Performance-based Specifications – State of the Industry and Way Forward

Speaker Name:

Date:

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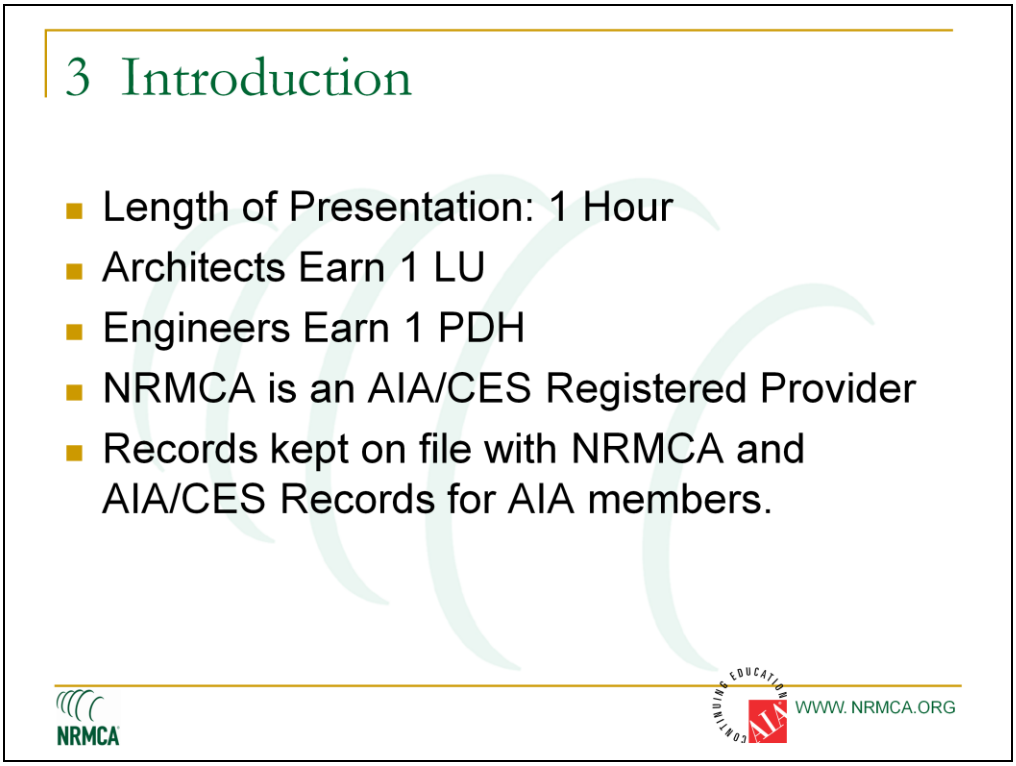

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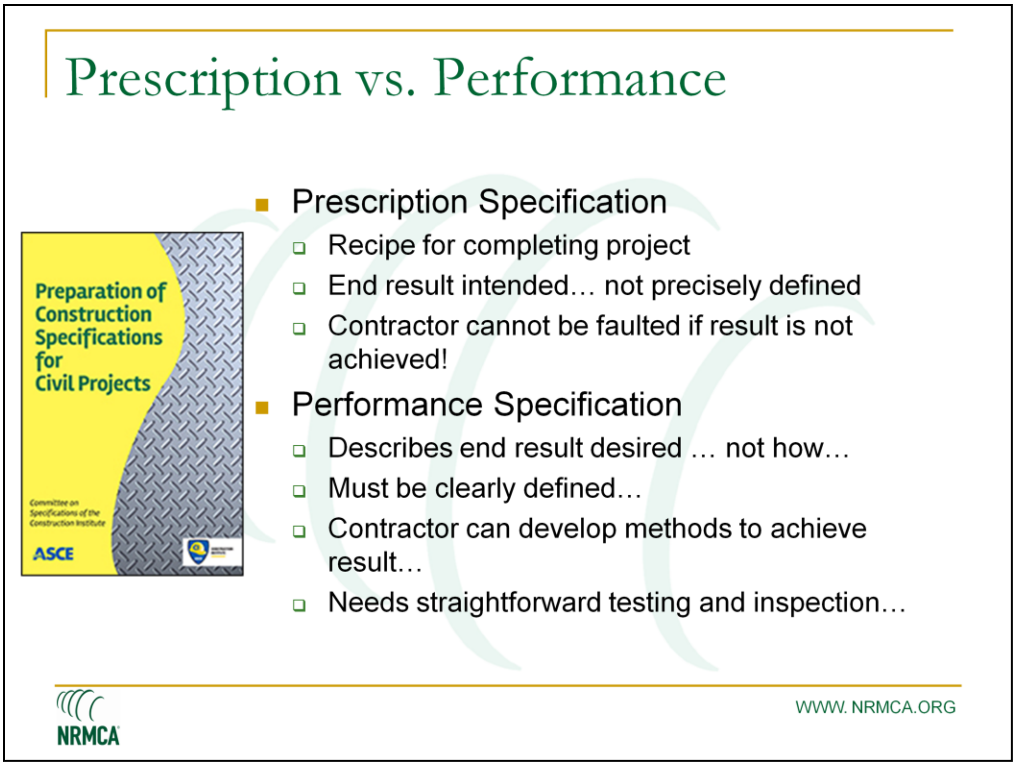
What is Prescription / Performance?

The acronym P2P stands for Prescriptive to Performance

This was initiated by the ready mixed concrete industry because of the preponderance of the prescriptive requirements in specification that prevented the optimized use of materials for mixtures and problems that often resulted with the assignment of responsibility to0 the concrete producer.

There has been considerable efforts to move towards the performance in industry standards and by public agencies.



This is an excerpt from a document by the American Society for Civil Engineers (ASCE) that summarizes the difference between the types of specifications.

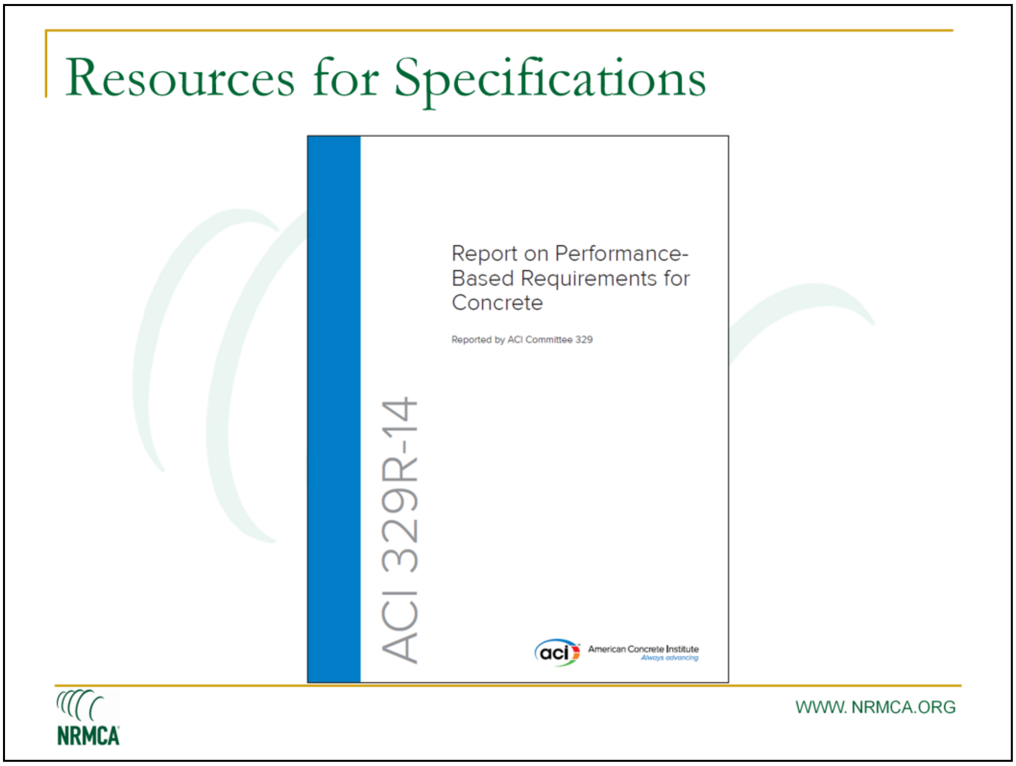
Prescriptive specifications provide detailed directions on means and methods while define an end result needed while assigning responsibility to the contractor to achieve these methods chosen by him. There is an implication of responsibility – with prescriptive specifications, the contractor cannot be held responsible if some intent is not achieved, However this is not always followed in practice, There is more responsibility to the contractor with a performance specification but the requirements need to tbe clearly defined.

There are different perceptions of what is meant by performance requirements. A concrete producer only has control on the characteristics of a concrete mixture as is required for workability and hardened properties. So this is an agreed upon definition as it applies to concrete mixtures. The performance indicator, like strength or some measure of durability, has to be defined. This property has to be measured by a standard test method with defined criteria for acceptability. The specification should not restrict the composition of the mixture.

The ultimate performance required by the owner is often implied – the structure should function for service conditions for an expected service life. It should be realized that this performance of a structure is impacted by the design, specification, materials used and construction. So there are different entities that control the ultimate needs of the owner. The evolution to performance specifications supports an important premise – that when one has the responsibility for some aspect of the project – they have the authority to develop means to achieve that.

For example, cracking in a concrete member cannot be controlled by the concrete mixture. It is impacted by the design of the member, cover over reinforcement, the characteristics of the mixture, the method of construction, curing and protection, and the service conditions consistent with the design.

These are a couple of documents developed by NRMCA that are resources for engineers to use as they choose to review their current specifications and update them. These documents use the MasterSpec format, most commonly used. The documents provide proposed specification clauses with detailed rationale (or notes to the engineer). The licensed version of the AIA masterspec is a bit dated compared to current ACI standards. The guide to improving specifications proposes language that is consistent with current versions of ACI 301 and ACI 318. It also indicates several instances where prescriptive requirements can be minimized. The second document proposes performance alternatives, again with proposed language and rationale.



Understanding the importance of moving to performance specifications, ACI formed a committee – ACI 329 to deal with this subject. This committee has a comprehensive guide (pictured) and is working on developing a guide performance specification.

NRMCA offers a number of resources for implementing performance based specs

The Credibility Issue

Quality Systems
Plants
People

Engineers are not comfortable to evolving to performance specs, because, sometimes due to past experience, they feel the industry cannot deliver

So the issue of credibility comes up. The engineer needs to be convinced that a particular company has the capability and expertise to deliver performance based concrete mixtures.

What will it take?

