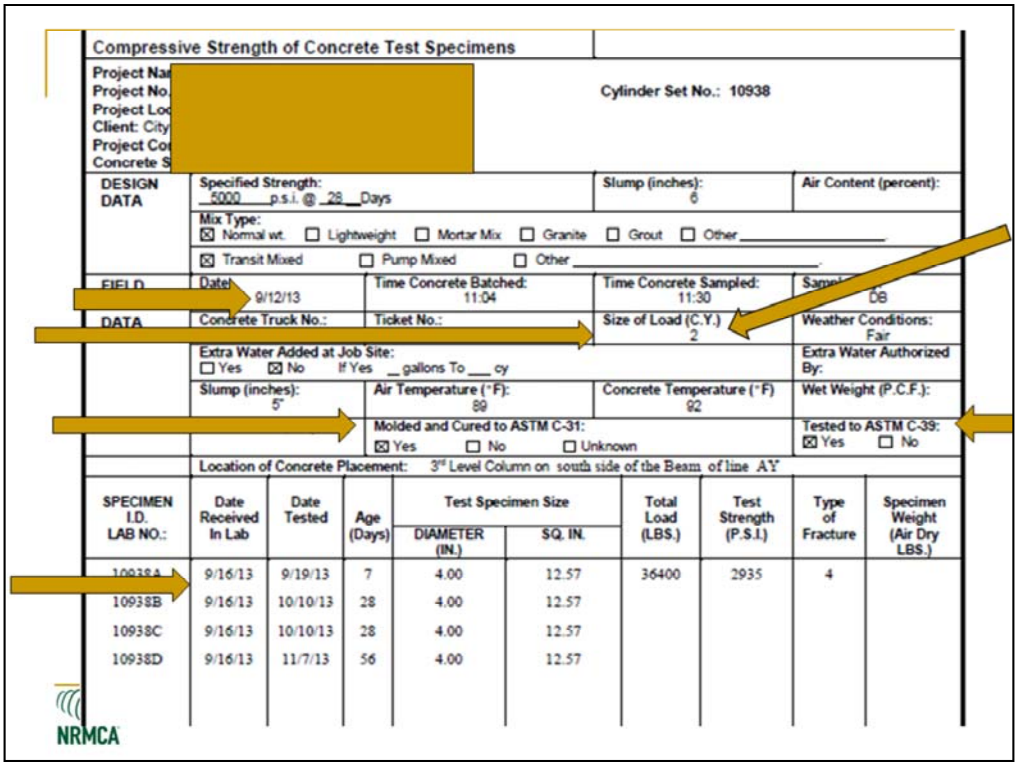
Ambient temperatures are of great importance especially when curing is non-standard.

Make sure proper test dates are reported.

All cylinder tests should have slump, air & temperature data.

The time the cylinders were removed from the job and transported to the lab is needed to confirm initial curing duration.

Each concrete mixture has a unique rate of strength gain between 7 and 28 days. It is not a constant percentage. The producer can check that this strength gain reported by the testing lab is consistent with what they know about that concrete mixture.



Compressive Strength of Concrete Test Specimens

Project Na[redacted]
Project No.[redacted]
Project Lo[redacted]
Client: City[redacted]
Project Co[redacted]
Concrete S[redacted]

Cylinder Set No.: 10938

DESIGN DATA
Specified Strength: 5000 p.s.i. @ 28 Days
Slump (inches): 6
Air Content (percent):
Mix Type: ☒ Normal wt. ☐ Lightweight ☐ Mortar Mix ☐ Granite ☐ Grout ☐ Other ____
☒ Transit Mixed ☐ Pump Mixed ☐ Other ____

FIELD DATA
Date: 9/12/13
Time Concrete Batched: 11:04
Time Concrete Sampled: 11:30
Samp[illegible]: DB
Concrete Truck No.:
Ticket No.:
Size of Load (C.Y.) 2
Weather Conditions: Fair
Extra Water Added at Job Site: ☐ Yes ☒ No If Yes __ gallons To ___ cy
Extra Water Authorized By:
Slump (inches): 5"
Air Temperature (°F): 89
Concrete Temperature (°F) 92
Wet Weight (P.C.F.):
Molded and Cured to ASTM C-31: ☒ Yes ☐ No ☐ Unknown
Tested to ASTM C-39: ☒ Yes ☐ No
Location of Concrete Placement: 3rd Level Column on south side of the Beam of line AY

SPECIMEN I.D. LAB NO.:	Date Received In Lab	Date Tested	Age (Days)	Test Specimen Size DIAMETER (IN.)	Test Specimen Size SQ. IN.	Total Load (LBS.)	Test Strength (P.S.I.)	Type of Fracture	Specimen Weight (Air Dry LBS.)
10938A	9/16/13	9/19/13	7	4.00	12.57	36400	2935	4	
10938B	9/16/13	10/10/13	28	4.00	12.57				
10938C	9/16/13	10/10/13	28	4.00	12.57				
10938D	9/16/13	11/7/13	56	4.00	12.57				

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This is an example of a test report that shows some issues. The specified strength is 5000 psi at 28 days.

