Code and Standards Requirements For Acceptance Testing

Philip Kresge
Vice-President, Local Paving
National Ready Mixed Concrete Association

NRMCA®

Disclaimer

This presentation has been prepared solely for information purposes. It is intended solely for the use of professional personnel, competent to evaluate the significance and limitations of its content, and who will accept full responsibility for the application of the material it contains. The National Ready Mixed Concrete Association and any other organizations cooperating in the preparation of this presentation strive for accuracy but disclaim any and all responsibility for application of the stated principles or for the accuracy of the content or sources and shall not be liable for any loss or damage arising from reliance on or use of any content or principles contained in this presentation. Unless otherwise indicated, all materials in this presentation are copyrighted to the National Ready Mixed Concrete Association. All rights reserved. Therefore reproduction, modification or retransmission in any form is strictly prohibited without the prior written permission of the National Ready Mixed Concrete Association.

Purpose of Acceptance Testing

- Concrete supplied complies with specification
- Sampling and testing should comply with standards
  - 1 cu.ft. sample represents 10 cubic yards…
  - OR 150 cubic yards (depending on frequency)
- Improper procedures generate inaccurate results
  - Will cost someone
  - Will delay project

Scope of Testing

- Samples obtained in accordance with ASTM C172
  - Point of delivery from transportation unit (or mixer)
  - Other sampling methods should be defined
- Fresh Concrete tests
  - Slump or slump flow – tolerances in ASTM C94; ACI 117
  - Air content – tolerance ±1.5%
  - Temperature – limits in specifications
  - Density – typically no limits unless its lightweight concrete
  - Strength specimens
    - Average of two 6x12 in or three 4x8 in cylindrical specimens
    - Standard cured in accordance with ASTM C31
    - Tested in accordance with ASTM C39 at 28 days or as per spec

Standard Curing vs. Field Curing

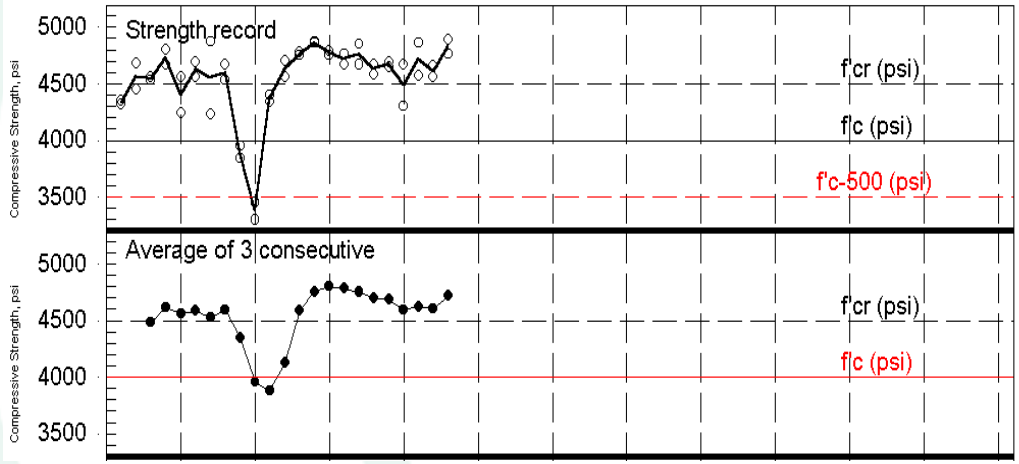
- Quality control
- Developing mixture proportions for strength requirements
- Acceptance testing for specified strength

- Removal of forms or shoring
- Minimum strength for post-tensioning
- Determine if structure can be put into service
- Adequacy of curing and protection
- Compare with standard cured or with other in-place tests

ACI Strength Acceptance Criteria

Test results - Should meet both criteria

- 1. Average of 3 consecutive ≥ f'_c
- 2. Single test ≥ (f'_c – 500)
  - For f'_c > 5000 psi – Single test ≥ 0.9f'_c



Probability of failure < 1 in 100 (1%)

ACI 318-14 for Low Strength Results

- Avg 3 consecutive - less than f'_c
  - Increase strength level

- Single test - less than (f'_c - 500)
  - Increase strength level
  - Investigate low strength - structural safety
    - Reduced load carrying capacity of structure confirmed by calculations
    - Core tests

Field Cured Cylinders

- For evaluating protection and curing of structure (ACI 318)
  - Acceptable if field cured cylinders…
    - > 85% of companion lab cured

      Or

    - > (f'_c + 500) psi
- Also used for formwork removal, post-tensioning

Requirements for Laboratories

ACI 318

26.12—Concrete evaluation and acceptance

26.12.1 *General*

(b) The testing agency performing acceptance testing shall comply with ASTM C1077.

