CEMEX USA - Technical Bulletin

9.1

The Effects of Water Additions to Concrete: "What's a little water going to hurt?"

Have you ever been at a concrete placement when someone said "How about adding some water to that load"? Water addition to a load of concrete may or may not be acceptable depending on the parameters that need to be met. ASTM C94/C94M, *Specification for Ready Mixed Concrete,* states the following in regard to water additions:

"If the desired slump or slump flow is less than specified, and unless otherwise stated, obtain the desired slump or slump flow within the tolerances stated in [applicable sections] with a one-time addition of water. Do not exceed the maximum water content for the batch as established by the designed mixture proportion. A one-time addition of water is not prohibited from being several distinct additions of water provided that no concrete has been discharged except for slump or slump flow testing. All water additions shall be completed within 15 min. from the start of the first water addition. Such additional water shall be injected into the mixer under such pressure and direction of flow to allow for proper distribution within the mixer. The drum shall be turned an additional 30 revolutions, or more if necessary, at mixing speed to ensure that a homogenous mixture is attained." [1]

The purpose of this article is to bring about a better understanding of how the performance characteristics of the concrete may be affected with water additions that exceed the designed mixture proportions as compared to performance of the concrete as designed.

Slump and water addition rule of thumb:

It is not uncommon in the concrete industry for the contractor to add water to the load prior to or even during the unloading process to increase the slump and improve the workability of the concrete. The rule of thumb: One gallon of water will increase the slump of 1 yard of concrete by approximately 1 inch. This should only be taken as a rule of thumb as there are various other conditions, like temperature and air content, that will change the water required to increase concrete slump.

Another important point is that water should not be added after any significant quantity of concrete has been discharged from the mixer because the quantity of concrete being adjusted is uncertain as is the impact of the water addition on the concrete properties. ASTM C94/C94M permits the measurement of slump and air content from a preliminary sample from the initial portion of the discharge so that adjustments for slump and air can be made to a full load of concrete.

The water content dilemma, how much is the right amount?

A general understanding of the role of water in the process of cement hydration is important. The cement in the concrete needs water to hydrate and form Calcium-Silicate-Hydrate (C-S-H) which is the glue that holds the concrete together. The water is chemically bound (consumed) during the reaction with the cement at approximately 25 pounds of water to every 100 pounds of cement. Therefore, it could be said that a water to cementitious materials ratio (w/cm) of 0.25 is needed for the C-S-H and hydration products to be formed. That, however, is not all of the water that is needed. There is additional water that becomes physically bound between the cement hydrates. In order to have enough water to possibly enable complete hydration of the cement, approximately 20 pounds of water to every 100 pounds of cement is necessary. Combined, this equates to approximately 45 pounds resulting in a w/cm of 0.45. Other studies have shown that an approximate ratio of 0.4 was necessary for complete hydration of the cement.[2, 3] It should be noted that a concrete rarely gets the benefit of complete cement hydration typically because of the lack of physical access to the inner unhydrated cement particles and also due to lack the minimum required curing that would be needed.

Contrary to the above discussion regarding increased w/cm values resulting in the maximum potential for cement hydration, a concrete designer is faced with the reality that lower w/cm values often enhance strength and other durability characteristics of their product. The reason is not because the crystals formed during hydration are weaker, rather, because with the higher amounts of water in the mixture comes greater dispersion. Therefore, less bridging of the C-S-H crystals can take place. The resulting concrete is less dense, lower in strength, and higher in permeability.

The dilemma that exists between wanting lower w/c_m values which result in a denser concrete and having enough water in the concrete mixture for adequate workability and to optimize hydration can be explored in further detail in a very insightful article entitled “Curing and Hydration - Two half truths don't make a whole” written by Ken Hover, PhD., FACI [4] . In that article, Dr. Hover states that the solution to the problem is to:

> “1. Restrict mix water content to bring the cement grains close together, and
> 2. Apply effective curing measures to minimize water loss, and whenever possible water-cure to externally provide the water needed to sustain hydration.”

In order to determine the correct amount of water as part of the design process, the Portland Cement Association (PCA) states the following: “Mixture proportioning refers to the process of determining the quantities of concrete ingredients, using local materials, to achieve the specified characteristics of the concrete. A properly proportioned concrete mix should possess these qualities:

1. Acceptable workability of the freshly mixed concrete
2. Durability, strength, and uniform appearance of the hardened concrete
3. Economy” [5]

What parameters of the concrete are affected?