It is a hot day – the ambient temperature is 89F, the concrete temperature is 92 F. So conditions are not too good for the initial curing.

The cylinders were cast on Sept 12 and received at the lab on the 16 – a difference of 3 to 4 days that does not conform to ASTM C31.

The sample was obtained from a 2 yd load. This should be avoided. Test samples should be obtained from larger load sizes – close to mixer capacity.

The lab indicates that it has complied with ASTM C31. But there is no record of max and min temps nor curing method during the initial curing at the jobsite.

The lab flagged this report because the one cylinder tested at 7-days was low. 1 cylinder is not a test result. There is no 7 day requirement; the rate of strength gain is unknown, so there is no basis to flag this.

Transporting Hardened Cylinders

Variables:

- Timing
  - Up to 48 hrs, or
  - 8 hrs after final set
- Duration of Travel
  - 4 hours
- Proper Cushioning
- Protect from Freezing
- Protect from Moisture Loss

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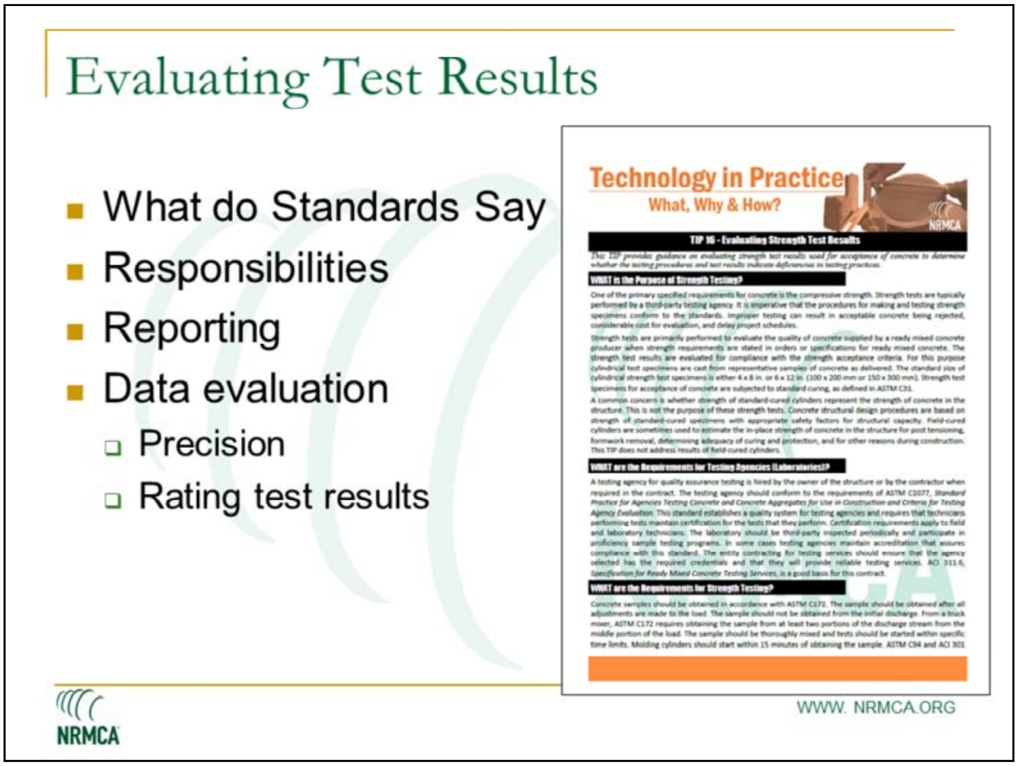
Upon completion of initial curing, cylinders should be transported to the laboratory for final curing within 48 hours after they were cast but at least 8 hours after final set. Specimens are generally only 24 hours old at this point and are very susceptible to damage if mishandled.

Specimens should be moved carefully and should be kept in their molds until they reach the laboratory.

Always ensure that caps or plastic bags remain on the specimens during transportation to ensure that there is no loss of moisture from the specimens.



This Technology in Practice sheet (TIP 16) discusses various details that can be useful when troubleshooting or evaluating strength test results. It discusses these topics and provides numerical examples.

Some of the details on evaluation of strength test results that is covered in this TIP are summarized in the next few slides.

Testing variability (ACI 214R)

- Within-batch coefficient of Variation (V_1)
- Average range ($\bar{R}$) from10 tests
- $\bar{X}$ = Average strength

$$s_1 = \frac{1}{d_2}\bar{R}$$

$$V_1 = \frac{s_1}{\bar{X}} \times 100$$

No. Specimens	d_2
2	1.128
3	1.693
4	2.059

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ACI 214R describes a procedure to evaluate variability associated with testing by calculating the within-batch variability. This is sometimes referred to as the within-test or single operator variability.

Variability due to testing is estimated by the within-batch coefficient of variation (V_1) calculated based on the average range (difference between maximum and minimum) in strengths of companion (replicate) cylinders comprising a strength test result which are cast from the same composite sample of concrete tested at the same age using Equation 1. Since the cylinders are made from the same concrete sample the material and manufacturing variability are assumed to be negligible and the strength difference between the cylinders is assumed as due to testing variability.

