

Specifying Requirements for Concrete Mixtures

By Colin L. Lobo, Ph.D., P.E.

Technological advances in concrete-making materials, production equipment, and processes have enhanced the possible innovative uses of concrete in a wide range of applications. Specifications for concrete mixtures, however, continue to be prescriptive, which often limits the ability to develop and use innovative products and construction methods. Specifications should be structured to leverage the expertise of the various stakeholders to deliver a high-quality structure with the desired service life to the owner.

The challenges and opportunities with performance-based specifications for concrete have been previously discussed (Lemay et al., *STRUCTURE*, April 2005). A prescriptive specification is one that includes compositional details of materials or means and methods of construction. The intended performance related to a prescriptive requirement may or may not be defined. Alternatively, a performance specification defines the needed outcome tied to acceptance criteria without detailing how it should be achieved. An important principle with performance requirements is the congruence of responsibility and authority. It provides the specific stakeholder the appropriate authority with assigned responsibility to achieve the desired outcome. A prescriptive specification, with a stated or undefined performance outcome, does not. Specifications that combine inconsistent prescriptive and performance requirements tend to be more problematic.

In a recent evaluation (Obla et al., 2015), prescriptive requirements that are considered onerous by concrete producers were ranked, and the frequency of these requirements was quantified by reviewing a sampling of about 100 specifications for different types of structures. Most of these prescriptive requirements are not consistent with the standards of the American Concrete Institute (ACI) and are discussed here.

Prescriptive Limits on Mixture Proportions

Mixture proportions for concrete should be developed to have the required workability for constructability and be composed of the lowest volume of a high-quality paste (cementitious materials and water) that will provide the required strength and durability in the structural member as required by the design, which includes consideration of the exposure conditions. This will require the use of good quality locally available cements and aggregates with consistent characteristics, use of supplementary cementitious materials (SCMs) for improved durability and long-term property development, and effective use of chemical admixtures that are compatible and provide the required workability and enhancement of hardened concrete properties. Specifications that detract from achieving these primary objectives should be reviewed for intent and the potential constraints they cause. Some of the prescriptive constraints on concrete mixtures include the following:

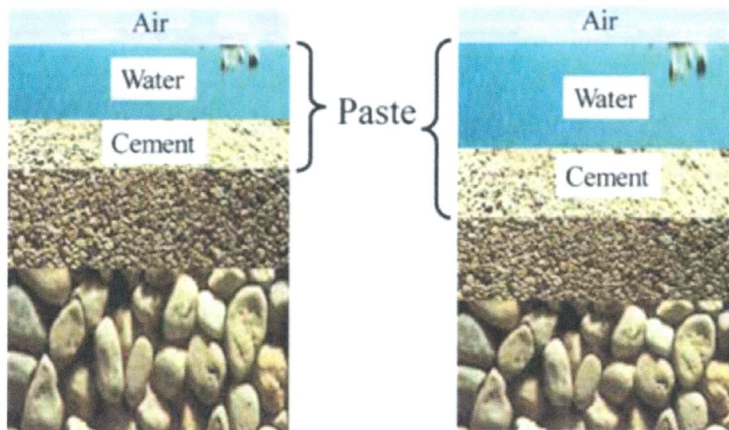


Figure 1. Illustration of two concrete mixtures with the same w/cm and different paste volume.

Maximum Water-Cementitious Materials Ratio (w/cm)

The w/cm of a mixture is an important parameter. For each set of materials, a unique relationship exists between strength and w/cm . Concrete producers use this relationship to proportion their mixtures. One should not assume that this relationship is universal. Two mixtures with the same w/cm but considerably different paste volumes will have considerably different properties (Figure 1). The w/cm also impacts the permeability or transport properties of concrete, important when durability is a concern. This property is also significantly improved by using SCMs like fly ash, slag cement, and silica fume. A maximum w/cm should be specified to address an exposure condition that impacts the durability of concrete. In 2008, ACI 318 established exposure classes for four durability categories with applicable maximum w/cm and an associated minimum specified strength. The premise is that, for quality assurance, w/cm cannot be verified but strength can.

In 73% of the specifications reviewed in the evaluation, a maximum w/cm was specified regardless of the exposure condition. In most cases, the specified strength was not consistent with the specified maximum w/cm ; for example, 3000 psi and w/cm of 0.40. This sets up an inherent conflict because the strength acceptance criteria do not assure the specified w/cm is being supplied. In some cases, the specified w/cm ratio was lower than 0.40 and did not seem appropriate for the type of member. The use of w/cm lower than 0.40 is limited to very high strength concrete or for severe exposure conditions and is not too common for concrete buildings. Specifying a low w/cm impacts the cost of the mixture and its workability for constructability. It can also result in a higher cementitious material content and paste volume, thereby increasing the permeability of the mixture and the potential for cracking due to temperature or drying shrinkage. If exposure conditions for a member require the use of a low w/cm , the resulting higher strength of the concrete should be advantageously used when designing the member.