(c) Qualified field testing technicians shall perform tests on fresh concrete at the job site, prepare specimens for standard curing, prepare specimens for field curing, if required, and record the temperature of the fresh concrete when preparing specimens for strength tests.

(d) Qualified laboratory technicians shall perform required laboratory tests.

(e) All reports of acceptance tests shall be provided to the licensed design professional, contractor, concrete producer, and, if requested, to the owner and the building official.

ACI 301

1.6.1.1 *Testing agencies*—Agencies that perform required tests of concrete materials shall meet the requirements of ASTM C1077. Testing agencies that test or inspect placement of reinforcement shall meet the requirements of ASTM E329. Testing agencies shall be accepted by Architect/Engineer before performing testing or inspection.

1.6.3.1(c) Owner's testing agency will report test and inspection results of Work to Owner, Architect/Engineer, Contractor, and concrete supplier within 7 days after tests and inspections are performed. Strength test reports will include location in Work where concrete represented by each test was deposited, date and time sample was obtained, and batch ticket number. Strength test reports will include information on storage and curing of specimens before testing.

Quality Assurance

Testing Lab conducting QA testing

- Conformance to ASTM C1077
  - Inspected
  - Accredited
- Technicians Certified
  - Field Testing
  - Strength Testing
  - Lab Testing
- Testing in accordance with ASTM or AASHTO
- Timely distribution of test reports to all parties

Laboratories – ASTM C1077

Quality System

- Written manual
- Under direction of PE
- Personnel evaluation
- Equipment calibration
- Inventory control
- Participation in proficiency sample program
- Laboratory inspection and accreditation

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

Frequent violations - Testing

Reason (Average strength reduction)

- Initial curing (30%)
- Damaging “green” specimens (18%)
- Filling in one layer (17%)
- From chute / no tapping (12%)
- Top etching / no lids (11%)

Adapted from Snell

Frequent violations - Testing

Acceptance of concrete

ACI 318 Section 26.12.3.1

(a) Specimens for acceptance tests shall be in accordance with (1) and (2):

(1) Sampling of concrete for strength test specimens shall be in accordance with ASTM C172.

(2) Cylinders for strength tests shall be made and standard-cured in accordance with ASTM C31 and tested in accordance with ASTM C39.

Strength Test Specimens

Standard Curing - ASTM C31

- Maintain moisture
- Initial temperature in field
  - 60°F to 80°F
  - f'_c > 6000 psi - 68°F to 78°F
- Transport to lab within 48 hrs
- Transportation time 4 hrs or less
- Lab curing 73.5±3.5°F and moist

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

ASTM C31 Note 8 – Standard Curing

Satisfactory temperature environment

- Use of ventilation
- Use of ice
- Thermostatically controlled heating or cooling
- Heat, such as stoves or light bulbs

- Immersion in water may be easiest to control temperature

Violation of standard procedures

Initial Curing is most frequent problem

Field Observation

Properly stored in initial curing environment 1/3 of time

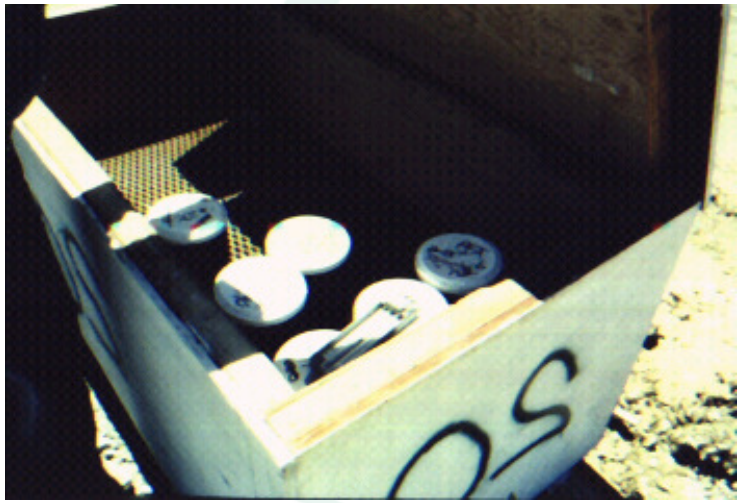
COLORADO READY MIXED CONCRETE ASSOCIATION