Average range should be calculated from at least 10 strength test results. The factor d_2 is used to estimate the standard deviation, s_1 from the average range and depends on the number of cylinders used

The within-batch coefficient of variation (V_1), in percent, is determined from standard deviation, s_1, estimated from the average range, and the average strength.

Example Calculation of V_1

Cylinder 1, psi	Cylinder 2, psi	Strength Test Result, psi	Range, psi
6740	7120	6930	380
7050	6750	6900	300
5640	5830	5735	190
5570	5550	5560	20
6030	5700	5865	330
5690	5650	5670	40
5530	5600	5565	70
5350	5320	5335	30
4650	5080	4865	430
5800	6080	5940	280
Average		**5837**	**207**

$$s_1 = \frac{207}{1.128} = 184 \text{ psi} \qquad V_1 = \frac{184}{5837} \times 100 = 3.2\%$$

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This is a numerical example of calculating the component of variation associated with testing. This set of data uses 2 cylinders for each test result.

V1 is calculated from range which is based on companion cylinders. Note that 10 test results are being used

The variation from this set of data is estimated to be 3.2%.

Within-batch precision

Quality Standards (ACI 214)	Excellent	Very Good	Good	Fair	Poor
V_1, %	< 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	> 6.0
Average Range of 2 Companion Cylinders (assuming avg. 4800 psi)	< 162	162 to 217	217 to 271	271 to 325	> 325

- V_1 > 6% - reason to question testing
- V_1 between 4 and 6% - potential problems
- V_1 between 2 and 3% - C39 testing variation
- < 1.5% - likely too good to be true

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ACI 214R indicates quality standards for testing based on the measured within-batch coefficient of variation V1

The associated average range range (R) of 2 companion cylinders, assuming an average strength level of 4800 psi (33 MPa) is included in the table.

To compare testing variation for different strength levels use V1 as opposed to the average range.

To track V1, concrete test reports need to report the strength of individual cylinders. The concrete producer inputs the results in a spreadsheet to calculate V1 based on the last 10 strength test

If V1 is between 4% and 6%, there are potential problems, and if V1 is above 6%, the testing should be questioned.

For reasonably good testing V1 should be in the range of 2 to 3% due to expected variation in the ASTM C39 compressive strength test method.

If it is a very low value, there may be cause to question whether cylinders are being tested to complete failure or if both cylinders are actually being tested.

ASTM C39 Single Operator precision

- Companion cylinders tested at same age
- Acceptable range should not be exceeded more often than 1 time in 20

	Coefficient of Variation[4]	Acceptable Range[4] of Individual Cylinder Strengths	
		2 cylinders	3 cylinders
150 by 300 mm [6 by 12 in.]			
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	2.9 %	8.0 %	9.5 %
100 by 200 mm [4 by 8 in.]			
Laboratory conditions	3.2 %	9.0 %	10.6 %

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Another method to evaluate testing is to use the Within-Test Precision of ASTM C39.

the within-test precision is derived from tests of 6 by 12 in. and 4 by 8 in. cylinders made from a well-mixed sample of concrete under laboratory conditions and under field conditions.

The acceptable range between two or three cylinders in the field or the lab can be used. There currently is no value for 4x8 inch specimens made in the field, but it is similar to that for 6x12 in. cylinders or slightly higher.

The acceptable range should not be exceeded very often – one time in 20 is a 5% occurrence that is considered acceptable.

Example Calculation within-batch Range

Cylinder 1, psi	Cylinder 2, psi	Test Result, psi	Range, psi	Range, %
6740	7120	6930	380	**5.5%**
7050	6750	6900	300	**4.3%**
5640	5830	5735	190	**3.3%**
5570	5550	5560	20	**0.4%**
6030	5700	5865	330	**5.6%**
5690	5650	5670	40	**0.7%**
5530	5600	5565	70	**1.3%**
5350	5320	5335	30	**0.6%**
4650	5080	4865	430	**8.8%**
5800	6080	5940	280	**4.7%**
Average		**5837**	**207**	

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In this set of 10 data points with 2 cylinders, the range exceeds 8% once. So this may not be a reason to question the quality of testing.

Example Calculation - within batch Range

No.	Cylinder 1	Cylinder 2	Test Result	Within-batch range	Within-batch range, %	Moving Average of 10 Tests	Moving average of 10 Ranges	Moving 10 test V_1, %
1	4498	4254	4376	244	5.6%			
2	4318	3842	4080	476	11.7%			
3	3782	3674	3728	108	2.9%			
4	3527	3263	3395	264	7.8%			
5	4571	3969	4270	602	14.1%			
6	4543	5415	4979	872	17.5%			
7	3988	4172	4080	184	4.5%			
8	3361	3339	3350	22	0.7%			
9	4831	4807	4819	24	0.5%			
10	3411	3315	3363	96	2.9%	4044	289	289/(1.128X4044) =6.3%
11	3619	3913	3766	294	7.8%	3983	294	6.5%
12	3880	4082	3981	202	5.1%	3973	267	5.9%