With the addition of water to a load of concrete in excess of the design w/cm, the following performance characteristics will likely be negatively affected:

- Compressive Strength
- Resistance to cycles of freezing and thawing
- Resistance to damage from Sulfates in soil and water
- Permeability – and its associated impact to strength and various durability characteristics
- Minimizing potential for corrosion of reinforcing steel

Compressive Strength:

The compressive strength of a concrete mixture is reduced when additional water is added. Figure 1 and Table 1 from "Design and Control of Concrete Mixtures", EB001.14, PCA, 2002 indicate a typical relationship between w/c_m and compressive strength.

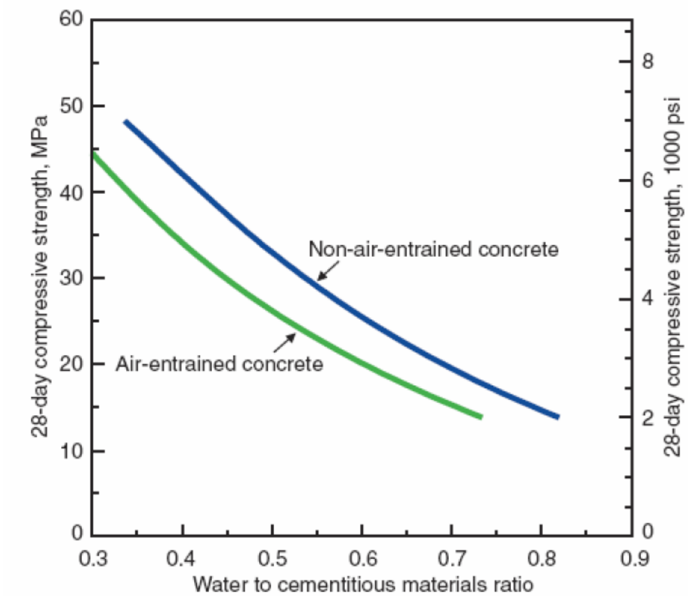


Figure 1 - Approximate relationship between compressive strength and water to cementing materials ratio for concrete using ¾-in. to 1-in. nominal maximum size coarse aggregate. Strength is based on cylinders moist cured 28 days per ASTM C31 (AASHTO T23). Adapted from Table 03, ACI 211.1, ACI 211.3, and Hover 1995.

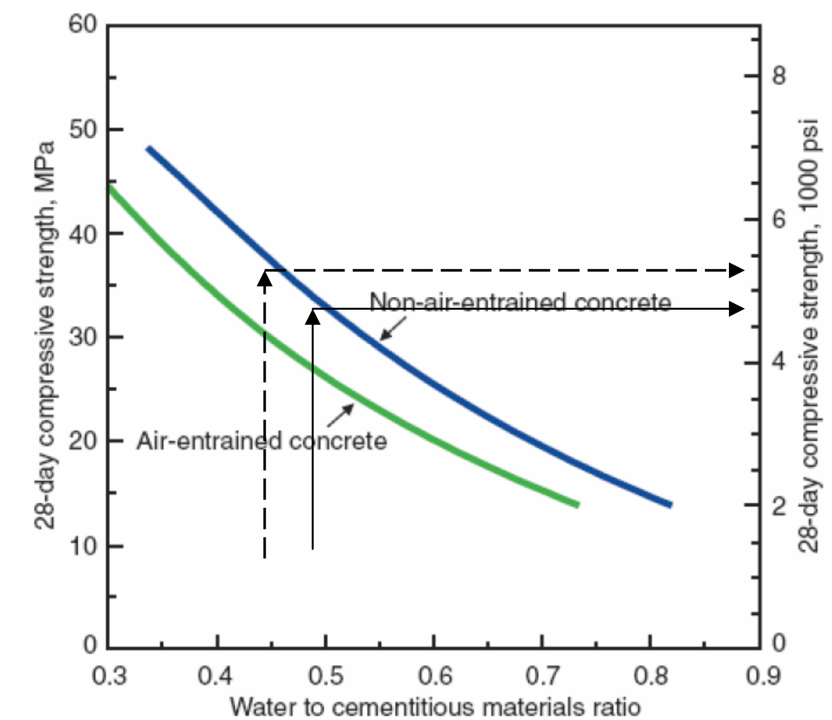
Table 1 – Relationship Between Water to Cementitious Material Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, psi	Water-cementitious materials ratio by mass	
	Non-air-entrained concrete	Air-entrained concrete
7000	0.33	—
6000	0.41	0.32
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

Strength is based on cylinders moist-cured for 28 days in accordance with ASTM C21 (AASHTO T 23). Relationship assumes nominal maximum size aggregate of about ¾ in. to 1 in. Adapted from ACI 211.1 and ACI 211.3

Real World Example:

Let's consider a ready mix truck containing 10 cubic yards of air-entrained concrete mixture (containing 564 lbs. of portland cement per cy) that has been proportioned at the maximum design w/cm of 0.45 (dashed arrows on Fig. 2). Upon arrival to the jobsite and prior to placement, 33 gallons of water are added to the 10 cubic yard load, resulting in a w/cm of approximately 0.50 (solid arrows on Fig. 2). The resulting 28-day compressive strength of the mixture prior to the water addition was approximately 4250 psi and the resulting compressive strength realized was approximately 3750 psi. This equates to a drop of 500 psi or a strength loss of nearly 12%.