Field Examiner Summary Details

August, 2015*

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
[illegible]	[illegible]	[illegible]
Average Score 9 (Properly stored in an initial curing environment)	**34%**	**30%**
the mixer truck discharge?)	93%	81%

Initial Curing Options



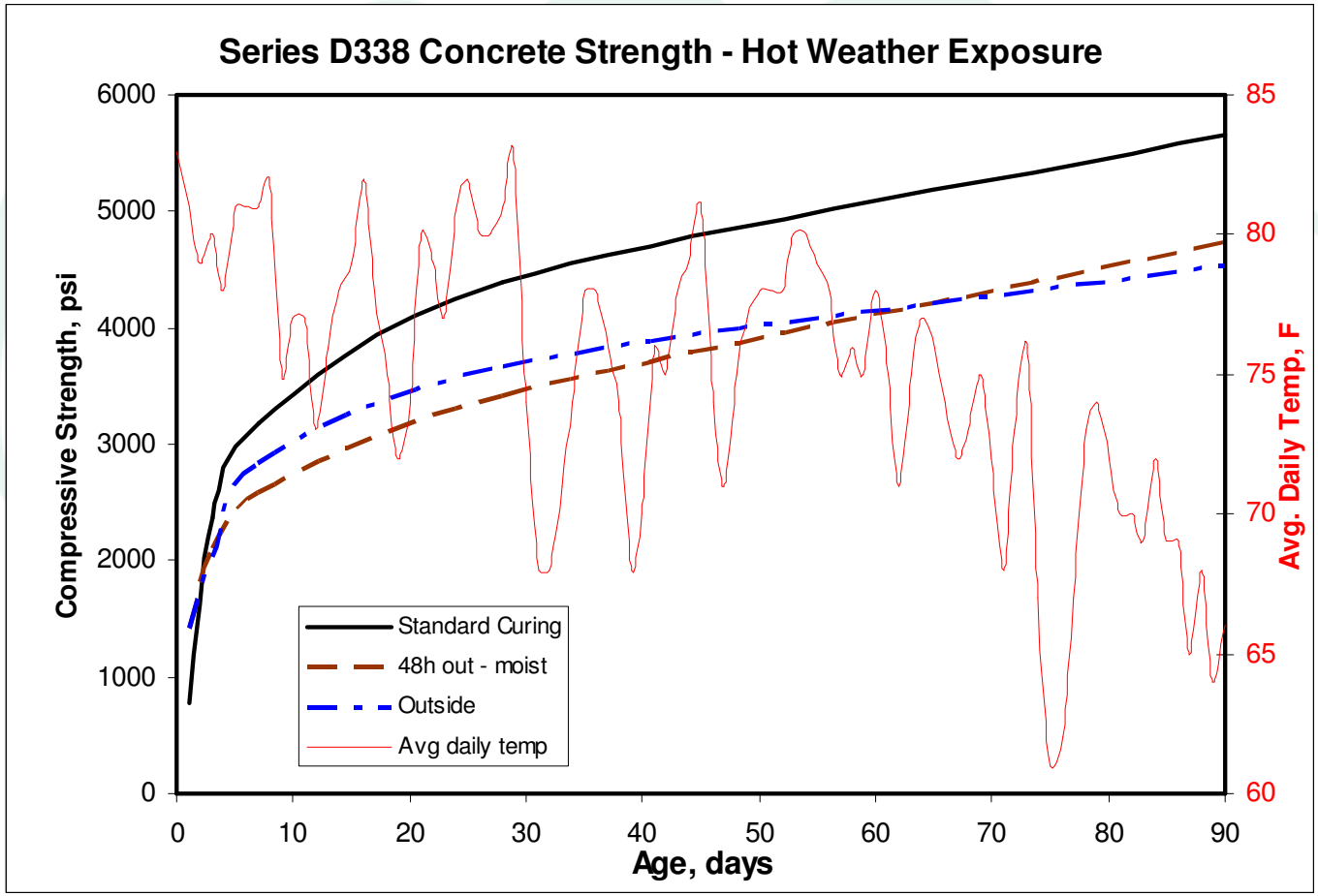
Using Sand

Immerse in Water/Coolers

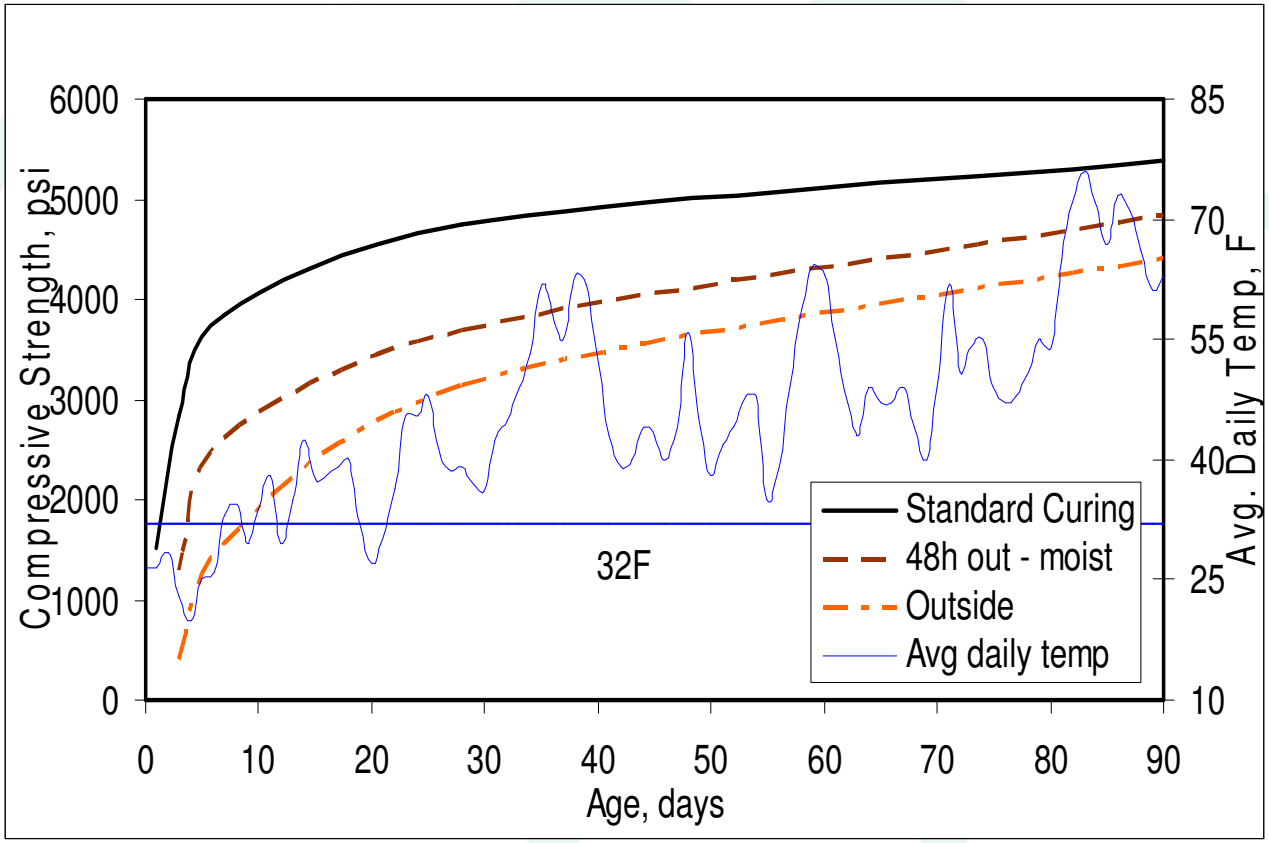
Add water (use ice if needed) and insert hi-low thermometer

Temperature Controlled

Effects of Initial Curing
Hot Weather



Effects of Initial Curing Cold Weather



Effects of Initial Curing

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

Initial Curing (days)	Relative Strength		
	Initial Curing Temp		
	37 °F	73 °F	100 °F
Moist cured	100% (5590 psi)		
1	100%	92%	88%
3	93%	89%	78%
14	89%	78%	67%
28	73%	73%	62%

NRMCA Pub 53; Delmar L. Bloem,1954

Effects of Initial Curing

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

Condition (1 day initial curing)	Temp Range	Relative strength	
Jobsite* – Curing box; in water	71 - 76ºF	100%	4860 psi
Lab – immersed in water	73 - 82ºF	100%	
Lab – in air	78 - 82ºF	88%	
Jobsite* – not protected	71 - 107ºF	85%	
Jobsite* – covered with wet burlap	94 - 135ºF	83%	

* Cylinders were kept exposed to sunlight; thermometer shielded

Data from F. Kozeliski – New Mexico, 2016

Effects of Initial Curing

Initial curing for 24 hours - Within limits of ASTM C31

Condition	Relative Strength (28-day)	
	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%

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%

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

ASTM C31 – Report

12. Report

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

12.1.1 Identification number,

12.1.2 Location of concrete represented by the samples,

12.1.3 Date, time and name of individual molding specimens,

12.1.4 Slump, 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

12.1.5 Curing method. For standard curing method, report the initial curing method with maximum and minimum temperatures 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.