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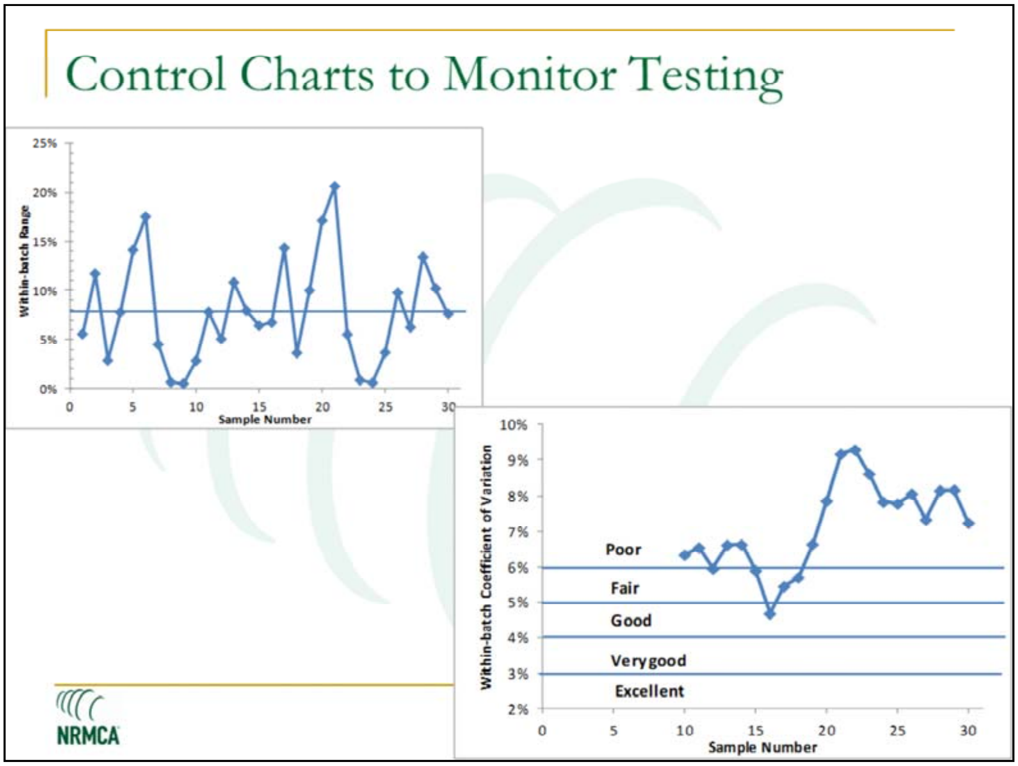
In this set of data, the Range is exceeded 3 times in 12 points (25%of the time). C39 precision statement says only 1 in 20 (5%) chances of this happening so clearly that is a violation

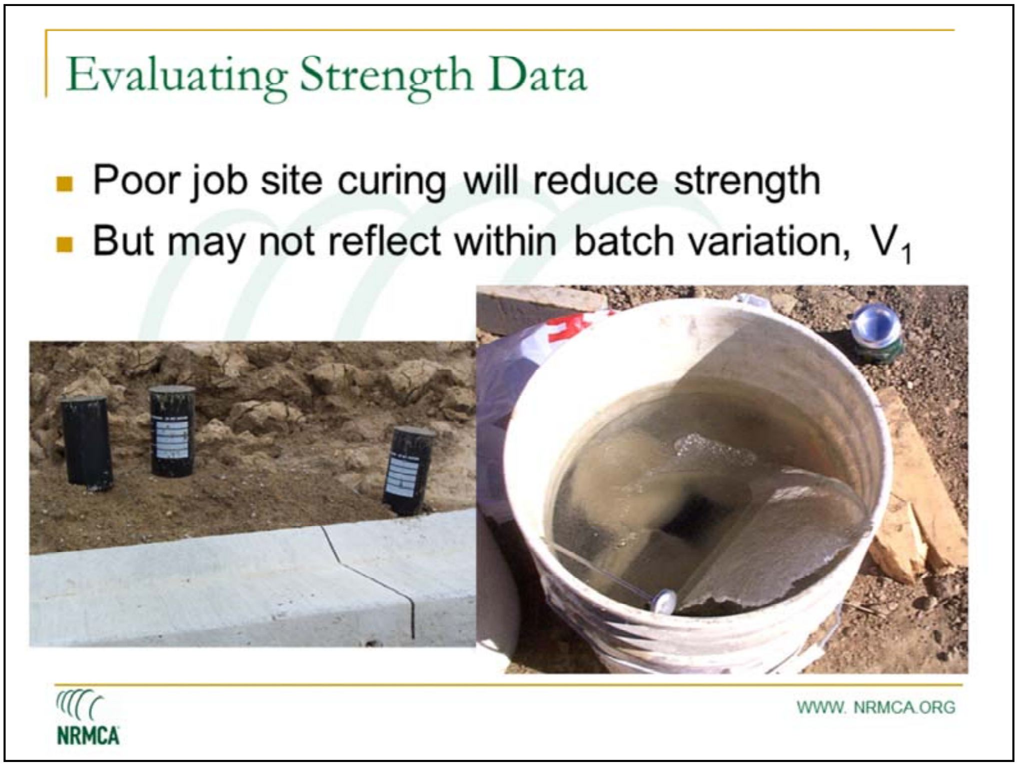
Also V1 calculated is high - at or higher than 6%. SO there is a concern with the quality of this testing. Note that last 10 test results are being used for V1 calculation. So, we don’t have any entry for the first 9 test results. Further, it is a moving 10 test V1.