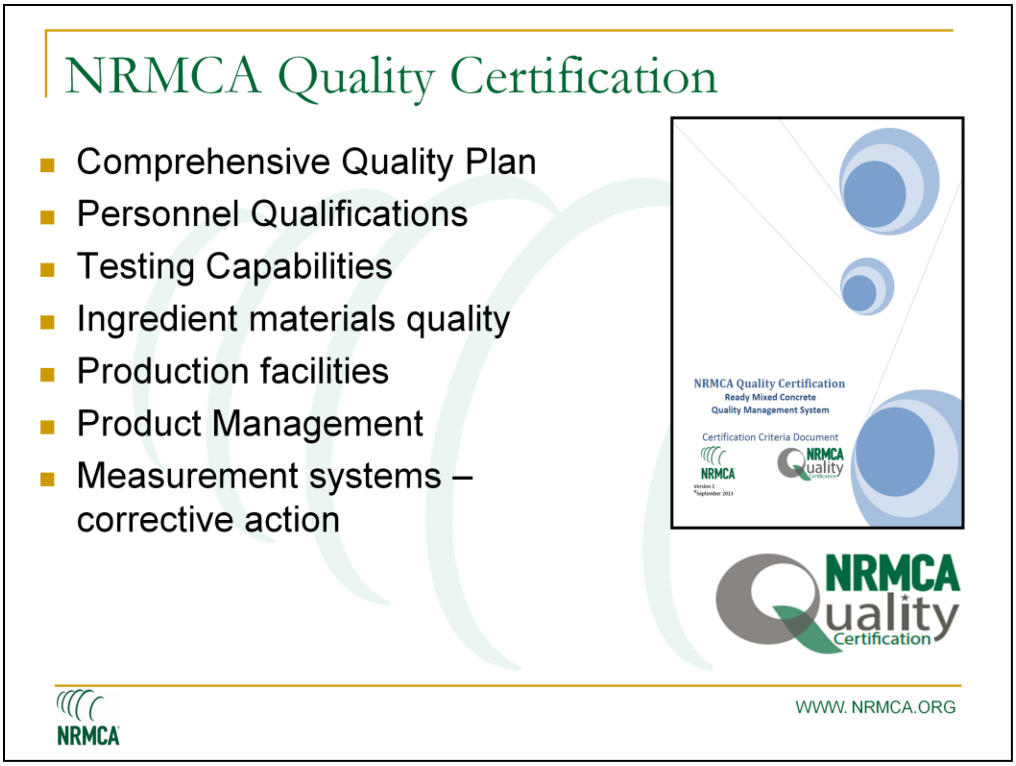
Credibility

- Company Reputation in local market
  - Knowledgeable personnel
  - Providing technical solutions
- Certifications (NRMCA, ACI…)
  - Plants and Trucks
  - Technical Personnel
    - NRMCA Concrete Technologist Levels 2, 3, 4
    - ACI Concrete Quality Technical Manager

Company credibility can be established by a local reputation of higher quality and delivering innovative solutions with knowledgeable people to consult with

Certifications can be used to establish credibility. These are some NRMCA certifications that are recognized.

ACI has recently developed a more comprehensive certification program that covers these aspects



NRMCA developed this quality certification program as a part of the P2P initiative to establish the “credibility” of a company so that they might be pre-qualified to bid and deliver on performance-based project. It is a comprehensive audit of the quality management system with minimum criteria established by the certification program. It is recognized that the level of expertise or the desire to move to performance

varies among concrete producers. Not all can deliver to a performance spec. This quality certification was developed as a part of the P2P initiative to establish the “credibility” of a company so that they might be pre-qualified to bid and deliver on performance-based project. It is a comprehensive audit of the quality management system with minimum criteria established by the certification program.

Benefits of Performance

The benefits of performance specifications need to be stated

Benefits of Performance

Stakeholders

- Owner
- Designer
- Contractor
- Producer
- …

- Quality
- Reliability
- Responsibility
- Optimize
- Innovation
- Schedule
- Cost
- Sustainability

Whats in it for me to all stakeholders

Some potential benefits

The benefits of performance specifications need to be stated

First Step - Minimize Prescriptive Requirements

- Limitations on source and composition of materials
- Minimum cement factors
- Limits on amounts of Supplementary Cementitious Matls
- Additional limitations on SCMs
- w/cm limits when durability doesn't apply
- Aggregate grading requirements
- Requirement to use potable water (C1602 alternate)
- Other limits to composition of mixtures
- Restrictive requirements for slump or air content
- Restrictions on concrete temperature outside standards

- Set requirements for concrete by application

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A relatively first easy step is to identify prescriptive requirements in specifications that can cause issues on a project. There are many that can be identified and reasons that these should be removed should be developed.

From reviewing several specifications, this is a list of common prescriptive requirements seen in project specs. In many cases the intended performance is not clear. These might exist because of historical reasons. SO the first step for an engineer would be to review their specification and minimize prescriptive requirements, such as these, especially if the intent is not clear.

Ultimately performance requirement – both fresh and hardened – for each type of concrete application can be developed. In many cases, the performance requirements do not need to be too complicated.

Industry Survey –
Most Onerous Prescriptive Requirements?

- How often are these seen?
- Does it restrict optimizing mixtures?
- Does it impact cost?
- Does it improve performance?
  - For the type of application

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In 2014 NRMCA sent out this list of prescriptive requirements to ready mixed industry members and asked them to rank these requirements considering these questions

Rating of Prescriptive Requirements

Prescriptive Requirements	Avg. Rating
Invoking maximum w/cm when not applicable	1.6
Invoking a minimum content for cementitious materials	1.9
Restriction on quantity of supplementary cementitious material (SCM)	2.0
Restrictions on characteristics of aggregates - grading etc.	2.1
Restriction on type and characteristics of SCM	2.3
Restriction on modifying approved mixtures	2.6
Restriction on type and source of aggregates	2.8
Requirement to use potable water	2.8
Restricting the use of a test record for submittals	2.9
Restriction on alkali content for cement	3.3
Prescriptive requirements for sustainability	3.3
Restrictions on type and source of cement	3.4
Restriction on use of recycled aggregates and mineral fillers	3.5
Restriction on type or brands of admixtures	3.8
Prohibiting cement conforming to ASTM C1157 and ASTM C595	4.3

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Result of survey. Most onerous specs have a rating of 1.0 and so the list is arranged from the most onerous. The top 5 most onerous are highlighted and were selected The most onerous requirements were assigned a rating of 1 with higher numbers being less so. This is a result of that ranking as an average of the survey response. This is a list of requirements arranged from the most onerous. It was decided to address the top 5 most onerous requirements that are highlighted

Quantify Frequency of Top 5

- Requested producers for actual specifications (past 12 months)
  - Private work
  - Application type
  - No residential
- NRMCA staff reviewed specifications
  - For just top 5 items

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Project specs were reviewed to see the frequency of just the top 5 selected items Members were requested for copies of project specifications from the most recent 12 months from private construction projects.

NRMCA reviewed these specifications to quantify the frequency at which the top 5 prescriptive specification requirements were used in these specs.

Review of Specifications

- 102 project specifications
- Types of Projects
  - 39% commercial buildings
  - 23% educational / public buildings
  - 18% public works
  - 14% environmental structures
  - 13% floors

NRMCA reviewed 102 specs from different regions of the US for a wide range of projects as listed. Specs from the same design firm or owner from different areas were avoided.

State of Prescription

Prescription	% of specs	Industry Standards
Restriction on SCM quantity	85%	Exposure F3
Max w/cm (when not applicable)	73%	ACI 318 – Durability
Minimum cementitious content	46%	ACI 301 – floors
Restriction on SCM type, characteristics	27%	None
Restriction on aggregate grading	25%	Suggested for floors
Overall average	**51%**	

If ACI standards are followed – these would not be an issue!

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This represents a summary of the review of these specification.

This is limited to the top 5 ranked prescriptive items and how often these were seen in the specifications reviewed.

To compare to our current industry standards, such as in ACI, the last column provides some context on where these requirements might exist.

For example, 85% of the specs placed a restriction on the quantity of supplementary cementitious material like fly ash or slag cement. In ACI standards, this restriction is only stated for concrete that will be exposed to cycles of freezing and thawing with the application of deicing salts – Exposure Class F3.

80% of the specs either have a max w/cm criterion or a minimum CM content criterion. Both of these requirements tend to lead to mixtures that are not optimized.

These items are the subject of the Specification in Practice topics and will be discussed in more detail in this presentation.

Prescriptive Specifications

A reality check

by Karthik H. Obla and Colin L. Lobo

About a decade ago, the National Ready Mixed Concrete Association (NRMCA) embarked on an effort to evolve specifications for concrete to be more performance-based. The title *P2P Initiative* was coined to reflect the effort's thrust from prescription to performance. The primary goals were (are) to improve the quality of concrete construction, facilitate the use of concrete mixtures optimized for the functional requirements of different applications, and support innovation and sustainable development. The basic principle of the effort is that specifications should capitalize on the expertise of the concrete producer and the contractor—in the former case, for development of concrete mixtures, and in the latter case, for construction means and methods. Prescriptive specifications that describe the details of concrete mixture parameters are constraints against achieving these objectives. With prescriptive specifications for example, the concrete producer is often held responsible if there is any problem with concrete on a project. This violates a basic principle that responsibility and authority should be congruent.

A working definition of performance requirements for concrete materials is that the concrete meets acceptance criteria when evaluated using standard test methods. The test methods and criteria should be pertinent to the intended performance of the concrete member in the anticipated service condition and for the expected service life. Design and construction also have significant impact on achieving these goals.

The *P2P Initiative* generated many products and outcomes:

- Investigators made a global review of the state of codes and specifications;
- Research documented improved performance with minimized-prescription guide specifications—both by minimizing prescription and suggesting performance alternatives;
- Discussion items were generated for pre-construction meetings between producers and contractors;
- A quality certification program was developed for ready mixed concrete producers; and
- An overview of the impact of prescriptive specifications on sustainability was assessed.

Many of these products are available on the NRMCA website, **www.nrmca.org/p2p**.

The ACI Strategic Development Council (SDC) recognized the importance of performance-based specifications toward progressing innovation in the concrete industry. In connection with that recognition, ACI established Innovative Task Group (ITG) 8 to develop a document discussing the topic. Subsequently, ACI formed a new committee, ACI Committee 329, Performance Criteria for Ready Mixed Concrete. That committee has published "Report on Performance-Based Requirements for Concrete (ACI 329R-14),"[1] which is based on the ITG 8 report, and it is currently working on a guide to writing a performance-based specification. ACI Committee 318, Structural Concrete Building Code, also developed durability exposure categories that established requirements for concrete as applicable to anticipated exposure in service (ACI 318-08[2]).

Prescriptive Requirements

Common restrictions

In 2014, NRMCA's Research Engineering and Standards (RES) committee decided to conduct a reality check on the impact of the *P2P Initiative*. The intent was to quantify the "state of prescription" in current specifications used for private work. Concrete producer members of NRMCA were provided a list of 15 prescriptive requirements commonly seen in specifications affecting concrete mixtures. They were asked to rate these prescriptive requirements in terms of the frequency that they were seen in specifications; the restrictive effects the requirements had on optimizing mixtures for performance and cost; and the effects the requirements had on performance for the type of placement and application. The list of prescriptive requirements is provided in Table 1, ranked relative to restrictive effect. It was decided to address the top five prescriptive provisions in the ranked list.