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[illegible]re field tests and cast, cure, and test compressive strength samples (ASTM C-31, C-3[illegible]7)

Responsibilities for Testing

ACI 301

1.6.2 *Quality control: Responsibilities of Contractor*

1.6.2.2(b) Allow access to project site or to source of materials and assist Owner's testing agency in obtaining and handling samples at project site or at source of materials.

1.6.2.2(d) 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.

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.

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

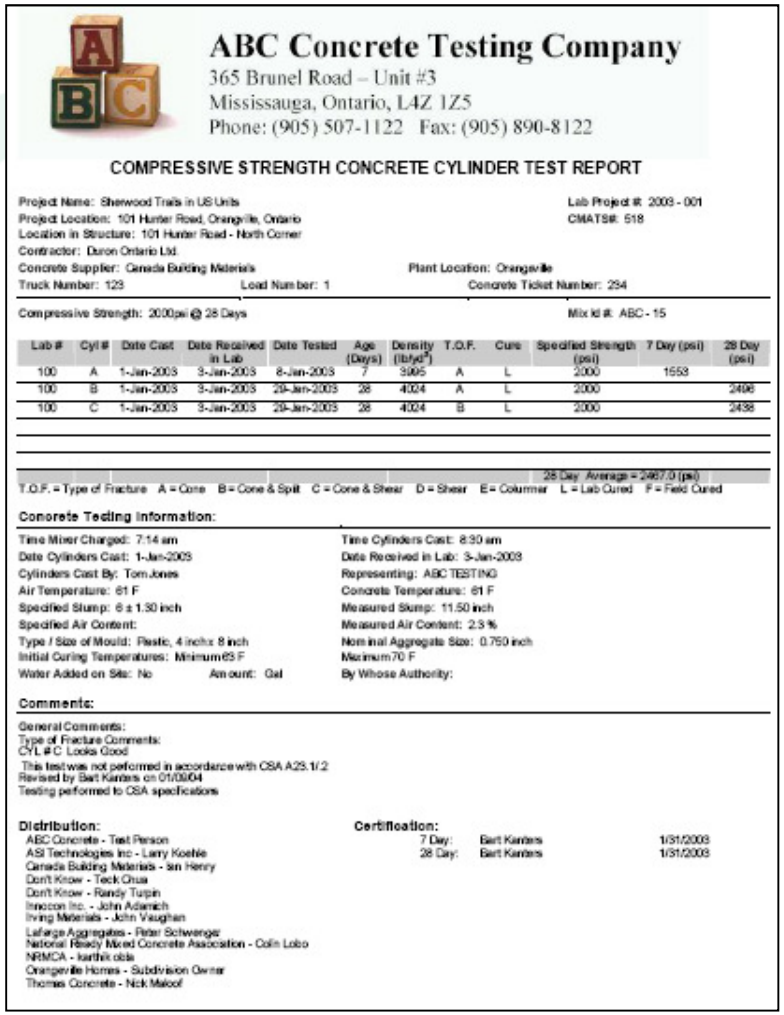
3.3.10 Location of placement represented by the strength test specimens

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

Review of a Test Report

- Reporting requirements of C31 and C39
- Dates – pour, cylinders made, rec'd at lab
- Ambient / concrete temperature
- Slump, air content, density
- Duration of initial curing
- Min / max temperatures
- Curing method
- 7 & 28 day strengths
  - Strength gain



ABC Concrete Testing Company
365 Brunel Road – Unit #3
Mississauga, Ontario, L4Z 1Z5
Phone: (905) 507-1122 Fax: (905) 890-8122

COMPRESSIVE STRENGTH CONCRETE CYLINDER TEST REPORT

Project Name: Sherwood Trails in US Units — Lab Project #: 2003 - 001
Project Location: 101 Hunter Road, Orangville, Ontario — CMATS#: 518
Location in Structure: 101 Hunter Road - North Corner
Contractor: Duron Ontario Ltd.
Concrete Supplier: Canada Building Materials — Plant Location: Orangeville
Truck Number: 123 — Load Number: 1 — Concrete Ticket Number: 294
Compressive Strength: 2000psi @ 28 Days — Mix Id #: ABC - 15

