TECHNICAL MEMORANDUM
GEMITE PRODUCTS INC.
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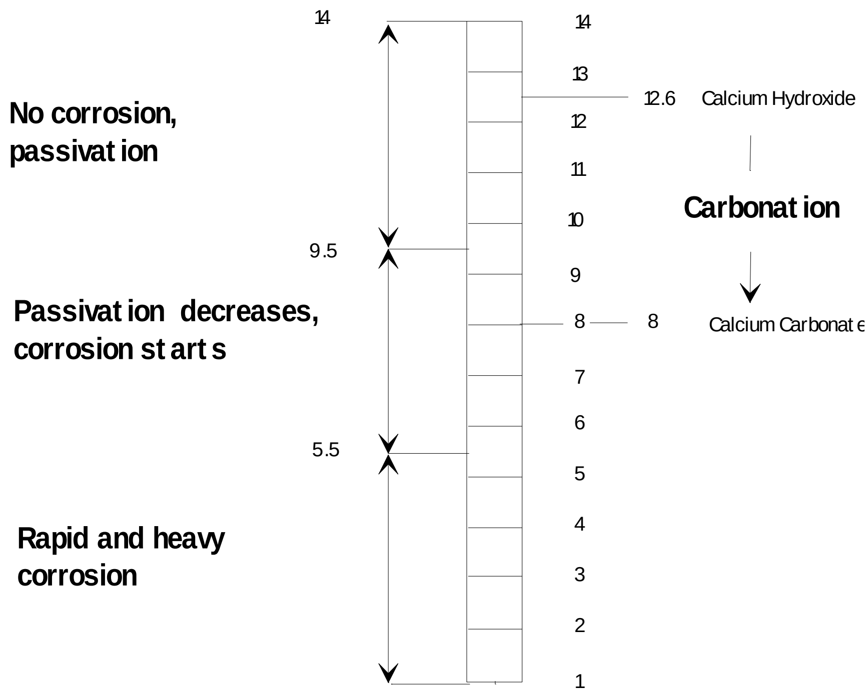
Corrosion of Steel in Concrete due to Carbonation

The high alkalinity of cement paste, approx. pH13, passivates the steel surface and protects it against oxidation (corrosion). The presence of chlorides, carbonation, acid attack or combination of all these, reduce pH of concrete and the reinforcing steel starts to corrode.

The Figure 1 shows the pH scale and divides it into three areas according to steel corrosion occurrence.

Figure 1. Corrosion of steel in concrete as a function of pH



The high alkalinity of cement paste is primarily due to the high calcium hydroxide content (lime) the product of cement hydration as schematically shown in equation 1. Calcium silicate compounds (CS) contained in Portland cement, when mixed with water react and form hydrated calcium silicates (CSH) and Calcium Hydroxide (lime). Lime and other oxides of alkali earth elements, such Sodium (Na) and Potassium (K) create the highly alkaline environment of fresh or "young" concrete.

$$\mathbf{CS + H \longrightarrow CSH + \text{Calcium Hydroxide (lime)}} \quad [1]$$

As concrete ages, lime reacts with the atmospheric carbon dioxide as shown in Equation 2.

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \quad [2]$$

This reaction "neutralizes" concrete and pH of concrete decreases. At pH level below 10 (approx. pH 9.5-9.6) the passivation protection of the steel surface due to the alkalinity of cement paste disappears and steel starts to corrode.

It has been shown (Ref.) that the depth of carbonation can be described by the following equation:

$$y := \sqrt{2 \cdot D \cdot \frac{C_1}{C_2} \cdot t} \qquad \textbf{(eq.1),}$$

where
y= depth of carbonation [mm]
D= diffusion coefficient [mm^2/a] (a=year)
C_1= concentration of CO_2 in the air (approx. 0.6-0.8g/m^3)
C_2= amount of CO_2 to carbonate concrete (Approx. 10,000-50,000 g/m^3)
t = time [years]

The depth of carbonation as a function of time for different qualities of concrete is shown schematically in Fig. 2.

Figure 2. Depth of carbonation as a function of time for different qualities of concrete

Depth of Carbonation (mm)

Time (years)

If we assume that the carbon dioxide concentration for a given exposure area and the amount of carbon dioxide to react with lime in m^3 of concrete are constants, then the equation 2 can be simplified an given as

$$y := \sqrt{C_c \cdot t} \qquad \textbf{(eq. 2)}$$

where
Cc = diffusion coefficient constant for a given concrete in a given environment.
y= depth of carbonation [mm]
t= time [years]

The equation 2 shows that the depth of carbonation is proportional to the root of carbonation time.

As an example we can look at the following case.

The depth of carbonation on a concrete structure was measured to be y= 6 mm and the age of the structure is t=10 years. From this data we can determine the constant C_c.

$$C_c := \sqrt{2 \cdot D \cdot \frac{C_1}{C_2}}$$

$$C_c := \frac{y}{\sqrt{t}}$$

$$C_c = 3.162 \cdot a^{-\frac{1}{2}}$$

This means that this type of concrete will be carbonated to depth of 3.16 mm in one year. If the concrete cover for this type of concrete is 15 mm, then for the carbonation to reach this level it will take 22.5 years, as shown by equation 3.

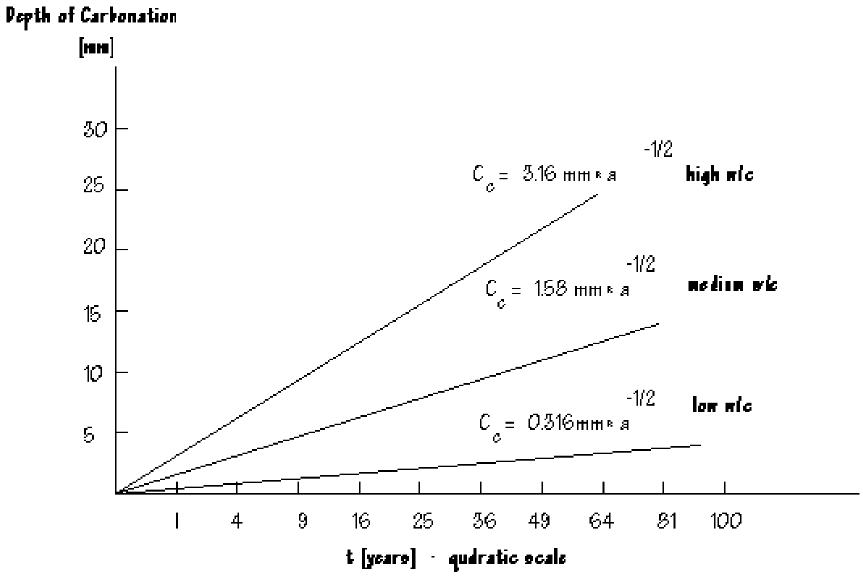
$$t := \left(\frac{15}{C_c}\right)^2$$

$$t = 22.504 \cdot a$$

The advance of carbonation & the concrete reserve thickness for the same quality concrete is as shown below:

Concrete Cover (y-mm)	**15**	**20**	**25**	
Time for carbonation to reach steel (years)	22.5	40	62.5	* a
Age of concrete (years)	10	10	10	* a
Time of carbonation "reserve" (years)	12.5	30	52.5	* a

The thickness of concrete cover is very important - More concrete one has covering the steel, longer it will take before steel starts corroding.



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