Frequency of use in specifications

In the next stage, the NRMCA's RES committee members provided copies of specifications from projects they had worked on in the previous 12 months. About 150 project

ACI Concrete International, August 2015

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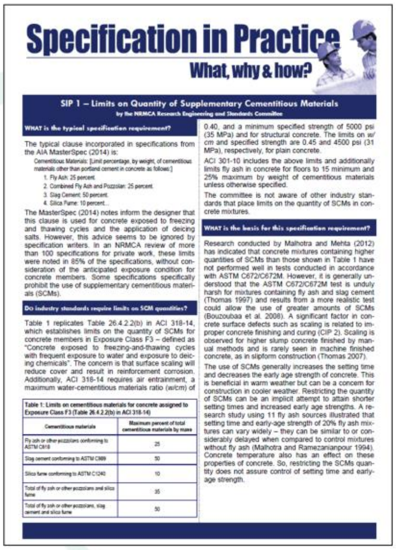
Survey findings published

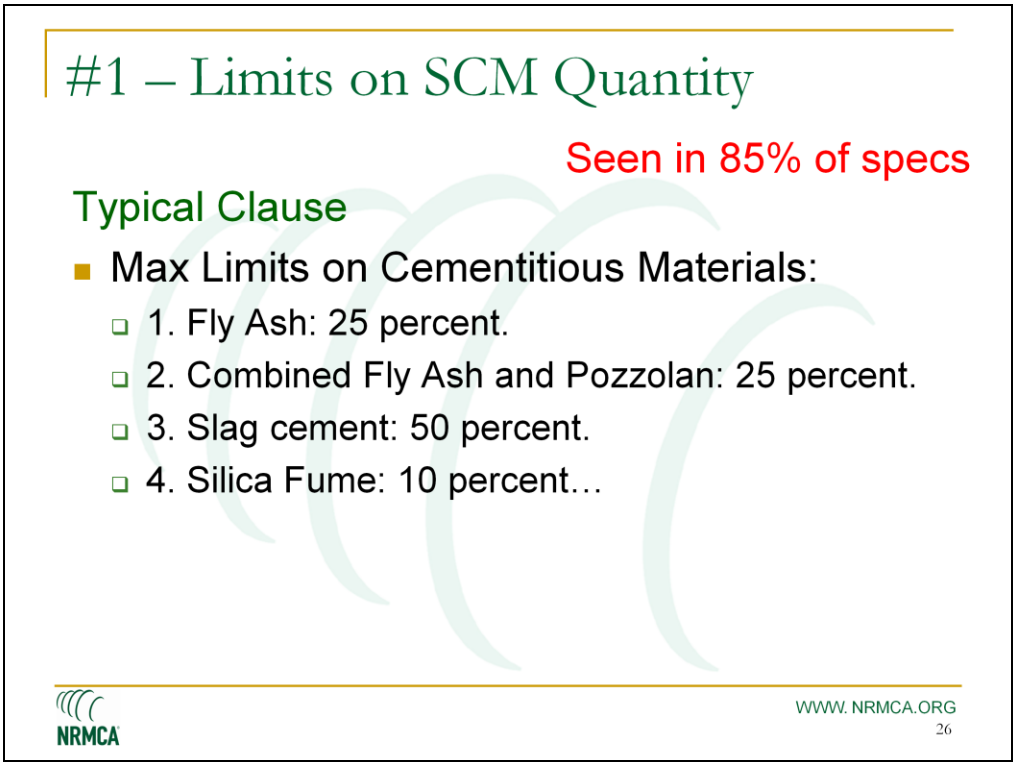
Specification in Practice

- State the prescriptive requirement
- Is this in industry standards?
- Basis for this? Real or perceived?
- Implications
- Suggested alternative
- Benefit of the alternative

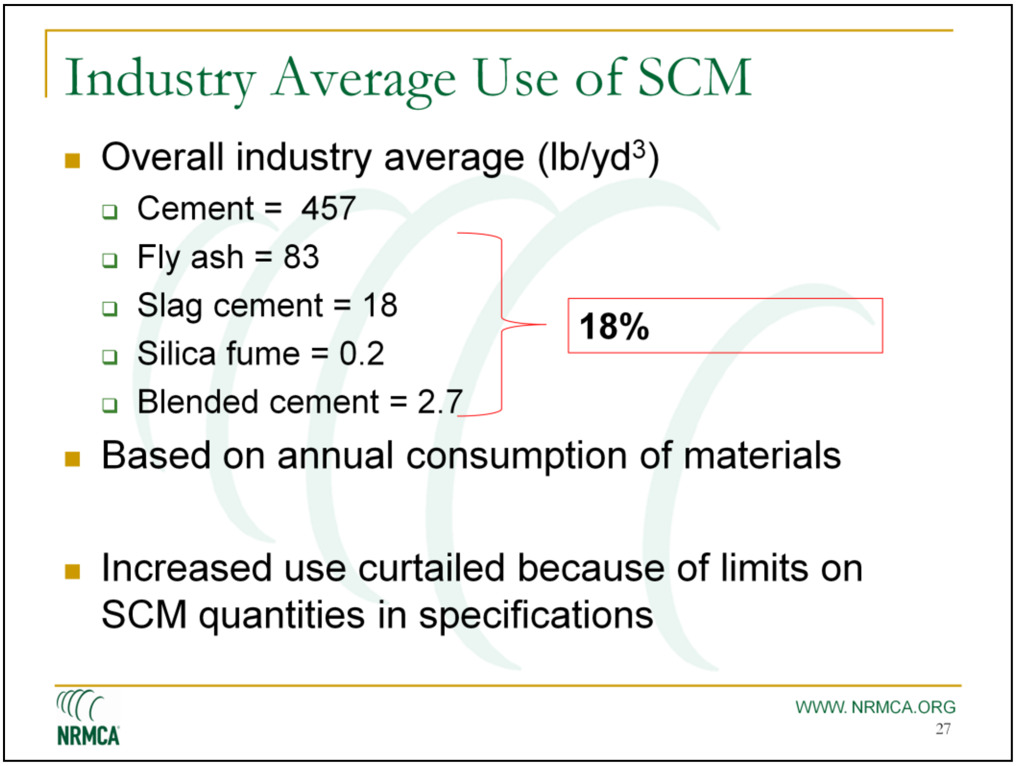
http://www.nrmca.org/p2p



Specification in Practice is a series of short (2 page) information sheets in an easy understandable “What, Why and How?” format. Each sheet addresses one prescriptive specification item listed earlier. The general discussion follows this sequence in the discussion. These SIPs are available from the NRMCA website at this link. The SIPs can be used by ready mixed producers and contractors in their discussion with specifying engineers.



The MasterSpec (2014) notes correctly inform the designer that this clause should only be retained for concrete members that will be exposed to freezing and thawing cycles and the application of deicing salts. However, this advice seems to be ignored by specification writers. In 85% of the specifications reviewed, there was a blanket restriction on the quantity of SCM in all concrete mixtures regardless of type of exposure to the elements.



An NRMCA industry survey quantified the use of cementitious materials in concrete mixtures. These numbers are total quantity of a material used divided by the reported volume of concrete produced in cubic yards. It is not the average quantiy of material in a typical mixture.

The quality of portland cement was 457 lb per yd^3 produced; blended cement was 2.7 lb/yd^3; fly ash was 83 lb/yd^3; slag cement was 18 lb/yd^3; silica fume was 0.2 lb/yd^3.

The SCMs in blended cement was also included in these estimates using some assumptions.

So on average the quantity of SCMs is at around 18% of the total CM in concrete mixtures. The survey also asked the producers on reasons that restricted the quantity of SCM used. Besides supply and technical reasons, the main reason was that the maximum limits stated in specification.

#1 – Limits on SCM Quantity

ACI 318

- Exposure Class F3–*Concrete exposed to freezing-and-thawing cycles with frequent exposure to water, deicing chemicals*

Cementitious Materials	Maximum Percent of Total Cementitious Materials by Mass
Fly ash or other pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans and silica fume	35
Total of fly ash or other pozzolans, slag cement and silica fume	50

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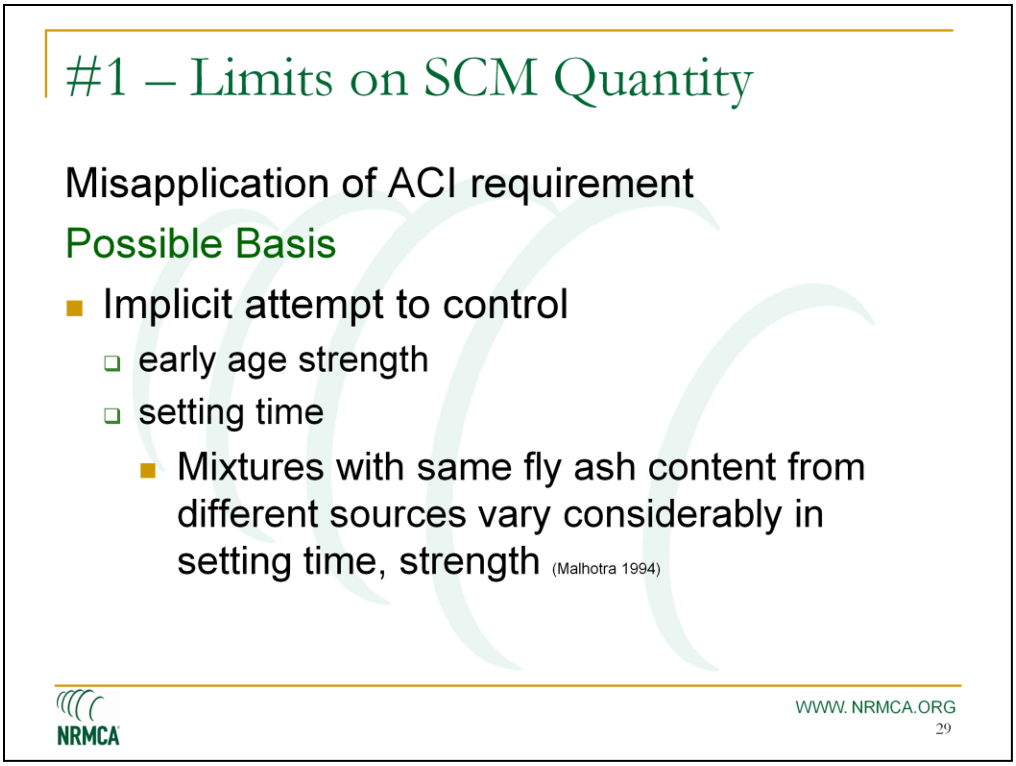
This is the only case where ACI 318 states this requirement. The concern in ACI 318 is that surface scaling will reduce cover and result in reinforcement corrosion. Additionally, ACI 318-14 requires air entrainment, a maximum water-cementitious materials ratio (*w/cm) of* 0.40, and a minimum specified strength of 5000 psi (35 MPa) and for structural concrete. The limits on *w/cm and specified strength are 0.45 and 4500 psi (31 MPa), respectively, for plain concrete.*

These limits on SCM are also stated in ACI 301 when this exposure class applies.



As stated, SCM limits are stated in specifications regardless of the anticipated exposure.

Possible reasons might be to ensure that there is some minimum content of portland cement or for technical reasons listed.

It should be recognized that SCMs are extremely useful to improve the strength and durability of concrete and these limits often prevent the ability to achieve these properties.

This is a misapplication of the ACI requirement.

The characteristics of SCMs vary considerably as do their impact on concrete properties. Prescriptive limits like this should not be used to control properties such as setting time or rate of strength gain. If these requirements are stated, it would be the responsibility of the concrete producer to develop the mixture to achieve those properties. Just controlling SCM quantities does not assure that you will get acceptable set time and early age strengths

#1 – Limits on SCM Quantity

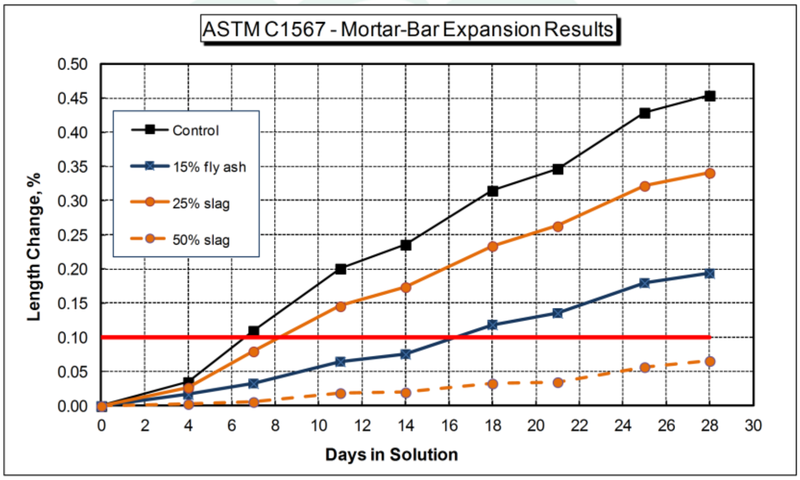
Restrictions Caused

- Quantity of SCM may be inadequate for later-age durability problems
  - ASR
  - Sulfate resistance
- Reduces ability to impact permeability
  - Corrosion of reinforcing steel
- Temperature control in mass concrete
- Later-age strength and durability is curtailed

This lists some of the problems caused by this limitation. These are discussed in the SIP.