Lab #	Cyl #	Date Cast	Date Received in Lab	Date Tested	Age (Days)	Density (lb/yd³)	T.O.F.	Cure	Specified Strength (psi)	7 Day (psi)	28 Day (psi)
100	A	1-Jan-2003	3-Jan-2003	8-Jan-2003	7	3995	A	L	2000	1553	
100	B	1-Jan-2003	3-Jan-2003	29-Jan-2003	28	4024	A	L	2000		2498
100	C	1-Jan-2003	3-Jan-2003	29-Jan-2003	28	4024	B	L	2000		2438

28 Day Average = 2467.0 (psi)

T.O.F. = Type of Fracture A = Cone B = Cone & Split C = Cone & Shear D = Shear E = Columnar L = Lab Cured F = Field Cured

Concrete Testing Information:

Time Mixer Charged: 7:14 am — Time Cylinders Cast: 8:30 am
Date Cylinders Cast: 1-Jan-2003 — Date Received in Lab: 3-Jan-2003
Cylinders Cast By: Tom Jones — Representing: ABC TESTING
Air Temperature: 61 F — Concrete Temperature: 61 F
Specified Slump: 6 ± 1.50 inch — Measured Slump: 11.50 inch
Specified Air Content: — Measured Air Content: 2.3 %
Type / Size of Mould: Plastic, 4 inch x 8 inch — Nominal Aggregate Size: 0.750 inch
Initial Curing Temperatures: Minimum 63 F — Maximum 70 F
Water Added on Site: No — Amount: Gal — By Whose Authority:

Comments:

General Comments:
Type of Fracture Comments:
CYL # C: Looks Good
This test was not performed in accordance with CSA A23.1/2
Revised by Bart Kanters on 01/09/04
Testing performed to CSA specifications

Distribution:
ABC Concrete - Test Person
ASI Technologies Inc - Larry Koehle
Canada Building Materials - Ian Henry
Don't Know - Teck Chua
Don't Know - Randy Turpin
Inocon Inc. - John Adamich
Irving Materials - John Vaughan
Lafarge Aggregates - Peter Schwenger
National Ready Mixed Concrete Association - Colin Lobo
NRMCA - karthik obla
Orangeville Homes - Subdivision Owner
Thomas Concrete - Nick Maloof

Certification:
7 Day: Bart Kanters 1/31/2003
28 Day: Bart Kanters 1/31/2003

Compressive Strength of Concrete Test Specimens

Project Name:
Project No.: **Cylinder Set No.: 10938**
Project Location:
Client:
Project Contractor:
Concrete Supplier:

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	Time Concrete Batched:	Time Concrete Sampled:	Sampled By:
9/12/13	11:04	11:30	DB

Concrete Truck No.:	Ticket No.:	Size of Load (C.Y.)	Weather Conditions:
0480	11043153	2	

Extra Water Added at Job Site:
☐ Yes ☒ No If Yes __ gallons To ___ cy
Extra Water Authorized By:

Slump (inches):	Air Temperature (°F):	Concrete Temperature (°F)	Wet Weight (P.C.F.):
5"	89	92	

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		Total Load (LBS.)	Test Strength (P.S.I.)	Type of Fracture	Specimen Weight (Air Dry LBS.)
				DIAMETER (IN.)	SQ. IN.				
10938A	9/16/13	9/19/13	7	4.00	12.57	36400	2935		
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				

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

Evaluating Test Results

What do Standards Say

- Responsibilities
- Reporting
- Data evaluation
  - Precision
  - Rating test results

Technology in Practice

What, Why & How?

NRMCA

TIP 16 - Evaluating Strength Test Results

This TIP provides guidance on evaluating strength test results used for acceptance of concrete to determine whether the testing procedures and test results indicate deficiencies in testing practices.

WHAT is the Purpose of Strength Testing?

One of the primary specified requirements for concrete is the compressive strength. Strength tests are typically performed by a third-party testing agency. It is imperative that the procedures for making and testing strength specimens conform to the standards. Improper testing can result in acceptable concrete being rejected, considerable cost for evaluation, and delay project schedules.

Strength tests are primarily performed to evaluate the quality of concrete supplied by a ready mixed concrete producer when strength requirements are stated in orders or specifications for ready mixed concrete. The strength test results are evaluated for compliance with the strength acceptance criteria. For this purpose cylindrical test specimens are cast from representative samples of concrete as delivered. The standard size of cylindrical strength test specimens is either 4 x 8 in. or 6 x 12 in. (100 x 200 mm or 150 x 300 mm). Strength test specimens for acceptance of concrete are subjected to standard curing, as defined in ASTM C31.

