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ACI 329.1T-18
TechNote

Minimum Cementitious Materials Content in Specifications

The issue

This TechNote discusses the implications of minimum cementitious materials content in project specifications (NRMCA 2015a). Prescriptive specifications for concrete construction projects often include a clause that requires a minimum cement content to be used in concrete mixtures (Obla and Lobo 2015). The typical clause in specifications for concrete states:

Concrete for XXX members shall comply with the following:

Minimum cement content xxx lb/yd^3 (kg/m^3)

OR

Minimum cementitious materials content xxx lb/yd^3 (kg/m^3)

Question

Is it appropriate to specify minimum cement or cementitious materials content, in addition to specifying strength and durability requirements for concrete mixtures?

Response

Unless a prevailing industry standard requires it, the requirement is unnecessary and prevents the development of an optimized concrete mixture.

Discussion

The reason for this prescriptive requirement needs to be explicitly stated to avoid expectations that may not be attained. Prescriptive requirements often prevent the concrete producer from developing an optimized concrete mixture to satisfy the project's performance requirements. Concrete mixtures with higher content of cementitious materials than needed for specified performance have a higher propensity for cracking, shrinkage and creep, increased permeability, and other detrimental performance properties. It increases the cost to the owner and results in concrete construction being less competitive. Higher quantities of cementitious materials in concrete mixtures without performance-based benefits is at odds with sustainable construction initiatives.

Industry standards

The following are relevant to this topic in current industry standards:

a) There is no requirement for minimum cement or cementitious materials content in ACI 318.

b) ACI 350 requires minimum cementitious materials content for some portions of environmental structures. The commentary suggests that a minimum amount of cementitious materials is necessary for long-term durability.

c) ACI 301 has minimum cementitious materials content requirements for interior floor slabs. The intent is to ensure adequate paste to facilitate finishability. A test slab placement is permitted as an alternative to the minimum cementitious materials content requirement.

d) The ordering information section of ASTM C94/C94M includes Option C, whereby the purchaser can state a minimum cementitious materials content in addition to a strength requirement. The manufacturer is responsible to comply with the strength requirement.

As shown in Table 1, minimum limits for cementitious materials in ACI standards are considerably lower than that seen in some project specifications (Obla and Lobo 2015).

Specifications of state highway agencies in the United States often define classes of concrete by cement content. The use of a minimum cement content is common in many codes and specifications outside the United States.

Table 1—Minimum cementitious materials content in ACI standards, lb/yd³ (kg/m³)

Nominal maximum size of aggregate, in. (mm)	Table 4.1.2.1 in ACI 350-06	Table 4.1.2.9 in ACI 301-16
1-1/2 (37.5)	515 (305)	470 (280)
1 (25.0)	535 (320)	520 (310)
3/4 (19.0)	560 (330)	540 (320)
3/8 (9.5)	600 (355)	610 (360)

The basis

Historically, when concrete was proportioned with only portland cement, a minimum cement content was commonly specified to ensure that the strength and durability requirements were met. As concrete technology and industry expertise have evolved, there is a better understanding of factors affecting performance of concrete, thereby rendering minimum cement content requirements obsolete. There is also a stronger focus on sustainable construction. Specifications of many agencies, such the U.S. Bureau of Reclamation, Illinois Tollway Authority, Port Authority of NY/NJ, NAVFAC United Facilities Guide Specifications, Virginia and Washington DOTs, and industry standards have eliminated these requirements and have adopted some performance-based requirements. The perception, however, remains that some minimum cement content, as required in many specifications, is necessary to ensure durability. There is now an adequate understanding that the use of supplementary cementitious materials (SCMs) is essential for improving most properties of concrete related to durability. Frequently, the specified minimum cement or cementitious materials content is set at a higher level as an implicit control on the quantity of SCMs that can be incorporated in concrete mixtures. This can adversely impact the performance of concrete.

Wassermann et al. (2009) identified three possible reasons for specifying a minimum cementitious materials content:

1. It provides assurance that a low water-cementitious materials ratio (*w/cm*) is attained, even if good control of the mixing water content is not exercised.
2. It ensures there is enough paste to fill the voids between the aggregates and provide adequate workability.
3. It offers corrosion protection by chemically binding the chlorides and CO_2 that penetrate the concrete.

A summary of some research on this topic is provided for perspective: Wassermann et al. (2009) and Dhir et al. (2004) report that at any given *w/cm*, increasing cement contents lead to similar compressive strengths and carbonation rates, but higher absorption and chloride penetration. A mixture with higher cement content had increased chloride thresholds to initiate corrosion, but this benefit was offset by higher chloride penetration. Dhir et al. (2004) reported that for mixtures with similar *w/cm* values, increasing cement contents led to similar flexural strengths, moduli of elasticity, and levels of deicer salt scaling. However, increasing cement contents led to reduced sulfate resistance, increased chloride diffusion, greater air permeability, and higher shrinkage. These studies conclude that minimum cementitious materials content should not be specified for concrete durability.