#1 – Limits on SCM Quantity

What if more SCM is needed for durability?



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This is an example where the quantity of SCM needed to mitigate deleterious expansion due to alkali aggregate reaction is more than the limits stated. So in this case the limit works against ensuring concrete that will be durable.

#1 – Limits on SCM Quantity

Suggested Alternative

- State SCM limits only for members assigned to Exposure Class F3
- State early age strength requirements as applicable
- Setting time can be addressed between contractor and concrete producer

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Also in the SIP are suggested alternatives, - retain these limits if the assigned exposure class is F3. define the requirements separately if the intent is to control other concrete properties such as strength or setting time.

#1 – Limits on SCM Quantity

Benefits Due to the Suggested Alternatives

- Assured resistance to ASR and sulfate attack
  - With performance testing
- Desired set time times and early age strengths can be evaluated by testing
- Enhanced durability to chloride induced corrosion
- Continued improvement in later age properties
- Supports sustainability

These are some benefits by replacing this type of specification clause with the suggested alternatives.

The concrete mixture can be better designed for resistance to ASR and sulfate attack, as well as concrete mixtures with low permeability that will delay the onset of corrosion. Concrete with SCMs continue to improve properties with time.

This also supports green construction as SCMs are typically byproducts from other industrial processes.

#1 – Limits on SCM Quantity

Example of Innovation Possible

I-35W bridge, MN – Concrete International, Feb 2009

Member	psi	w/cm	CM, lb/yd^3	PC, %	FA, %	SL, %	SF, %
Super structure	6500	0.35	700	71	25	-	4
Piers	4000	0.45	575	15	18	67	-
Footings	5500	0.45	<600	40	18	42	-
Drilled Shafts	5000	0.38	<600	40	18	42	-

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This is an example of a specification that was performance based that did not have limits on the quantity of SCMs. More details are in the reference paper on the I-35W bridge in Minneapolis.

These type of mixtures are not possible with the limit on SCMs

Concrete mixtures with up to 85% SCMs by weight of cementitious materials have been used in structural members to achieve the performance requirements

#1 – Limits on SCM Quantity

I-35W bridge, MN – Concrete International, Feb 2009

Member	Performance Achieved
Super structure	Air entrained; PT; Strength > 8000 psi; RCP <250 Coulombs (90 d); shrinkage <0.04% (56d drying)
Piers	Conventional slump; thermal control for 3 d; strength > specified; RCP 500 coulombs (90 d)
Footings	Similar to drilled shaft mix; conventional slump; shrinkage = 0.04% (28d drying)
Drilled Shafts	Strength > 10,000 psi (cores); RCP 750 coulombs (28d) Low heat considerations (mass concrete); SCC mix

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This summarizes the superior performance achieved on the various parts of the structure with the different types of mixtures for which different performance requirements were defined.

Early age strength for PT, very low permeability, lower shrinkage and reduced heat of hydration in massive members.

#2 – Max w/cm (when not applicable)

Seen in 73% of specs

Typical Clause

- The maximum w/cm ratio for all concrete on this project shall be 0.XX
- Compressive strength for different members in the structure shall be as indicated on the drawings

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The second prescriptive item (SIP 2) deals with a specified maximum w/cm ratio regardless of whether it is required or not for durability. This is often stated as a blanket requirement for all mixtures of specifically stated by member type. The spec review quantified instances where there was no assignment of durability exposure class or indication that the member needed to have a low w/cm for durability reasons. Another issue is when the w/cm is not consistent with the strength required. Often a minimum cement content is additionally specified. All these together establish conflicts in a concrete specification.

#2 – Max w/cm (when not applicable)

ACI 318

- Max w/cm and min strength required with assigned durability exposure class (permeability)
- w/cm and strength stated as a pair - consistent

Exposure Class	Max w/cm	Min f'_c, psi
F1	0.55	3500
W1, S1	0.50	4000
F2, F3 (plain concrete), S2, S3	0.45	4500
F3 (structural), C2	0.40	5000

In ACI standards the limit on *w/cm is always stated with a specified compressive strength that is consistent with the level of strength anticipated at that w/cm.*

In ACI 318 – max w/cm and a companion specified strength is stated based on an assignment of a durability exposure class. Any member that is not asigned one of these exposure classes, does not need to have a max w/cm limit specified. ACI 301 incorporates the ACI 318-08 requirements in the reference specification.

Exterior work, such as parking areas, which are not covered by ACI 318, have similar requirements for *w/cm and strength*

#2 – Max w/cm (when not applicable)

CONCRETE STRENGTH AND DURABILITY REQUIREMENTS

LOC.	STRUCTURAL MEMBERS	(1) EXPOSURE CLASS	(3) MINIMUM 28 DAY COMPRESSIVE STRENGTH (PSI)	MAXIMUM WATER/CEMENT RATIO (PERCENT)	(4) RECOMMENDED MINIMUM SLUMP (INCHES)
		FOOTINGS			
BELOW GRADE	PLACED COMPLETELY BELOW REQUIRED FROST DEPTH	C1 (2)	3000	0.50	3
BELOW GRADE	WITH BOTTOM OF FOOTING POURED AT REQUIRED FROST DEPTH	F2	3000	0.45	3
		FOUNDATION WALLS			
BELOW GRADE	PROTECTED FULL HEIGHT,	CO (2)	3000	0.50	3
BELOW GRADE	PARTIALLY EXPOSED AT GRADE, PROTECTED FROM MOISTURE	F0 (2)	3000	0.50	3
		SLABS ON GRADE			
AT GRADE	INTERIOR HEATED, NOT IN DIRECT CONTACT WITH SOIL	C0 (2)	3000	0.50	3
AT GRADE	INTERIOR CONCRETE EXPOSED TO OCCASIONAL MOISTURE AND DE-ICING CHEMICALS	C2	3500	0.40	3
AT GRADE	INTERIOR UN-HEATED, NOT IN DIRECT CONTACT WITH SOIL	F0 (2)	3500	0.50	3
AT GRADE	EXTERIOR, NOT IN DIRECT CONTACT WITH SOIL, NOT EXPOSED TO DE-ICING CHEMICALS	F1	4500	0.45	3
AT GRADE	EXTERIOR, IN DIRECT CONTACT WITH SOIL, NOT EXPOSED TO DE-ICING CHEMICALS	F2	4500	0.45	3
AT GRADE	EXTERIOR, IN DIRECT CONTACT WITH SOIL, EXPOSED TO DE-ICING CHEMICALS	F3/C2	5000	0.40	3
		ELEVATED SLABS, BEAMS AND GIRDERS			
ABOVE GRADE	CONCRETE COLUMNS	F0 (2)	5000	0.40	4
		F1	5000	0.40	4
ABOVE GRADE	ELEVATED SLABS, BEAMS AND GIRDERS	F0 (2)	6000	0.40	4
		F1	6000	0.40	4
		C2 (2)	6000	0.40	4

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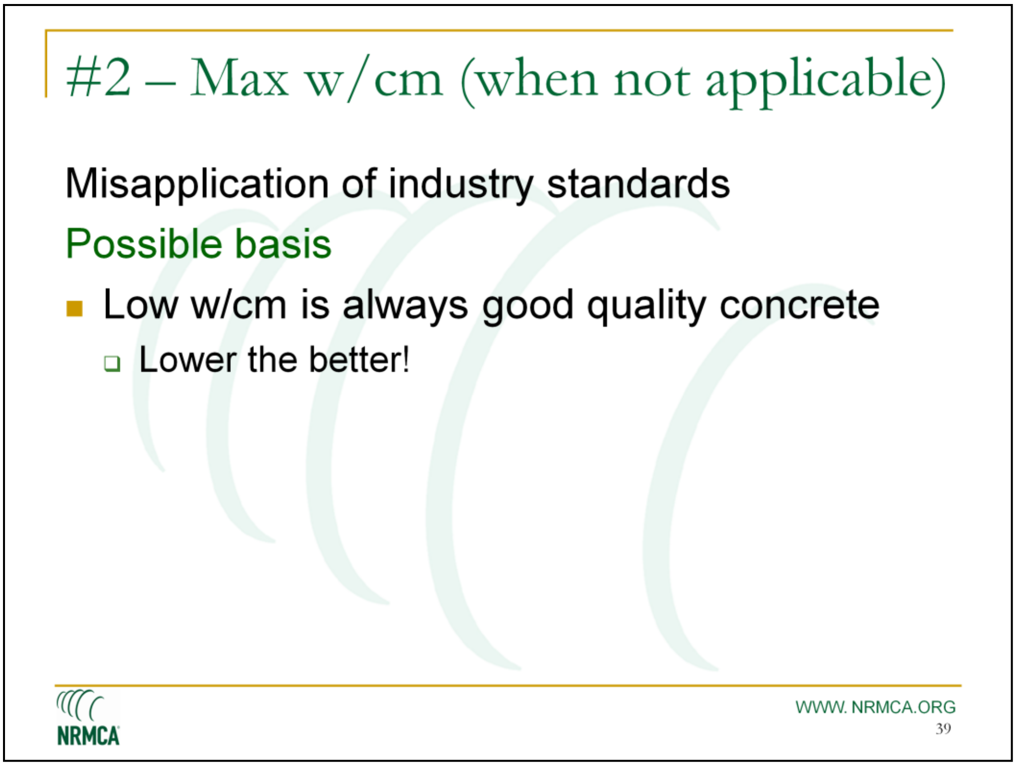
This is an example of an actual project specification. While there is an attempt to assign exposure classes to different members, the w/cm and strength requirements are not consistent with ACI 318. Concrete with C0, F0 exposures (where such durability issues are not a concern) are specified with w/cm of 0.50 and compressive strength of 3000 psi. Clearly conflicting specs.



The w/cm is frequently specified even for concrete that is not exposed such as in the past example. The thinking is that low w/cm is always good

#2 – Max w/cm (when not applicable)

No. 8 aggregate non-air topping mix (interior)

- w/cm = 0.40; 4000 psi
- Mixture required 290 lb/yd^3 of water
- Total CM = 725 lb/yd^3

Mixture very susceptible to cracking

Application did not require 0.40 restriction

- With w/cm=0.50, Total CM=580 lb/yd^3
- Cracking would be considerably reduced

The above example shows that low w/cm is not always good. It can lead to mixes that are not optimized, not sustainable and actually attain a poorer performance.

Avg. Strength vs. w/cm

w/cm	Non air	Air
0.40	6900	6200
0.45	6000	5400
0.50	5200	4700
0.55	4500	4000

Source: NRMCA Survey (2014)

- Design for 3500 psi
- If w/c is specified (0.40)
- Actual strength vs. Design strength
- Strength acceptance criteria will not assure required concrete is being furnished

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The Table lists the typical strengths attained by producers as reported in a NRMCA survey of the industry. The average strength achieved at different w/cm are summarized for air-entrained and non air-entrained concrete mixtures.