These are two types of plots monitoring the quality of testing. The figure on the left plots the range of the two cylinders prepared from the same concrete sample expressed as a percent of the average strength. For this

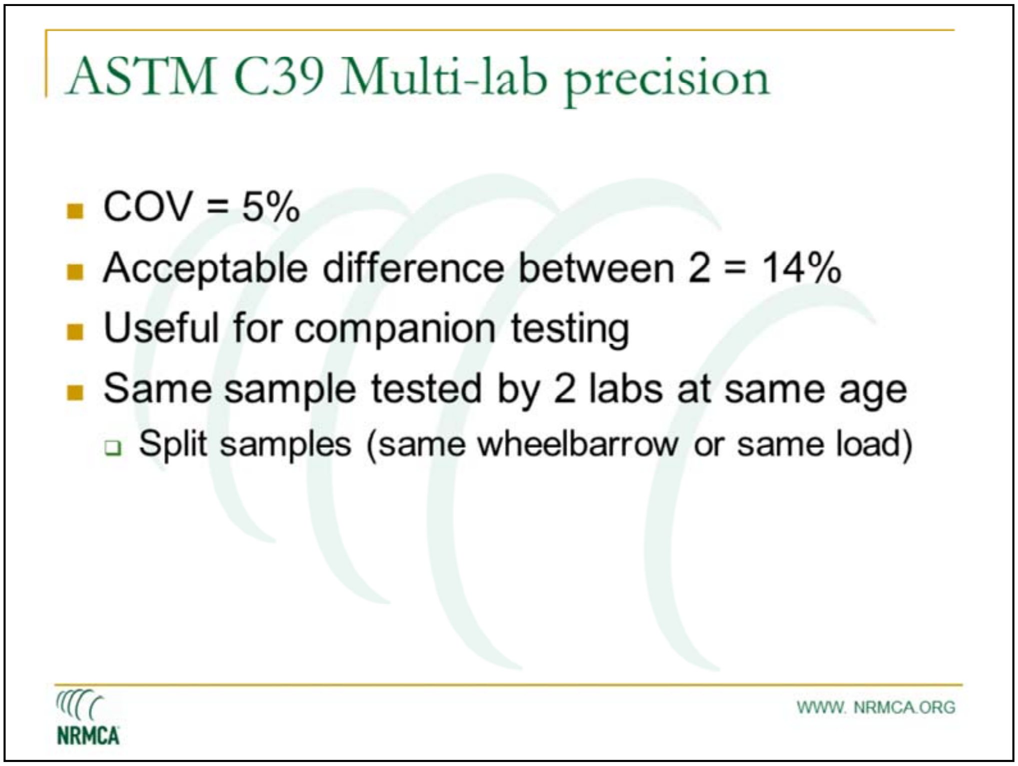
the control limit for acceptable range of two cylinders uses the C39 precision statement of 8% (appropriate for 6x12s for 4x8s since 3 cylinders are used it should be 11%, use 9% if only 2 4x8 cylinders are tested). The range of 8% is exceeded more often than 1 in 20, suggesting that cylinder fabrication and testing techniques need to be reviewed.

In the right hand figure the moving 10 test within-batch coefficient of variation (V1) in percent is plotted relative to the ACI 214R categories for testing variation. . For this example also, the testing quality is poor most of the time.



The analysis of strength data from companion cylinders to determine range or V1 may not capture improper testing. If sampling and testing procedures are deficient - initial and final curing, capping material, testing-machine