A common concern is whether strength of standard-cured cylinders represent the strength of concrete in the structure. This is not the purpose of these strength tests. Concrete structural design procedures are based on strength of standard-cured specimens with appropriate safety factors for structural capacity. Field-cured cylinders are sometimes used to estimate the in-place strength of concrete in the structure for post tensioning, formwork removal, determining adequacy of curing and protection, and for other reasons during construction. This TIP does not address results of field-cured cylinders.

WHAT are the Requirements for Testing Agencies (Laboratories)?

A testing agency for quality assurance testing is hired by the owner of the structure or by the contractor when required in the contract. The testing agency should conform to the requirements of ASTM C1077, *Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation*. This standard establishes a quality system for testing agencies and requires that technicians performing tests maintain certification for the tests that they perform. Certification requirements apply to field and laboratory technicians. The laboratory should be third-party inspected periodically and participate in proficiency sample testing programs. In some cases testing agencies maintain accreditation that assures compliance with this standard. The entity contracting for testing services should ensure that the agency selected has the required credentials and that they will provide reliable testing services. ACI 311.6, *Specification for Ready Mixed Concrete Testing Services*, is a good basis for this contract.

WHAT are the Requirements for Strength Testing?

Concrete samples should be obtained in accordance with ASTM C172. The sample should be obtained after all adjustments are made to the load. The sample should not be obtained from the initial discharge. From a truck mixer, ASTM C172 requires obtaining the sample from at least two portions of the discharge stream from the middle portion of the load. The sample should be thoroughly mixed and tests should be started within specific time limits. Molding cylinders should start within 15 minutes of obtaining the sample. ASTM C94 and ACI 301

Testing variability (ACI 214R)