A designer might use a strength of 3500 psi when designing a member but if durability applies, the specified strength should be consistent with the w/cm. This is because strength is used as a basis to verify that the requirements of the concrete have been met.

A requirement of 0.40 / 3500 psi will yield concrete with a strength significantly greater than the specified strength and the strength acceptance criteria do not work appropriately. Concrete test results can be as low as 3000 psi and this does not assure that the mixture was at a w/cm of 0.40. So it is important that there is no mismatch between specified w/cm and strength.

#2 – Max w/cm (when not applicable)

Restrictions Caused

- Workability can be adversely impacted
- If specified strength is low, including w/cm
  - Increases strength – acceptance criteria do not work
  - Increases paste volume – and associated problems
  - Concrete not optimized for member as designed
- Specifying w/cm less than 0.40 can impact workability, and increase potential for cracking

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These are issues that can occur on a problem when w/cm is inappropriately specified. These are discussed in the SIP.

#2 – Max w/cm (when not applicable)

Suggested Alternative

- Specify w/cm and companion strength when applicable to exposure conditions (ACI 318)
  - Do not specify w/cm when not applicable – such as for interior members
- Avoid disconnect between strength and w/cm
  - Eg. 3000 psi and 0.40
- Avoid specifying w/cm considerably below 0.40
  - Consider alternative performance based tests

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These are alternatives suggested –

Only specify w/cm when required for durability

Make sure the specified strength and w/cm are consistent so that quality assurance is possible. If durability requires a higher strength, use that higher strength in the design of the member.

Avoid specifying w/cm that is less than 0.40 as its not needed for most applications and causes other issues with construction. Performance based tests that measure permeability can be used as an alternate.

#2 – Max w/cm (when not applicable)

Benefits Due to the Suggested Alternative

- Concrete applicable and optimized to specific application
- Reduces potential constructability problems when a low w/cm is specified
- Ensures w/cm requirements can be enforced by the strength acceptance criteria
- Improved sustainability

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44

These are some benefits with the proposed alternatives

Performance Alternative

Bridge decks, marine structures, parking garages

- Low permeability concrete
- Reduced potential for cracking

Prescription	Performance Alternative
Low w/cm	Strength and concomitant w/cm
Minimum CM content	ASTM C1202–1500 coulombs or Resistivity (AASHTO T 358-15) (standard cure 56 days OR accelerated cure 28 days)
SCM types/dosages	ASTM C157 - 0.05% (7 day cure; 28 days drying)

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Specify requirements for concrete by application – as suggested with these alternatives

WA DOT Bridge Deck Spec

(source: WA-RD 845.1 June 2015)

	Original Class 4000D	Revised Class 4000D
Minimum 28-day Compressive Strength	4,000 psi	4,000 psi
Cement	Type I or II Portland	Type I or II Portland
Cementitious Content	735 lbs minimum (660 lbs cement & 75 lbs fly ash)	No set limits
Fly Ash	Required	Optional
Nominal Max. Aggregate Size	1-inch	1½-inch
Water Reducing Admixture	Required	Optional
Air Content	4.5% to 7.5%	4.5% to 7.5%
Freeze-Thaw Durability Test (instead of above air content requirement)	Not an Option	3.0% min. air content 90% minimum durability factor after 300 cycles per AASHTO T 161
Permeability	No Requirement	Less than 2000 coulombs at 56 days per AASHTO T 277
Length Change ("shrinkage")	No Requirement	Less than 0.032% (320 microstrain) at 28 days per AASHTO T 160
Scaling	No Requirement	Visual rating ≤ 2 after 50 cycles per ASTM C 672
Modulus of Elasticity	No Requirement	Measured and Submitted per ASTM C 469
Density	No Requirement	Measured and Submitted per ASTM C 138

This is an example of an evolution from prescription to performance for bridge structures by the WA DOT. A survey of bridges built with this perf spec after 2 years showed that it had fewer cracks than those built with prescriptive approach

#3 – Min cementitious content

Seen in 46% of specs

Typical Clause

- Concrete for XXX members shall comply with the following:
  - Minimum cementitious content of xxx lb/yd^3
  - …

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The third most common prescriptive requirement observed in reviewing specifications is a requirement for minimum content of cementitious material, sometimes stated as minimum content of cement

#3 – Min cementitious content

Industry Standards

- No requirement in ACI 318
- Some cases in ACI 350 (Environmental Structures)
- ACI 301 for floors – finish-ability

Nominal maximum size of aggregate, in.	Minimum cementitious material content, lb/yd^3
1-1/2	470
1	520
3/4	540
3/8	610

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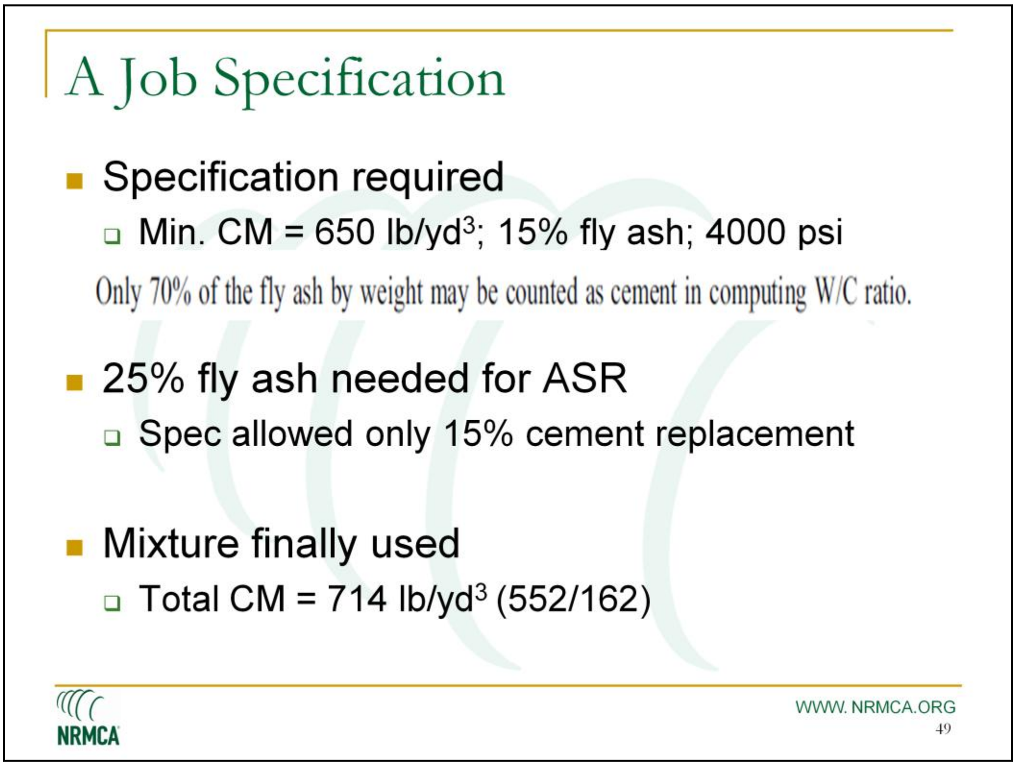
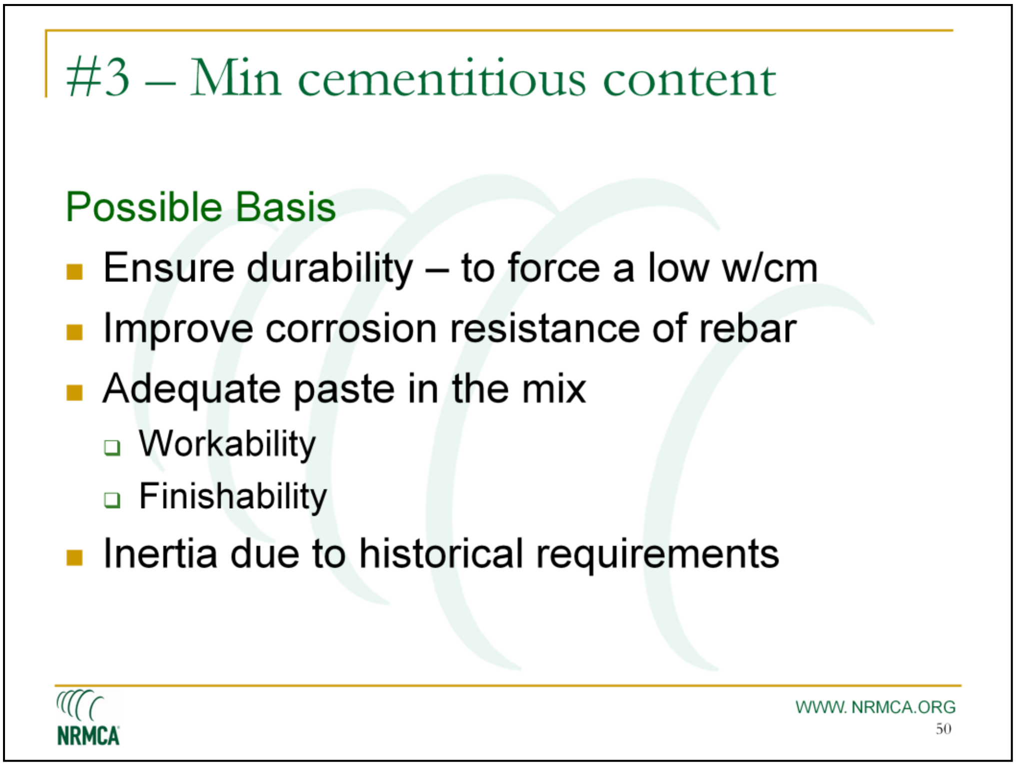
There are no restrictions on minimum CM content in ACI standards. There is a requirement in ACI 350 for environmental structures.

ACI 301 states a minimum cement content in one application - for interior floors only. The purpose is to ensure adequate paste for hard trowelled finishes. These limits are considerably lower than that seen in some specifications. A test slab placement is permitted as an alternative to the minimum cementitious content requirement.



This is an actual project spec. The min CM content and SCM dosage requirement required that a very high CM content had to be used.

This type of specification can cause problems with cracking due to temperature differentials and drying shrinkage due to the higher paste volume. Also the limits on SCM were not adequate to minimize ASR.

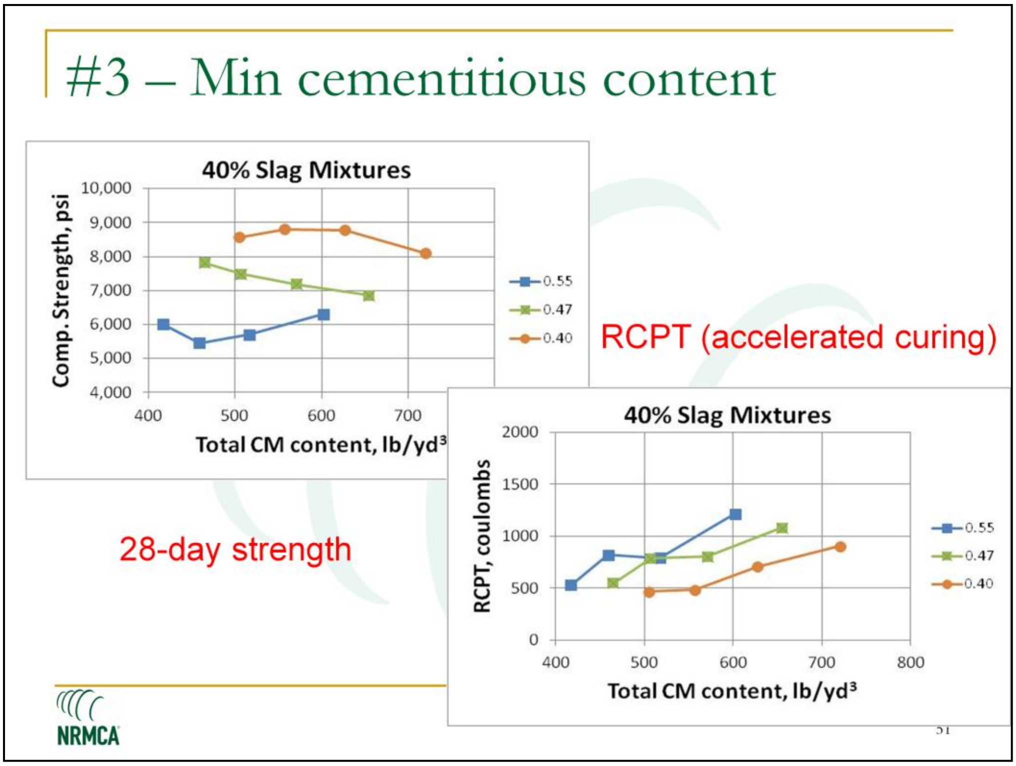


Some of the possible reasons for specifying a low w/cm are

It improves durability by providing assurance that a low water-cementitious materials ratio (*w/cm) is attained, even if good control* of the mixing water content is not exercised.