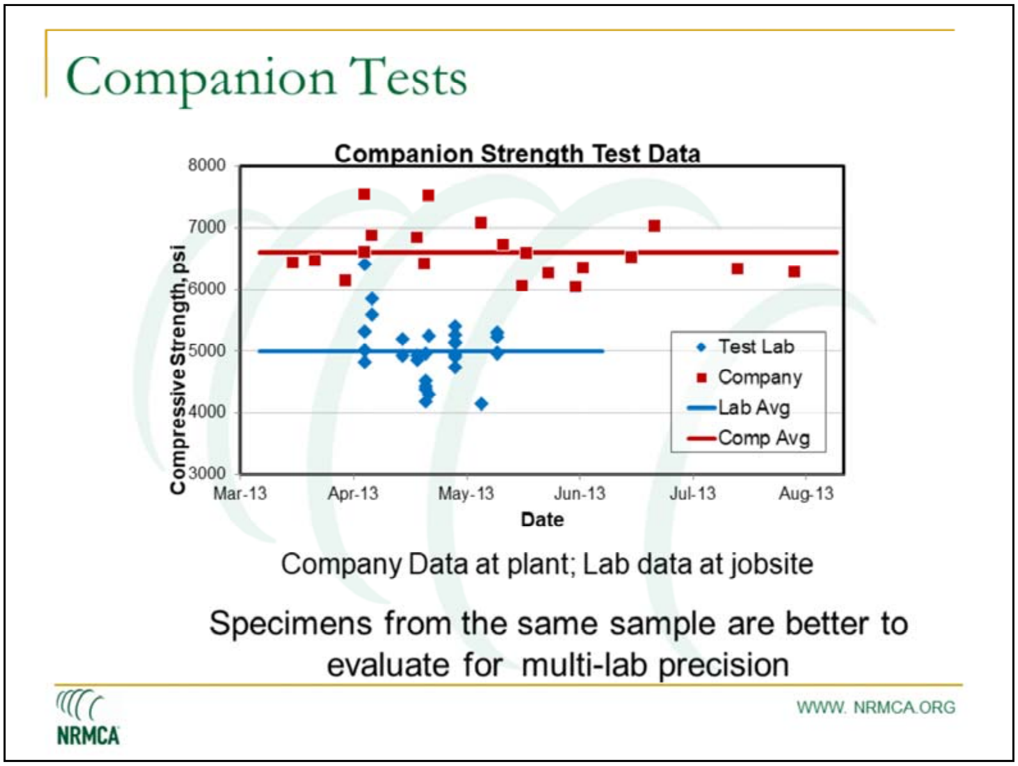
calibration, etc. - these would affect companion cylinders from the same sample equally and may not increase V1 but will still result in lower measured strengths and impact the standard deviation of strength test results. Job-site conditions (temperature, humidity) and practices vary every day; therefore, cylinders cast at different time periods are expected to experience different initial curing conditions if not subject to standard curing. *However, companion cylinders cast from the same batch of concrete should experience identical initial uring conditions. In summary, variations in initial curing conditions are* unlikely to influence the range of compressive strength of companion cylinders prepared from a batch but will impact the batch-to-batch variation and therefore the overall strength variability.



Another thing that can be useful is to perform companion testing with the laboratory of record. This is sometimes done on large projects or when there have been problems with testing. ASTM C39 has a Multilaboratory Precision statement that can be useful in determining whether two sets of results performed by different laboratories are significantly different (statistically based).

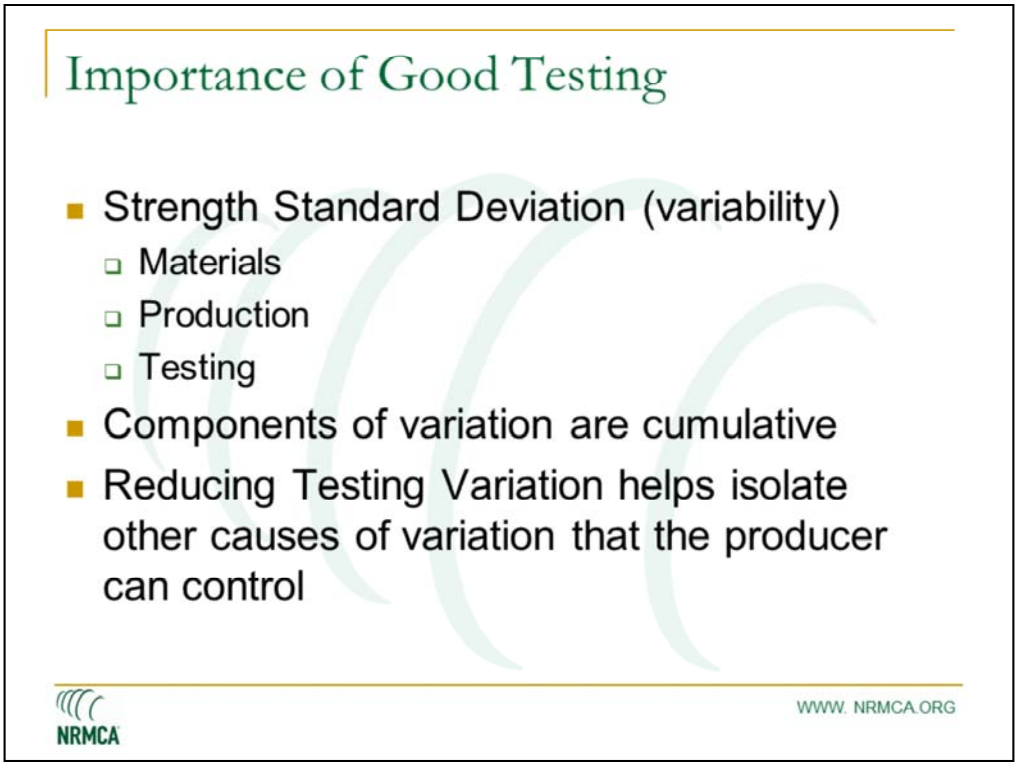
Ideally companion testing should be done on a split sample – the test specimens for each lab should be prepared from the same concrete sample. Sometimes this is not possible, but testing concrete from the same load is also possible. Alternatively, a poplulation of data tested by two labs can be compared to observe differences in overall average.

The ASTM C39 multilaboratory precision says that the difference in test results between two labs testing the same concrete should not exceed 14% of the average more often than 1 time in 20.



