Chloride Ion Contribution of Admixtures to Concrete

ACI Chloride Limits in Concrete

Water-soluble chlorides, in combination with oxygen and moisture, can cause corrosion of embedded metals in concrete. Unfortunately, chlorides are among the most abundant materials on earth. Therefore, it is not practical to specify a maximum chloride content of “zero” for a concrete mixture. Because of this fact, the American Concrete Institute (ACI) has established some practical limits for chloride ions in concrete based on service conditions.

Tables 1 and 2 represent the recommendations of both ACI 222R, “Protection of Metals in Concrete Against Corrosion,” and ACI 318/318R, “Building Code Requirements for Structural Concrete.”

Table 1 – Chloride Limits for New Construction[1]

	CHLORIDE LIMIT FOR NEW CONSTRUCTION (% BY WEIGHT OF CEMENT)		
	TEST METHOD		
	ACID-SOLUBLE	WATER-SOLUBLE	
CATEGORY	ASTM C1152	ASTM C1218	ASTM C 1524 (SOXHLET[2])
Prestressed concrete	0.08	0.06	0.06
Reinforced concrete in wet conditions	0.1	0.08	0.08
Reinforced concrete in dry conditions	0.2	0.15	0.15

1 Taken from Table 3.1 in ACI 222R

2 The Soxhlet test method is described in ACI 222.1

Table 2 –Maximum Chloride Ion Content for Corrosion Protection of Reinforcement[1]

	MAXIMUM WATER-SOLUBLE CHLORIDE ION (CL-) IN CONCRETE (% BY WEIGHT OF CEMENT)
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.25

Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

1 Taken from Table 4.4.1 in ACI 318/318R

Relevant Documents

Both tables are in agreement regarding their recommendations for prestressed concrete. However, ACI 318/318R is more liberal in their reinforced concrete limits. The chloride limit corresponding to the category of concrete service closest to the specific application in question should be used.

It is important to note that the chloride limits in these tables encompass contributions from **all** sources, whether purposefully added as part of an admixture, or naturally occurring within the other concrete making materials used (i.e. mixing water, aggregates, cement, etc.).

It is also important to note that both tables specify a maximum **water-soluble** chloride ion content; since these are the chloride ions that are available to participate in the corrosion of embedded steel. However, for ease of analysis, most chemical laboratories prefer to test for **acid-soluble (total)** chloride ion content.

Total (Acid-Soluble) Chloride vs. Water-Soluble Chloride

Studies have shown that up to about 50% of the total chloride ions in concrete can be “tied up” by the cement matrix. Chloride ions have been found to chemically combine with the C3A and C4AF during the hydration process by forming Friedels Salt (Ca3Al2O6CaCl210H2O). Other studies have reported that a significant portion of “bound” chloride ions have actually been sorbed by the CSH gel in the concrete.

Chloride ions that have been “bound” by the cement matrix are not water extractable from concrete when tested according to ASTM C1218 or C1524. Those “bound” chlorides ions can only be extracted from concrete when the cement matrix is acid digested according to ASTM C1152.

The difference is important because the equations in this document are used to calculate the **total** chloride ion quantity contributed by the admixture to the concrete, while the ACI limits refer to **water-soluble** chloride ions in the hardened concrete.

If the **total** chloride ions contributed by all concrete-making materials, including admixtures, do not exceed the applicable ACI limit (see Tables 1 and 2), there is no problem with compliance.

However, if the total chloride ions contributed by all concrete-making materials, including admixtures, add up to somewhat more than the applicable ACI limit, it will be necessary to test the concrete according to ASTM C1218 or C1524 to determine whether or not it can be used in the intended application.

If the water-soluble chloride ion content of the concrete is greater than allowed by ACI, the specifying engineer may allow the use of DCI®Corrosion Inhibitor to offset the corrosive effects. See technical bulletin "Offset the Potential Corrosive Effect of Chlorides in a Concrete Mix Using DCI" (TB-0901) for more information on this subject.

How to Determine the Quantity of Chloride Ion per Unit Volume of Admixture

The first step in determining the chloride contribution of admixtures added to concrete, is to determine how much chloride is in the admixture being considered. The concentrations of chloride ions in GCP Advanced Technologies products are listed in Table 3.