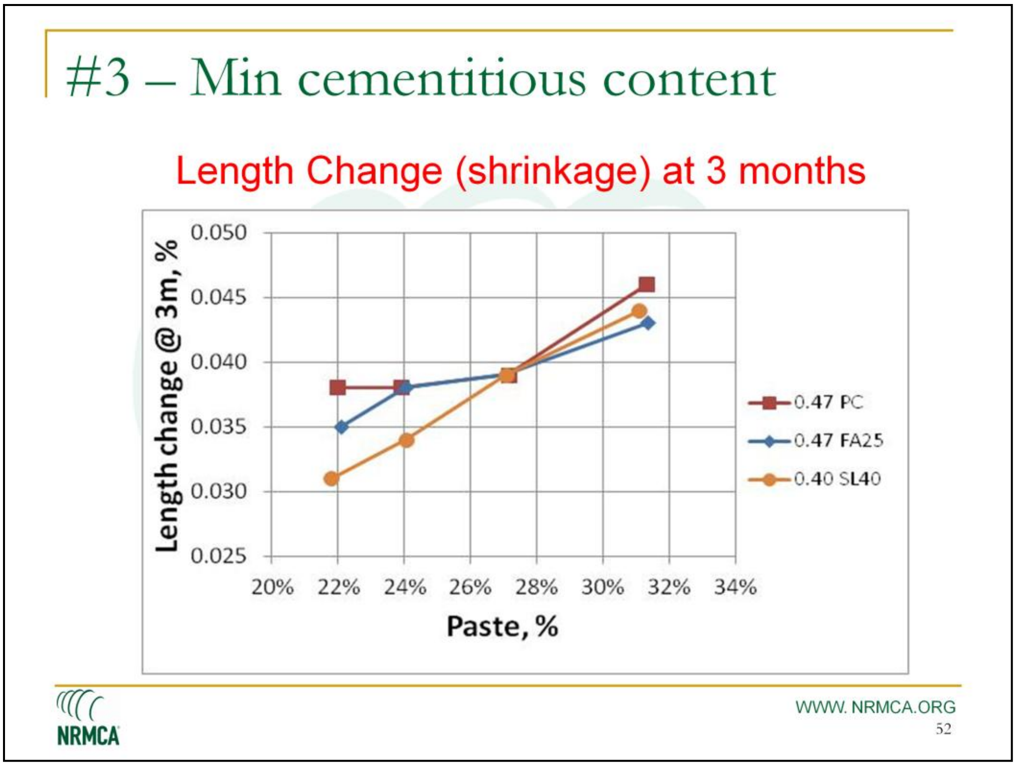
Enough cement content will ensure a high pH of the pore solution that can ensure corrosion resistance of the rebar

For the most part, min cementitious requirements is a historical remnant in many specs where there is inertia to delete this requirement

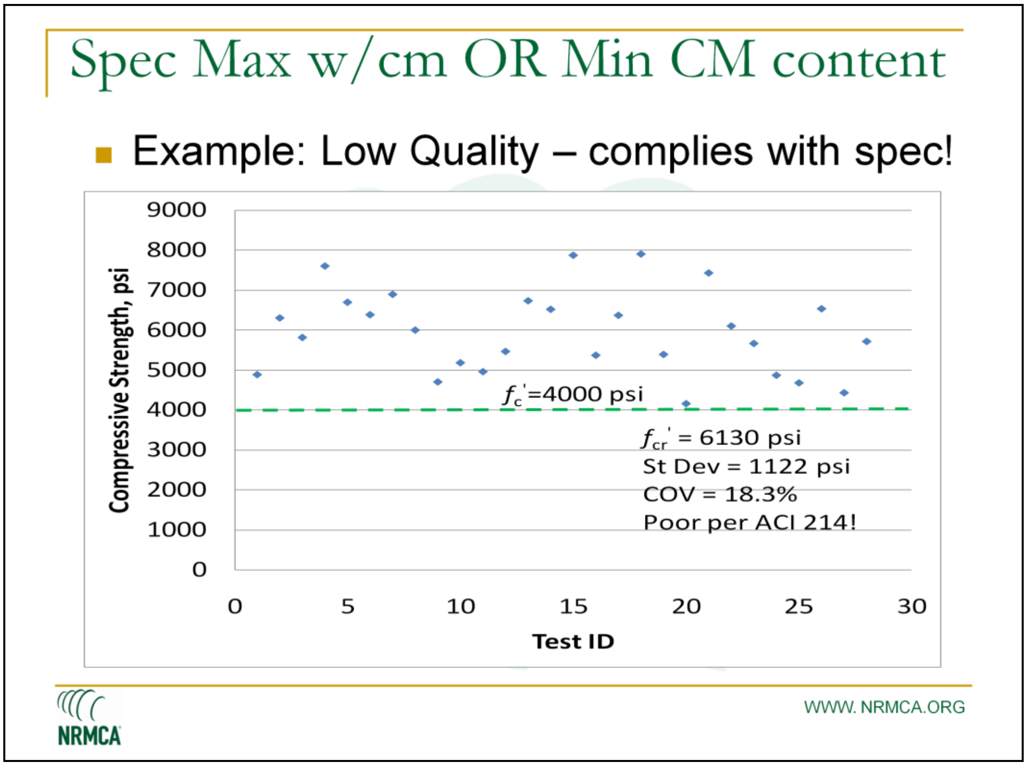


This summarizes results from an NRMCA study that developed mixtures at different cement contents at the same w/cm.

Higher CM mixes had same strength but higher RCPT (permeability) and shrinkage. The higher permeability and shrinkage is a consequence of the higher paste volume



These data from the same study show the increased shrinkage – same w/cm but increasing paste volume.



Another potential consequence is that the concrete may have a high variability as illustrated in this set of data – as there is no incentive to achieve better control.

In this example the Spec had 658 lbs CM content requirement, so strengths attained averaged 6000 psi as opposed to a specified level of only 4000 psi. There was no incentive for the producer to control strength variation since strengths attained were much higher than specified strength. This resulted in high concrete variability which is indicative of poor quality control practices. Combining a low w/cm and a low strength requirement will lead to same outcome. High variability concrete is not in the best interest of anyone.

Optimized Prescriptive Mix?

- Good materials engineer can optimize mix
- Specifying this is difficult
- Prescriptive Specs are then over-designed
  - A spec with minimum CM = 600 lb/yd^3, w/cm = 0.45 will obtain 3000 psi even with substandard materials, production, testing
- Penalizes better performers

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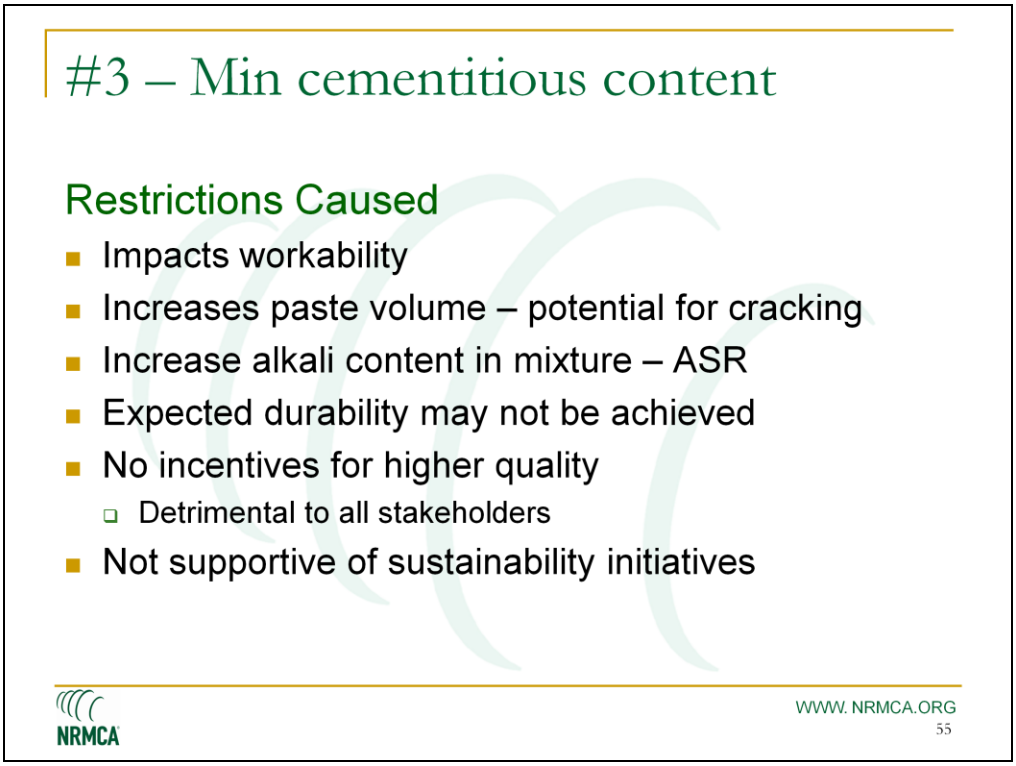
Prescriptive spec caters for the lowest common denominator. In its attempt to keep the worst out it ends up penalizing the better performers. Prescriptive specs are often overkill for intended performance. Perf specs on the other hand provides incentives to the best performers to achieve mixtures that are optimized for the intended performance.



It is estimated that producers use on average 100 lb more CM than required for performance

These are the problems caused by min cement content in specifications

#3 – Min cementitious content

Suggested Alternative

- Do not specify min CM content
- Use ACI durability requirements when applicable
  - If intent is for low w/cm, specify appropriate f'_c
- Specify the intended performance
  - No technical basis for min CM if this is done
- ACI 301 permits test slab placement (mock-up) in lieu of CM limit

These are suggested alternatives – clearly removing this requirement and a more thorough evaluation of the intended performance and specifying those requirements would improve the specification. The only thing that a specified minimum cement content assures is that the mixture contains that quantity at a minimum.

#3 – Min cementitious content

Benefits Due to the Suggested Alternative

- Concrete performance can be verified, when specified including workability
- Incentivizes quality focus
- Knowledgeable producer can better optimize mixture for specified performance
- Can reduce potential cracking, ASR
- Supports sustainability

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These are some benefits listed that result from the suggested alternatives and are discussed in more detail in SIP 3.