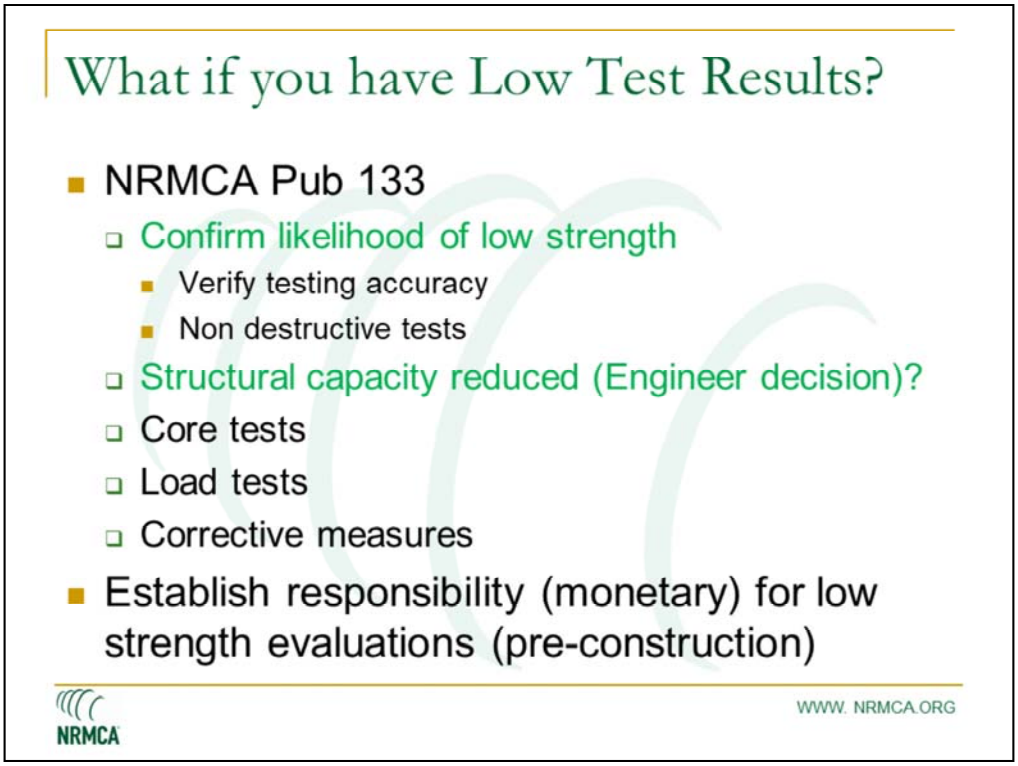
This is a series of test data comparing tests done by the laboratory of record and the concrete producer. In this case, split sample testing was not possible. The producer obtained samples at the plant, the testing agency at the jobsite. The loads tested were different. There could have been some modifications to the loads before concrete was discharged at the jobsite.

However, the plot indicates a distinct difference in the averages between the two sets of test results. The average difference is about 1600 psi. and all the testing lab results are lower than those made and tested by the concrete producer.



The significance of testing is important to the overall quality of the project.

The components of variation associated with strength test results can be broadly attributed to materials, production and testing. The components of variation are cumulative. Thus if the component of variation associated with testing is large, the variation that the producer needs to control (materials and production) through his quality control activities become difficult to isolate. Further, this increases the variation of the strength test results that is not representative of what the producer is doing. This inflates the standard deviation and will require a higher level of over-design for strength that increases the materials cost to the concrete producer.



When there are low strength results, this results in some evaluation that will delay and add costs to participants on a project including the contractor and the owner.

NRMCA Publication 133 recommends a sequence of steps that should be followed. The first step is to evaluate whether the low strength results can be confirmed – by evaluating data and practices and follow that by non-destructive tests.

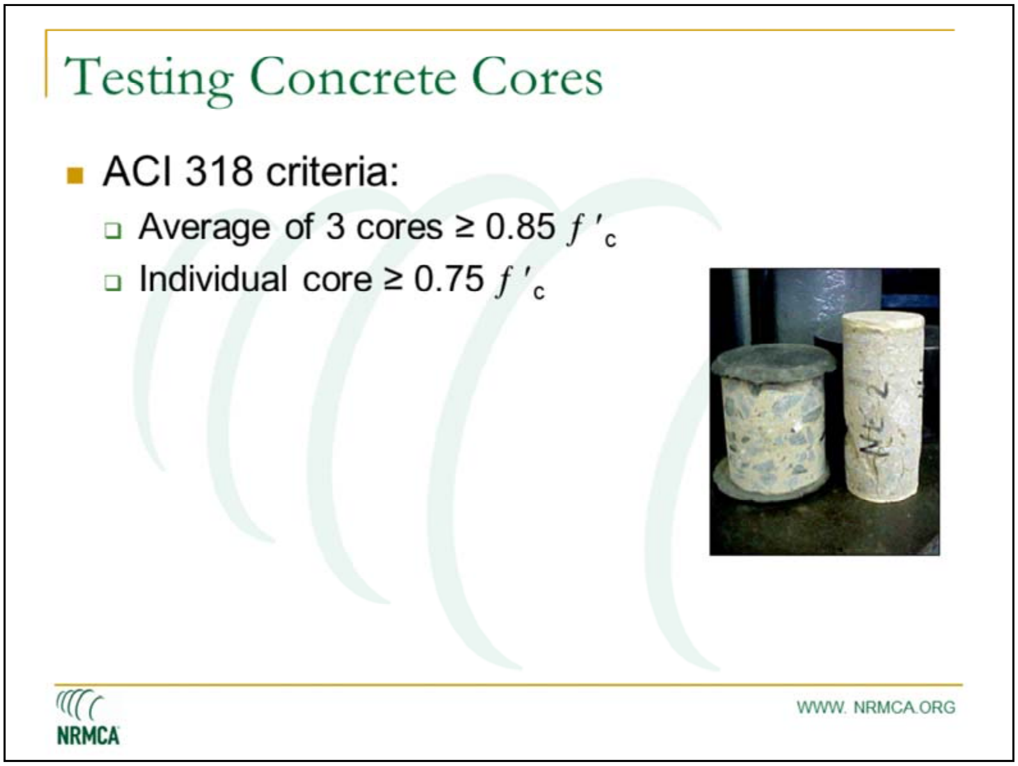
The next step is to establish (by design calculations) whether the low strength impacts the structural capacity in that portion of the structure. Its possible that the specified strength level is not required.