Obla (2012) and Yurdakul (2010) looked at a broader range of cementitious materials contents and found that increasing cement content at a given *w/cm* did not result in higher strength. With increasing cement contents, concrete resistance to chloride penetration was reduced and shrinkage increased. Mixtures with very low paste contents resulted in poor workability and reduced compressive strengths.

It should be noted that mixture proportioning approaches outlined in ACI 211.1 typically yield adequate paste volume for workability.

The problem

The specified minimum cementitious materials content:

a) May be much higher than the amount needed to meet the performance requirements
b) Can impact the ability to place and finish the mixture in some applications
c) Can increase the paste volume in the mixture, increasing potential for cracking due to plastic or drying shrinkage and temperature effects
d) Can increase the alkali content in the mixture and may contribute to an alkali-aggregate reaction problem
e) May result in a mixture that fails to achieve durability objectives
f) Uses excessive cement with no benefit and is not supportive of sustainable construction
g) Represents a disincentive to concrete producers that invest in higher level of quality and optimize concrete mixtures as the required overhead cannot be justified to be competitive

A survey of the ready mixed concrete industry (Obla 2014) revealed that the average cementitious material content used is approximately 100 lb/yd³ (60 kg/m³) more than that required to meet strength requirements.

Figure 1 shows test results representing a poor level of quality control of concrete produced on a project. The specified strength was 4000 psi (28 MPa) with a minimum cementitious materials content of 650 lb/yd³ (390 kg/m³). The coefficient of variation of strength result was 18.3 percent, which is categorized as poor control according to ACI 214R. There were no low strength test results and, as a result, there was no incentive to reduce variability. This does not benefit the owner.

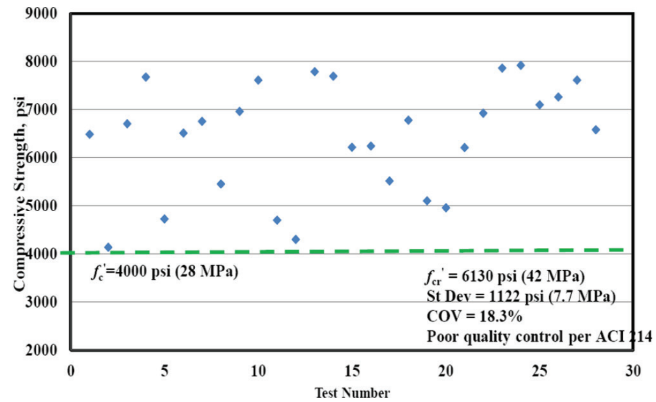

Fig. 1—Variability of compressive strength test results from a project with a specified minimum cementitious materials content requirement.

The alternatives

a) Delete limits on content of cement or cementitious materials for concrete mixtures.

b) Specify the performance requirements for the project (NRMCA 2012, 2015b). There is no technical basis for specifying cement content if the performance requirements are defined.

i. Specific performance characteristics can include strength, air content, shrinkage, indicators of permeability, thermal properties, fresh concrete properties for placement, and other criteria applicable to the exposure and application of the concrete member.

ii. Many performance characteristics can be established by prequalification testing, mixture performance history, or established from service life models for intended service life. Refer to ACI 365.1R for more information on service life prediction.

iii. Many performance requirements, but not all, can be verified during construction.

c) Invoke the durability requirements of ACI 318 by specifying *w/cm* and appropriate compressive strength, and other performance requirements when applicable (NRMCA 2012).

d) Consider requiring a test floor slab placement or documentation of successful past field history as an alternative to specifying the cement content.

e) Specify an appropriate compressive strength rather than a minimum cementitious materials content.

f) If the implicit purpose is to ensure improved quality, require and review the quality plan of the producer (NRMCA 2016) and contractor.

Conclusions and benefits

Eliminating requirements for minimum or specified cementitious materials content and adopting performance-based alternatives in specifications can:

a) Allow for concrete mixtures to be better optimized for workability, mechanical, and durability characteristics required for different members in a concrete structure.

b) Ensure that concrete mixtures will have lower paste volume that will have reduced potential for cracking due to shrinkage and thermal effects, reduced permeability, improved durability, and longer service life.

c) Improve assurance of achieving explicitly stated performance objectives rather than an implied objective from a prescriptive requirement.

d) Reduce the responsibility of the specifier if an intended performance objective is not achieved by the prescriptive requirement.

e) Attract competitive bidders that are more focused on quality and performance that can benefit owner's objectives and project schedule.

f) Support sustainable construction initiatives by using concrete with a lower environmental impact.

g) Reduce cost to the owner by use of mixtures optimized for performance and thereby make concrete construction more competitive relative to other systems and construction materials.

References

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ACI 214R-11—Guide to Evaluation of Strength Test Results of Concrete

ACI 301-16—Specifications for Structural Concrete

ACI 318-14—Building Code Requirements for Structural Concrete and Commentary
ACI 350-06—Code Requirements for Environmental Engineering Concrete Structures
ACI 365.1R-00—Service Life Prediction

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