#4 – SCM Type / Characteristics

Seen in 27% of specs

Typical Clauses

- Class C fly ash is not permitted
- The CaO content of fly ash shall not exceed XX%
- Slag Cement is not permitted
- The Loss on Ignition (LOI) of fly ash shall not exceed X.X% (more restrictive than ASTM C618)
- Fly ash fineness - The percent retained on the 45 µm (No. 325) sieve shall not exceed XX% (more restrictive than ASTM C618)
- The [available] alkali content of fly ash shall not exceed X.X%

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The fourth most restrictive prescriptive requirement observed in the review was additional limits on the characteristics of the SCMs – beyond what the specifications require.

There are likely technical reasons for these but there is no assurance that these requirements will achieve the intended performance.

#4 – SCM Type / Characteristics

Industry Standards

- ACI 318 permits fly ash conforming to ASTM C618
  - No additional restrictions
- ASTM C618 requirements

Requirement	Class F	Class C
(SiO_2 + Al_2O_3 + Fe_2O_3), min %	70.0	50.0
LOI, max %	6.0*	6.0
Fineness, retained on 45 µm (No. 325) sieve, max %	34	34

Additional requirements and reporting apply

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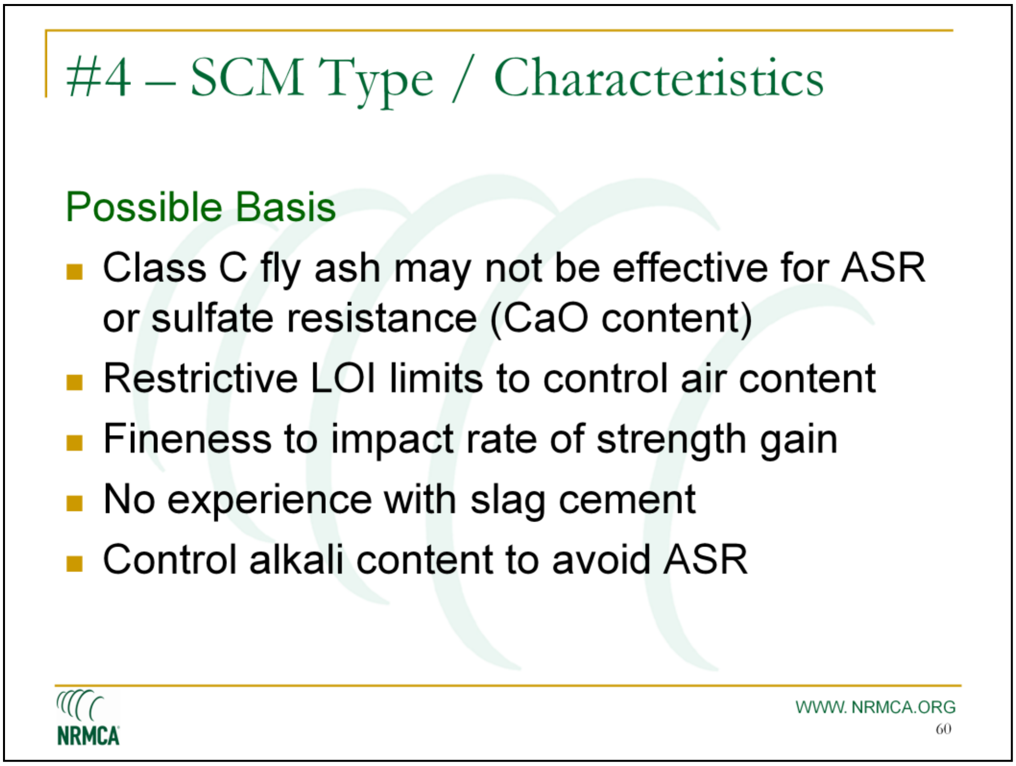
There are no additional limits on the characteristics of SCMs in ACI standards.

ACI 318 just references the applicable specifications with no additional restrictions.

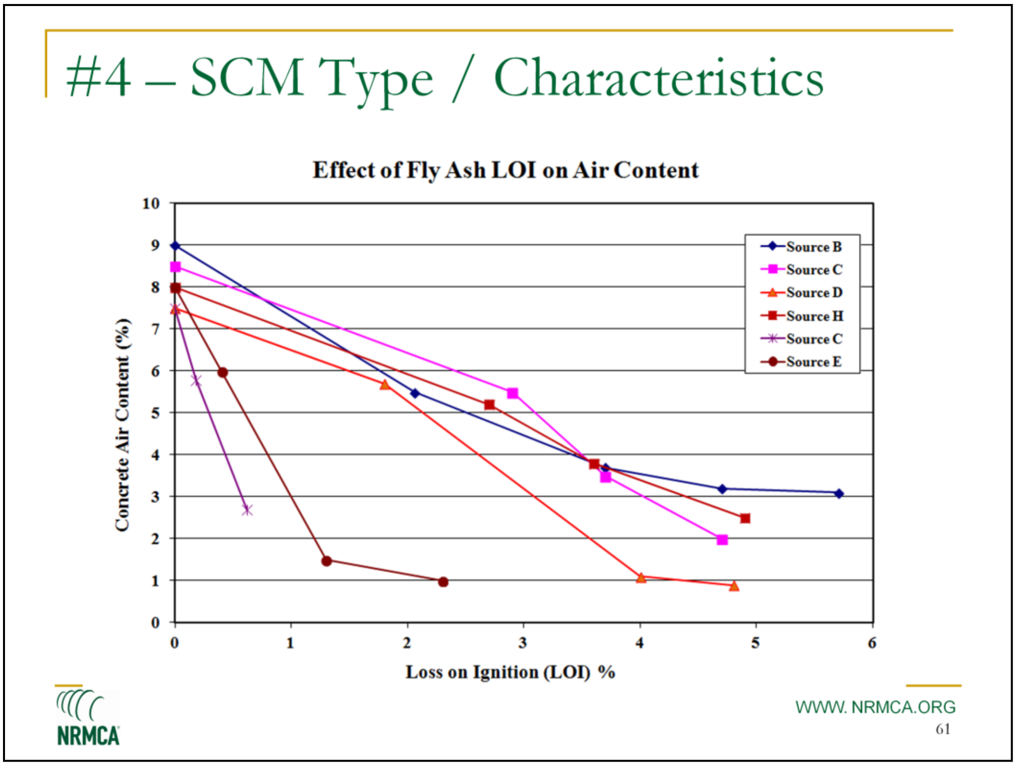
ASTM C618 classifies fly ash by these requirements and additionally, includes limits on sulfur trioxide (SO3), moisture content, soundness, strength activity index, water requirement, and uniformity requirements for material from a single source. Optional requirements, when specifically requested, are also covered in the specification. There are no limits on alkali content of fly ash, but the supplier may report this, expressed as equivalent sodium oxide (Na2O)



Class C - However, specifying Class F fly ash does not ensure that the concrete will be resistant to ASR and sulfate attack. A methodical approach to addressing ASR is covered in ASTM C1778. Sulfate resistance of concrete is addressed in ACI 318-14 and the effect of fly ash in improving sulfate resistance is covered in the optional requirements of ASTM C618

Fineness - Research on this aspect indicates that when fineness of fly ash from the same source varied substantially (between 15% and 30%) over a period of time, there was no significant difference in strength of mortar cubes. Besides fineness, fly ash reactivity is impacted by factors such as chemical and physical composition, morphology, and the portland cement with which it is used (ACI 232.2R-03). The concrete producer is responsible for supplying concrete mixtures that meet the specified strength requirements.

A limit on available alkalis was removed from ASTM C618 in the 1990s based on work that indicated that the available alkalis in fly ash were not a good indicator when considering the use of fly ash in concrete containing potentially reactive aggregate (Smith 1987)



Restricting LOI doesn't ensure air entrainment problems go away. Low LOI ash sources in above chart were more sensitive to air entrainment. Imposing a lower LOI limit on fly ash does not ensure better control of the air content in air-entrained concrete. The concrete producer is responsible for achieving the specified air content in concrete.

#4 – SCM Type / Characteristics

Restrictions Caused

- Available fly ash with performance history and service records cannot be used
- Fly ash may need to be shipped in from long distances
- False sense of security of achieving intended performance

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These are some problems caused by these specification requirements – the producer is often forced to use alternative sources that they do not have experience with. These requirements establish a false sense of security that the intended performance will be achieved.

#4 – SCM Type / Characteristics

Suggested Alternative

- Consider performance based evaluation of fly ash for ASR and sulfate resistance
  - ASR – use ASTM C1567
    - < 0.1% at 16 days (ASTM C1778)
  - Sulfate resistance – ASTM C1012
    - Moderate < 0.10% at 6 m
    - Severe < 0.10 at 12 m
    - Very Severe < 0.10% at 18m

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These are suggested alternatives depending on the intended performance.

#4 – SCM Type / Characteristics

Suggested Alternative

- Do not include more restrictive requirements on fly ash, such as LOI and fineness, than those in ASTM C618
  - Market will control use of unacceptable product

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The fly ash supplier and concrete producer are responsible for monitoring the quality and uniformity of fly ash to ensure that the specified air content and strength are achieved

#4 – SCM Type / Characteristics

Benefits Due to the Suggested Alternative

- Assurance of improved durability when specified
  - ASR
  - Sulfate Resistance
- Restrictions do not assure intended performance
- Improved sustainability and lower cost
  - Permits use of local materials with service records and producer experience

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Mitigation of ASR has been attained by increasing the percentage of Class C fly ash, or by using Class C fly ash with other supplementary cementitious materials (SCMs) and lithium based admixtures (Shehata and Thomas 2000). Sulfate resistance has been attained with ternary blends of Class C fly ash and silica fume (Shashiprakash and Thomas 2001). The alternative performance requirements can make it feasible to use locally available Class C fly ash sources that results in cost-effective concrete mixtures, and supports sustainability initiatives.

#5 – Aggregate Grading Limits

Typical Clauses

Seen in 25% of specs

- Grading of the combined aggregate shall conform to the % retained on individual sieves between 8 and 18% (or 6 and 22%), with the exception of the smaller and higher sieves.
- The Coarseness Factor and the Workability Factor determined from the combined aggregate grading shall be within the [required] Zone on the Aggregate Constructability Chart.
- The combined aggregate grading when plotted on a 0.45 power chart of the sieve size shall not deviate from a line drawn from the origin to the largest aggregate size within a tolerance of 2%.

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The last type of prescriptive specification is on combined aggregate grading addressed in SIP 5.

These types of requirements are typically included in specifications for some conventional and industrial floor slabs, specifications of some state highway agencies for road pavements, and a specification for airport pavements (FAA 2014). In some cases, these are stated as general requirements for all concrete on a project.