The ACI 318 has provisions for strength tests of cores.

Load tests can be used to determine structural capacity etc. This is covered in ACI 318.

Corrective measures may be retrofitting the structure to increase its load carrying capacity or to remove and replace. This will generally cost much more than it cost to construct the structure in the first place.

If low strength results can be attributed to the responsible party, then it is appropriate that the cost for the evaluation is borne by this entity. These aspects should be established in a pre-construction meeting.

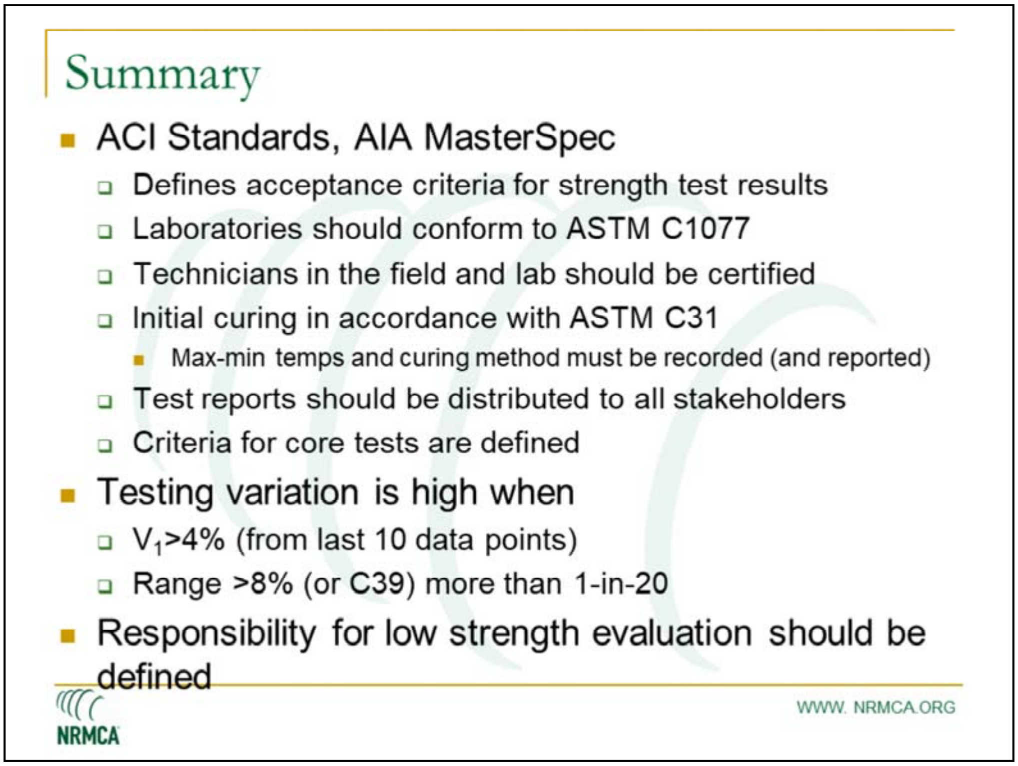


When cores are tested for the purpose of investigation of low strength test results, the cores should be obtained, preconditioned and tested according to the provisions of ASTM C 42. The ACI 318 Building code indicates that

Concrete in an area represented by core tests shall be considered structurally adequate if

The average of three cores is equal or greater than 85% of f'_c.

No single core should test less than 75% of f'_c.



Industry standards are clear and consistent on testing concrete and acceptance criteria. The qualifications of inspectors and testing agencies are stated. The details regarding testing are clearly stated. There are ways to evaluate whether testing has been performed in accordance with the standards.

It is incumbent on a testing agency to ensure that testing of concrete is reliable and provides assurance that the these results are appropriate to ensure compliance with the contract.

The responsibility for low strength test results can be either due to the quality of the concrete or the quality of the testing. The responsible party for low strengths should be liable for associated costs for evaluation and recourse.

Code and Standard Requirements on Concrete Testing

Questions

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