While w/cm is one factor that impacts permeability, the beneficial contribution of SCMs is not recognized. There are performance-based tests that can be used as an alternative to w/cm .

Maximum Limits on SCMs

There is one condition in ACI 318 that sets maximum limits on the quantity of SCMs for concrete that will be exposed to cycles of freezing and thawing and application of deicing chemicals (Exposure Class F3). The limit is intended because of an increased potential for

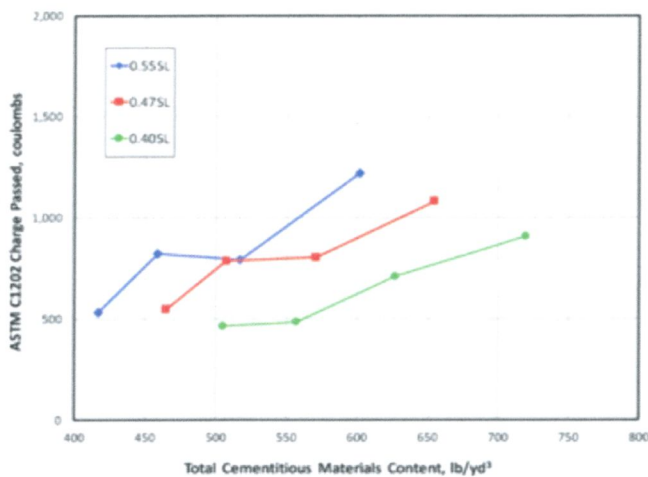


Figure 2. Increase in an indication of the permeability of concrete by ASTM C1202 with an increase in cement content [mixtures with 40% slag cement by weight of cementitious materials at w/cm 0.40, 0.47, and 0.55]. (Obla et al., 2017)

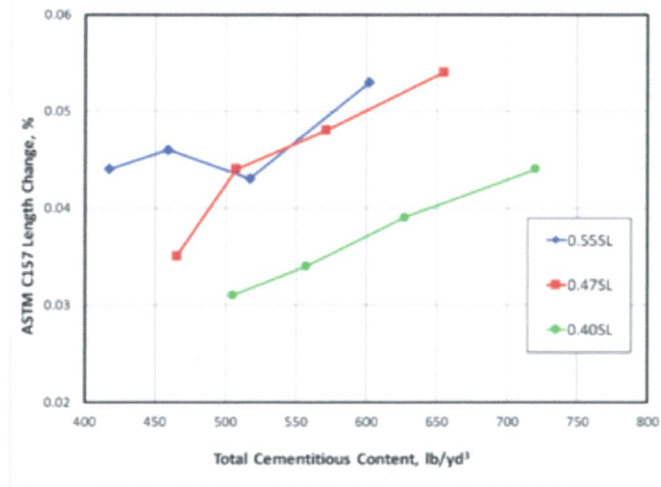


Figure 3. Increase in the drying shrinkage of concrete by ASTM C157 with an increase in cement content [mixtures with 40% slag cement by weight of cementitious materials at w/cm 0.40, 0.47, and 0.55]. (Obla et al., 2017)

scaling in this type of exposure. In reinforced concrete, scaling will reduce cover and exacerbate reinforcement corrosion. This exposure condition is rare in buildings. This limit was stated in 85% of the specifications reviewed in the evaluation. The specification of this limit is either a misunderstanding of the intent or a directive to minimize the use of SCMs in concrete.

The use of SCMs for improved durability – reduced permeability and resistance to deterioration due to alkali-silica reactions, sulfate attack, and other chemicals – is well established. Reduced permeability of concrete protects the corrosion of reinforcement. In mass concrete members, increasing the quantity of SCMs is the more economical means to reduce the potential for thermal cracking. The use of SCMs also improves the workability of concrete by achieving higher slump with less water and reducing the potential for segregation. It also supports sustainability initiatives. Resulting slower setting or rate of strength gain can be offset by the judicious use of admixtures and verified by maturity methods to estimate in-place strength of concrete with age. It is suggested that these limits only be specified for exposure class F3.