Other Durability considerations:

As stated previously, there are other performance characteristics of concrete related to durability such as resistance to freezing and thawing, sulfate damage, permeability, and corrosion. The American Concrete Institute (ACI) 318 *Building Code Requirements for Structural Concrete* uses the w/cm as the primary concrete mixture parameter to achieve the minimum durability requirements for concrete in buildings. It states "the licensed design professional shall assign exposure classes based on the severity of the anticipated exposure of structural concrete members for each exposure category." [6]

ACI 318 then requires that concrete mixtures comply with the most restrictive requirements according to a table in the document which lists limitations including a maximum water to cementitious materials ratio (w/cm) and minimum specified compressive strength (f'c) for each exposure class of concrete. The ACI 318 table also includes additional minimum requirements of other parameters such as air content, cementitious materials types and limitations regarding the types, the use of calcium chloride admixtures, maximum water-soluble chloride ion content in concrete expressed as percent by weight of the cement, and other related provisions.

While ACI 318 requires a maximum w/cm for durability, it has a companion specified compressive strength, f'c for each level of w/cm. This is a recognition that w/cm cannot be reliably measured and verified for conformance to the requirement, while compressive strength can. ACI 318 provides commentary related to the requirement that concrete mixtures shall be proportioned to comply with the maximum w/cm and the other requirements based upon the anticipated exposure classification of the structural concrete.

"Maximum water-cementitious material ratios (w/cm) of 0.40 to 0.50 that may be required for concretes exposed to freezing and thawing, sulfate soils or waters, or for corrosion protection of reinforcement will typically be equivalent to requiring f'c of 5000 to 4000 psi, respectively. Generally, the required average compressive strengths, f'cr, will be 500 to 700 psi higher than the specified compressive strength, f'c. Because it is difficult to accurately determine the w/cm of concrete, the f'c specified should be reasonably consistent with the w/cm required for durability. Selection of an f'c that is consistent with the maximum permitted w/cm for durability will help ensure that the maximum w/cm is not exceeded in the field. For example, a maximum w/cm of 0.45 and f'c of 3000 psi should not be specified for the same concrete mixture. Because the usual emphasis during inspection is on concrete compressive strength, test results substantially higher than the specified compressive strength may lead to a lack of concern for quality and could result in production and delivery of concrete that exceeds the maximum w/cm." [6]

Conclusion:

In summary, a great deal of care is taken to develop the proportions of the concrete mixtures to achieve desired performance characteristics such as compressive strength and resistance to damage from freezing and thawing, exposure to sulfates, and corrosion. It is critical to understand that these performance characteristics may become vulnerable with additions of water above the design limitations. In addition, the provision of proper curing will further promote the optimal characteristics of the concrete. Strict adherence to the most restrictive design w/cm limitations of ACI 318 for structural concrete based on the exposure conditions is of great importance and the project specified design strengths should closely relate to proven concrete performance at the maximum permitted w/cm.

References:

1 - ASTM C94/C94M -12, "Specification for Ready Mixed Concrete", , ASTM International, West Conshohocken, PA

2 - Powers, T. C., A Discussion of Cement Hydration in Relation to the Curing of Concrete, Research Department Bulletin RX025, Portland Cement Association, 1948

3 - Powers, T. C., The Nonevaporable Water Content of Hardened Portland Cement Paste – Its Significance for Concrete Research and Its Method of Determination, Research Department Bulletin RX029, Portland Cement Association, 1949

4 - "Curing and Hydration - Two half truths don't make a whole" written by Ken Hover, PhD., FACI published by L & M Concrete News, Vol.3, No. 2, 2002 http://www.lmcc.com/concrete_news/0207/curing_and_hydration.asp

5 - Kosmatka, Steven, H., Kerkhoff, Beatrix, and Panarese, William C., PCA, Design and Control of Concrete Mixtures – 14th edition, EB001.14, Portland Cement Association, pg. 149

6 - American Concrete Institute (ACI) 318-11, Building Code Requirements for Structural Concrete (ACI 318-11 and Commentary), ACI, Farmington Hills, MI.

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