Table 3 – Total Chloride Ion Contribution by GCP Admixtures

GCP PRODUCT	DOSAGE RATE	CHLORIDE (CL-) CONTENT	% CHLORIDE BY WEIGHT OF CEMENT
Daraccel®	520–2600 mL/100 kg (8–40 oz/100 lbs)	0.2911 g/mL (0.0189 lb/oz)	0.15–0.76
Daracem® 50	190–590 mL/100 kg (3–9 oz/100 lbs)	0.1089 g/mL (0.0071 lb/oz)	0.02–0.06
WRDA® 15	190–325 mL/100 kg (3–5 oz/100 lbs)	0.2116 g/mL (0.0138 lb/oz)	0.04–0.07
WRDA® 86	190–390 mL/100 kg (3–6 oz/100 lbs)	0.0805 g/mL (0.0052 lb/oz)	0.02–0.03

Since the total chloride contribution of an admixture is dependent on the quantity of admixture used in the concrete, it is impractical to specify a chloride ion content limit for the admixture without considering the amount of admixture that will be used.

Products from other manufacturers may or may not list their chloride ion content. However, if listed, the amount of chloride present may be expressed in a number of different ways, depending on the quantity and on manufacturer preference. If this information is not available from the admixture supplier, actual chemical analysis will be required to generate it.

The common ways to express this quantity is either as percent (%) or parts per million (ppm) of chloride ion in the admixture. In some cases the quantities may be expressed as a chloride ion salt, such as calcium chloride ($CaCl_2$). Regardless of how the chloride content is initially reported, the first step is to convert it to grams of chloride ion per milliliter (pounds of chloride ion per ounce) of admixture.

$$\left(\frac{\text{lb of } Cl^-}{\text{1 oz of admixture}}\right) = \left(\frac{\text{ppm of } Cl^-}{1{,}000{,}000}\right) \times \left(\frac{\text{1 gal}}{\text{128 oz}}\right) \times \left(\frac{\text{8.33 lbs of water}}{\text{1 gal of water}}\right) \times \text{Sp. G. of admixture}$$

Or

$$\left(\frac{\text{g of } Cl^-}{\text{1 mL of admixture}}\right) = \left(\frac{\text{ppm of } Cl^-}{1{,}000{,}000}\right) \times \left(\frac{\text{1 L}}{\text{1000 mL}}\right) \times \left(\frac{\text{1000 g of water}}{\text{1 L of water}}\right) \times \text{Sp. G. of admixture}$$

Calculations:

$$(\text{ppm of } Cl^-) = 10{,}000 \times (\%Cl^-)$$

$$(\text{ppm of } Cl^-) = \left(\frac{70.906}{110.986}\right) \times (\text{ppm of } CaCl_2)$$

$$(\text{ppm of } Cl^-) = 10{,}000 \times \left(\frac{70.906}{110.986}\right) \times (\text{ppm of } CaCl_2)$$

Useful Calculations:

Calculating Chloride Ion Contribution to Concrete by Admixtures

Since both ACI 222R, “Corrosion of Metals in Concrete” and ACI 318/318R, “Building Code Requirements for Reinforced Concrete” specify maximum chloride limits as a function of cement weight, the calculations introduced below will be used to calculate chloride ion contribution of an admixture by weight of cement.

% Chloride by weight of cement = (	Mass of chloride ________ Volume of admixture	) x (	Volume of admixture ________ Mass cement	) x 100
More specifically,				
% Chloride by weight of cement = (	lb of Cl^- ________ 1 oz of admixture	) x (	1 oz of admixture ________ 100 lbs of cement	) x 100
Or				

% Chloride by weight of cement = (	g of Cl^- ________ 1 mL of admixture	) x (	1 kg 1000 g	) x (	1 mL of admixture ________ 100 kg of cement	) x 100

Please note that by expressing the dosage rate of admixture in mL/100 kg (oz/100 lbs) of cement, the actual cement content of the concrete does not have to be known to calculate the chloride ion contribution as a function of weight of cement.

As an example, the following calculates the chloride ion contribution of Daraccel®, a calcium chloride based ASTM C494, Type C accelerator, when used in concrete at a typical 780 mL/100 kg (12 oz/100 lbs) of cement dosage rate:

(	0.0189 lb of Cl^- ________ 1 oz of admixture	) x (	12 oz of admixture ______ 100 lbs of cement	) x 100 =	0.227% Cl^-	by weight of cement

Or

(	0.2911 g of Cl^- ________ 1 mL of admixture	) x (	1 kg 1000 g	) x (	780 mL of admixture ___________ – 100 kg of cement	) x 100 =	0.227% Cl^-	by weight of cement

Thus, Daraccel®admixture, when used in concrete at a dosage rate of 780 mL/100 kg (12 oz/100 lbs) of cement will contribute 0.227% chloride ions by weight of cement.

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