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

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

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

No. Specimens	d_2
2	1.128
3	1.693
4	2.059

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**

$$s_1 = \frac{207}{1.128} = 184 \text{ psi}$$

$$V_1 = \frac{184}{5837} \times 100 = 3.2\%$$

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

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 %

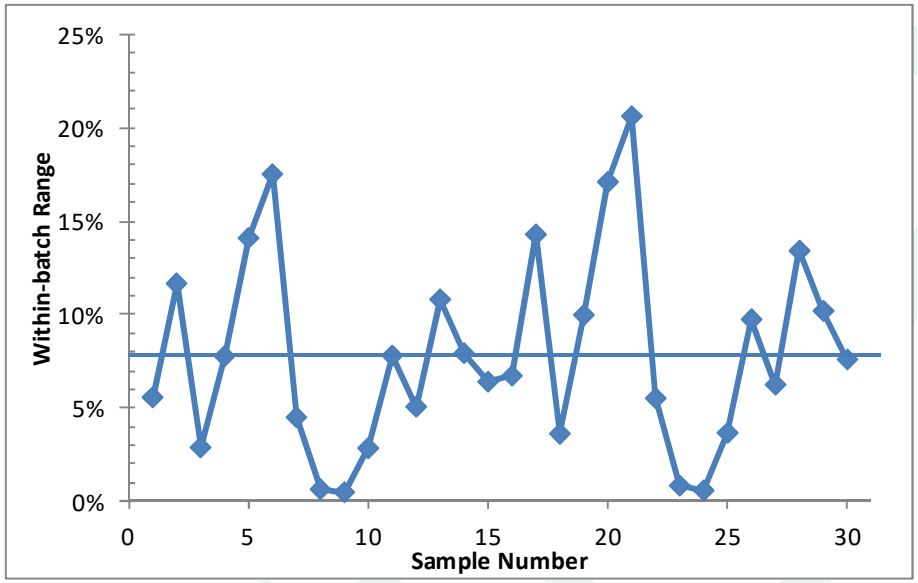
Example Calculation within-batch Range

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**	

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%

Control Charts to Monitor Testing



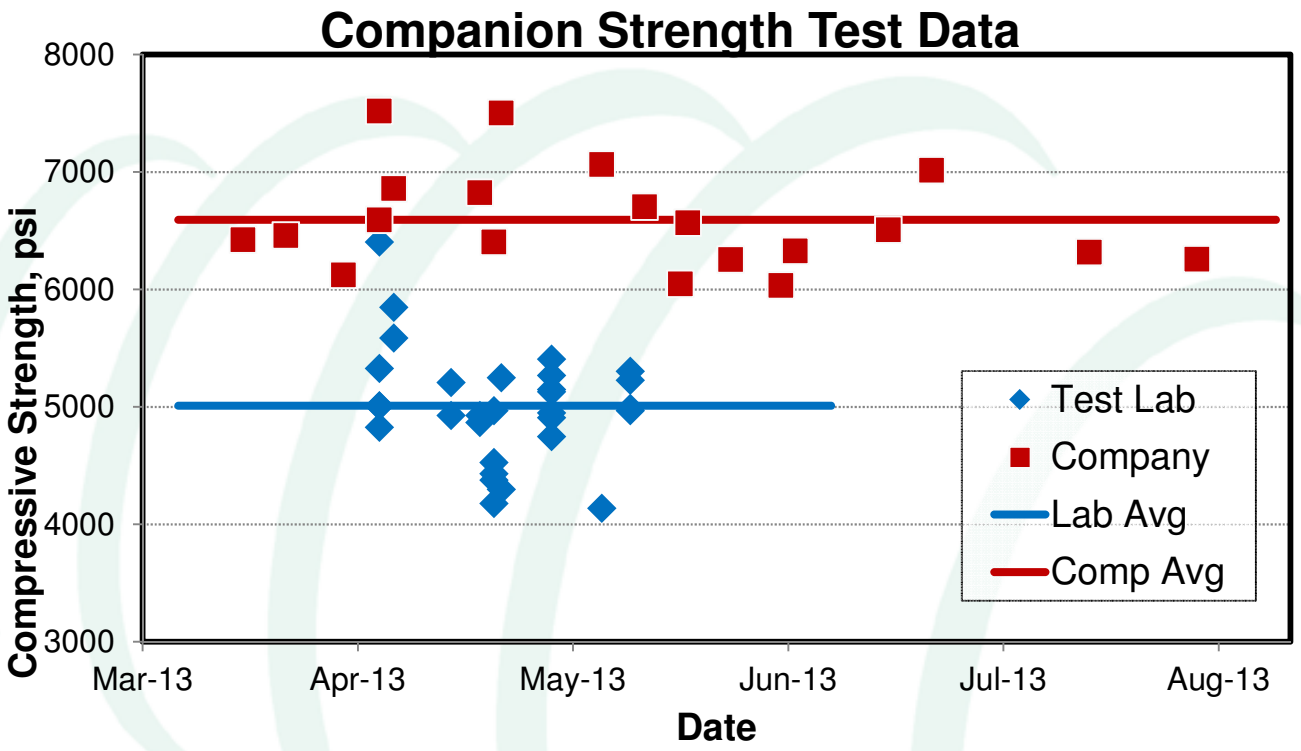
Evaluating Strength Data

- Poor job site curing will reduce strength
- But may not reflect within batch variation, V_1

ASTM C39 Multi-lab precision

- COV = 5%
- Acceptable difference between 2 = 14%
- Useful for companion testing
- Same sample tested by 2 labs at same age
  - Split samples (same wheelbarrow or same load)

Companion Tests



Company Data at plant; Lab data at jobsite

Specimens from the same sample are better to evaluate for multi-lab precision

Importance of Good Testing

Strength Standard Deviation (variability)

- Materials
- Production
- Testing

Components of variation are cumulative

Reducing Testing Variation helps isolate other causes of variation that the producer can control

What if you have Low Test Results?

NRMCA Pub 133

- Confirm likelihood of low strength
  - Verify testing accuracy
  - Non destructive tests
- Structural capacity reduced (Engineer decision)?
  - Core tests
  - Load tests
  - Corrective measures

Establish responsibility (monetary) for low strength evaluations (pre-construction)

Testing Concrete Cores

ACI 318 criteria:

- Average of 3 cores ≥ 0.85 f'_c
- Individual core ≥ 0.75 f'_c

Summary

- ACI Standards (Code and Specification)
  - Defines acceptance criteria for strength test results
  - Laboratories should conform to ASTM C1077
  - Technicians in the field and lab should be certified
  - Initial curing in accordance with ASTM C31
    - Max-min temps and curing method must be recorded (and reported)
  - Test reports should be distributed to all stakeholders
  - Criteria for core tests are defined
- Testing variation is high when
  - V_1>4% (from last 10 data points)
  - Range >8% (or C39) more than 1-in-20
- Responsibility for low strength evaluation should be defined

Thank You!


NRMCA
Philip Kresge
Vice President – Local Paving
pkresge@nrmca.org
215-779-7375
PAVE AHEAD
DURABLE. SUSTAINABLE. CONCRETE.