#5 – Aggregate Grading Limits

Industry Standards

- ACI 318 – aggregates conform to ASTM C33
  - No requirements on grading of combined aggregate
- ASTM C33 – grading bands for aggregates
- ACI 302.1R non-mandatory guide – suggests requirements on combined aggregate grading
  - For proportioning concrete mixtures for floors

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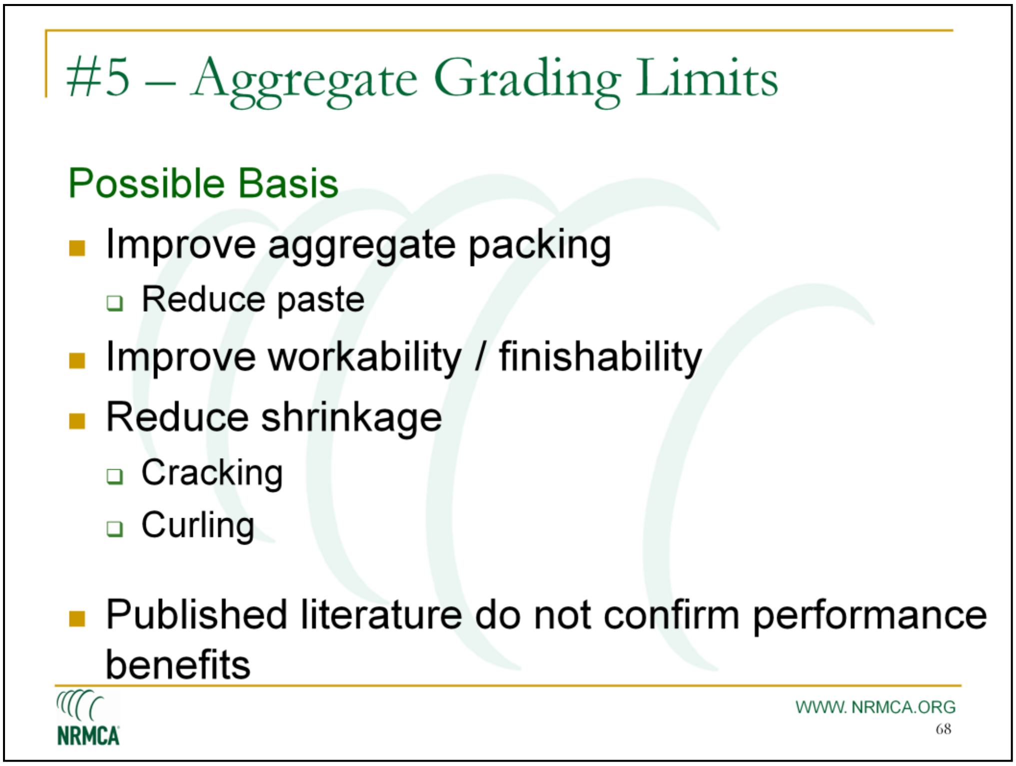
There are no such limitations in industry standards. There are guidance documents that suggest optimizing aggregate grading that are directed to the person proportioning concrete mixtures.



Research at NRMCA (Obla et al. 2007a, b; Obla and Kim 2008) found that combined aggregate gradings meeting the 8-18 and the coarseness factor chart requirements did not result in reduced aggregate void content and did not improve concrete performance through lower water demand, shrinkage, or higher strength. Based on experimental studies on Florida aggregates, McCall et al. (2005) concluded that concrete with combined aggregate grading meeting the 8-18 requirements did not yield lower water demand, drying shrinkage, or cracking. A study conducted for the Mississippi highway department (Varner 2010) concluded that optimized combined aggregate grading did not lead to concrete with lower shrinkage, chloride ion penetrability, or higher strength. Recently, Cook et al. (2013) and Varner (2012) have shown that the typical 8-18 and coarseness factor chart requirements did not lead to improved concrete performance, but did recommend modified limits on the individual percent retained for combined aggregate.

Some additional references that led to similar conclusions are:

••Tuthill, L.H., “Better Grading of Concrete Aggregates,” *Concrete International, V. 2, No. 12, Dec. 1980, pp. 49-51;*

••Anderson, K.W.; Uhlmeyer, J.; and Russell, M., “Combined Aggregate Gradation as a Method for Mitigating Studded Tire Wear on PCCP,” *Report WA-RD 663.2, Washington* State Department of Transportation, Olympia, WA, 2009, 15 pp., www.wsdot.wa.gov/research/reports/fullreports/663.2.pdf

••Dilek, U., and Leming, M.L., “Effects of Proposed Well-Graded Aggregate Gradations on Frost Durability of Concrete,” *Journal of ASTM International, V. 2, No. 5,* May 2005, pp. 1-14.

#5 – Aggregate Grading Limits

Restrictions Caused

- Intended performance may not be achieved
  - False sense of security
  - Improper assignment of responsibility
- Requirement cannot be verified during project
- Availability of sizes and storage at plants
- Some local sources cannot achieve grading requirements easily

Optimizing grading is a tool for proportioning – should not be a specification requirement

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In some cases producers who like blended aggregates find it difficult to comply with these specs and attain good performance. They may blend aggregates based on their sources and attain desired perf but may be unable to meet the combined agg. grading spec. Also if they comply with the grading and the intended performance is not achieved, they cannot be faulted.

#5 – Aggregate Grading Limits

Suggested Alternative

- Consider performance test for shrinkage
  - ASTM C157 – 0.05% at 28 days drying
- Consider test slab placement to evaluate workability/finishability with proposed placement equipment
- Consider successful service record with floor mixtures

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Ultimately the proponents of prescriptive aggregate grading requirements are interested in attaining low shrinkage, good workability, finishability and set times. By requiring these performance requirements the prescriptive requirements become redundant.

#5 – Aggregate Grading Limits

Benefits Due to the Suggested Alternative

- Assurance of reduced shrinkage, cracking, finishability
- Appropriate assignment of responsibility
- Reduces cost due to local use of materials, and reduced storage
- Supports sustainability

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If performance alternatives to aggregate grading are specified, these are some of the benefits.

Performance Options – Floor Slabs

- Reduced potential for cracking and curling
- Consistent setting time
- Workability and finishability
- Achieve flatness tolerances

Prescription	Performance Alternative
Cement content Aggregate grading Water content Mortar content SCM limits	ASTM C157 - 0.05% (7 day cure; 28 days drying) Setting time (C403) Test slab placement

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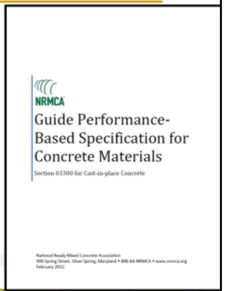
These are suggested performance options for floor slab mixtures

So how do we go about requesting changes in specifications

NRMCA offers a number of resources for implementing performance based specs

Review these guides to specifications from NRMCA as you consider modifying your specification. The SIPs address 5 issues. These documents cover more details on specifications.

Evolution to Performance



- The Engineer specifies
  - Basic requirements (Code)

Primary Requirements

Member	Mix ID	Durability Exposure				Specified Strength, f'_c, psi	Max w/cm	Nom. max aggregate, in.	Air content	Slump / Slump flow	Chloride limit	Temperature limits
		F	S	P	C							
Footings												
Foundation Walls												
Slabs-on-grade												
Exterior slabs												
Suspended slabs (interior)												
Suspended slabs (exterior)												
Frame members												
Columns (interior)												
Columns (exterior)												
Walls (interior)												
Concrete toppings												

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This is a Table from the Guide document. For each class list the application (where it will be used), the exposure (none, freeze-thaw, deicing chemicals, sulfate), and specified compressive strength. Then begin limitations on materials and quantities based on chapter 19 and 26 of ACI 318 that address material and durability requirements. Maximum aggregate size is based on limitations in ACI 318. Limits on air content, water-cement ratio, cementitious materials, admixtures, and chloride ions are provided in ACI 318. All of these are ACI 318 basic Code requirements.

Evolution to Performance

- The Engineer specifies
  - Performance requirements as applicable

NRMCA
Guide Performance-Based Specification for Concrete Materials
Section 03300 for Cast-in-place Concrete

Additional Requirements

Member	Mix ID	RCP, C1202	Shrinkage, C157	Freeze Thaw		ASR	MOE	Thermal Control Plan	Density	Other	Other
				C666	C457						
Footings											
Foundation Walls											
Slabs-on-grade											
Exterior slabs											
Suspended slabs (interior)											
Suspended slabs (exterior)											
Frame members											
Columns (interior)											
Columns (exterior)											
Walls (interior)											

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These are similar to the prev slide. These requirements are not in the building Code but are suggested as option for the A/E to consider. Not all concrete applications will require all of these. It is always a good idea to include acceptance criteria for performance that are only needed for the concrete application. Otherwise it can lead to mixtures that are not optimized for performance.

ACI 211.5R Performance Mix Submittal

Performance Submittal
(Company Name)
Address
Phone Fax

Project Name: **Date:**
Location: **Submitted By:** **Contractor:**
Contact:

	MIXTURE NUMBER	01	02	03	04
Specifications items as per ACI 318	**Application**	Parking structure suspended slab	Interior slab-on-ground	Footings, foundation walls	Curbs and gutter
	Structural requirements				
	ACI 318 exposure class	F3, S0, C2	F0, S0, C0	F0, S1, C1	F3, S0, C1
	Maximum w/cm (consistent with 318 exposure class)	0.40	—	0.50	0.45
	28-day specified strength, psi (MPa)	5080 (35)	3620 (25)	4060 (28)	4500 (31)
	Nominal maximum course aggregate size, in. (mm)	3/4 (20)	1-1/2 (40)	3/4 (20)	3/4 (20)
	Air content requirements	4.5 to 7.5	NA	NA	4.5 to 7.5
	Supplementary cementitious materials meet ACI 318 requirements for durability	Yes	NA	Yes	Yes
	Chloride ion content meets ACI 318 requirements for durability	Yes	NA	Yes	Yes
	Durability requirements				
	Exposure to sulfate attack (consistent with 318 exposure class)	NA	NA	—	NA
	Alkali aggregate reactivity	NA	NA	NA	NA
	Other	—	—	—	—
	Architectural requirements				
	Color	—	—	—	Midnight blue
	Other	—	—	—	—
Contractor items	**Rate, yd^3 (m^3)/h**	39.2 (30)	52.3 (40)	31.4 (24)	39.2 (30)
	Quantity, yd^3 (m^3)	1635 (1250)	3924 (3000)	471 (360)	327 (250)
	Slump range, in. (mm)	4-3/4 ± 1-1/4 (120 ± 30)	8 ± 1-1/2 (200 ± 40)	3-1/8 ± 3/4 (80 ± 20)	3-1/8 + 3/4 (80 ± 20)
	Strength/age	20 MPa/3 days	NA	NA	NA
	Other	—	—	—	—
	Specialty information	NA	Steel fibers	NA	NA
	Initial set (D: delay, N: normal, A: accelerated)	N	A	N	N
	Floor or slab type – (exposed/covered) other (for example, fibers)				
	Method of placement	Crane and bucket	Chute	Pump	Slip-form
Material items	**Type and information**				
	Portland cement	Conform to ASTM C150/C150M Type II unless otherwise specified (mill test reports attached)			
	Admixtures	Conform to ASTM unless otherwise specified (C494/C494M and C260/C260M test report attached as needed)			
	Aggregates	Conform to ASTM unless otherwise specified (ASTM C33/C33M test report attached as needed)			
	SCMs	Conform to ASTM unless otherwise specified (ASTM C618, C989, C1240 test report attached as needed).			
	Other (for example, fibers)				

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ACI 211.5R has a proposed submittal form for performance based mixtures. Consider using this

Conclusions

- Consideration of the performance alternatives can result in:
  - Assured (not assumed) performance
  - Mixtures optimized for the design and application
  - Higher quality; incentivized to achieve performance
  - Appropriate assignment of responsibility
  - Producer that can technically support project
  - Reduced time and cost to address project problems
  - Greater confidence in concrete construction
  - Supports sustainability

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82

In conclusion – evolving to performance specification does not have to be very complicated. Prescriptive provisions that intend some performance may not be achieved and the producer cannot be faulted with associated failures from a prescriptive spec. It prevents mixtures from being optimized and provides no incentive for operating at a higher level of quality or to consider innovation.

These are the other benefits with changes to specifications from prescriptive to performance.

This concludes the American Institute of Architects Continuing Education Systems Course

Performance-based Specifications – State of the Industry and Way Forward

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