Minimum Cement Content

Specifying a minimum cement content for concrete tends to be a historical remnant in many specifications. It was observed in 46% of the specifications reviewed. In many cases, the minimum cement content specified was significantly more than that required for the specified strength. State highway agencies continue to define classes of concrete by cement content. The intent may be for improved durability, but this is faulty. The adverse impact on the heat of hydration, shrinkage, and permeability by requiring a higher minimum cement content has been documented (Obla et al., 2017). The effect on the transport properties (or permeability) and

drying shrinkage is illustrated in Figure 2 and Figure 3, respectively. This tends to reduce the amount of SCMs that can be used and increases the paste volume to impact performance adversely. There are no minimum cement content requirements in ACI standards for buildings. This requirement considerably constrains the ability of a concrete producer to optimize a mixture for the best performance and limits competitive bids. This requirement, in addition to conservative requirements for w/cm , results in actual concrete strengths 30 to 40% higher than the specified strength, thereby causing an ineffective design that makes the concrete construction more expensive and less sustainable.

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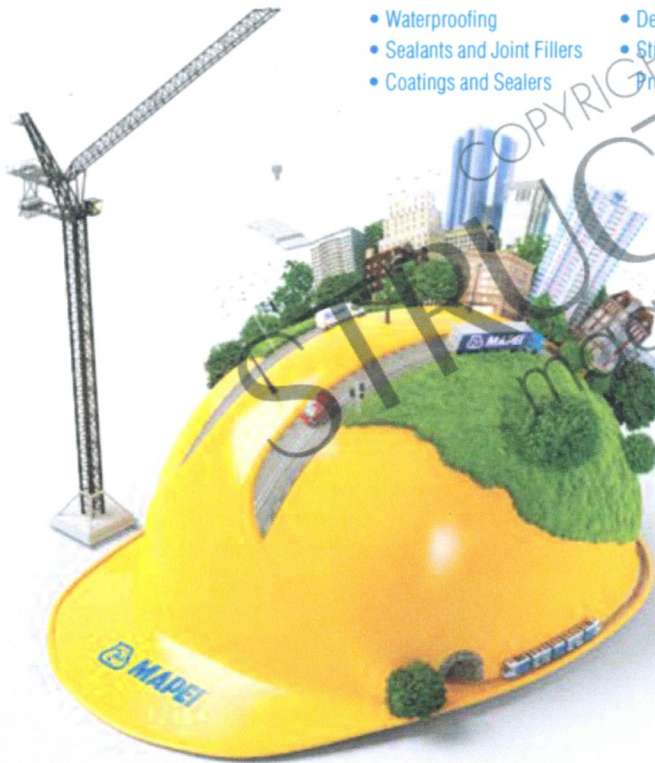
- Invoking more restrictive requirements for concrete-making materials, like aggregates or fly ash, than what is in the ASTM specifications – this causes available sources with local history to be restricted from use or requires materials to be imported.
- Requiring the use of specific brands or sources of materials, like admixtures or cements – producers have established contracts and requiring the use of materials they are not familiar with can cause problems.
- Specifying the combined grading of aggregates to relatively tight bands with the intent to control workability or shrinkage/curling – this typically cannot be enforced and often cannot be achieved with local materials or during production. The intended performance may not be achieved.

- Prohibiting the adjustment of mixture proportions of approved mixtures – real-time minor adjustments (without requesting approval) are needed to maintain quality and consistency to accommodate variation in source materials and environmental conditions.
- Restriction on cement alkali content, primarily as an attempt to minimize the potential for deleterious cracking due to alkali-aggregate reactions (AAR) – ASTM C1778 recognizes that the use of a low alkali cement does not necessarily prevent the problem and provides various options to mitigate AAR.
- Tight controls on the slump or other fresh concrete properties – can impact constructability. ACI 301 permits the contractor to select the slump and document that in a submittal. In today's concrete, slump is not a measure or control on water content.

- Including references to the Code or non-mandatory guides or state-of-the-art reports – these include committee opinions, observations, and list several options, making the reference unclear. The contractor cannot be responsible for Code requirements by a general reference to ACI 318. Any desired requirement from these documents should be explicitly stated in the specification.

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Summary

Prescriptive requirements for concrete mixtures in specifications often cause inherent conflicts that can negatively impact constructability, project costs, and deficiencies in the constructed project. Many prescriptive provisions observed in specifications are not consistent with ACI standards that have been developed through a consensus process. While some of these requirements are prescriptive, they are tied to specific conditions. Reliable performance-based test methods and criteria are evolving and should be the direction of the future. In the meantime, designers should review their specifications and consider addressing some of the items discussed in this article. This will help optimize concrete construction and make it competitive to alternative systems. ■

The online version of this article contains references. Please visit www.STRUCTUREmag.org.



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