Profile Grinder

Purpose

The **Profile Grinder** is used to obtain concrete powder samples by precision grinding at small depth increments for accurate determination of the chloride ion profile for the following applications:

- Following immersion of specimens in a chloride solution in the laboratory, e.g., according to NT Build 443 “Concrete, Hardened: Accelerated Chloride Penetration” or ASTM C1556 "Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion"
- Directly on-site on existing structures that have been exposed to chloride ion ingress or on cores extracted from them.

From the chloride ion content profile, the chloride ion diffusion coefficient can be estimated in accordance with ASTM C1556 or NT Build 443 and used for estimating the remaining service life.

Principle

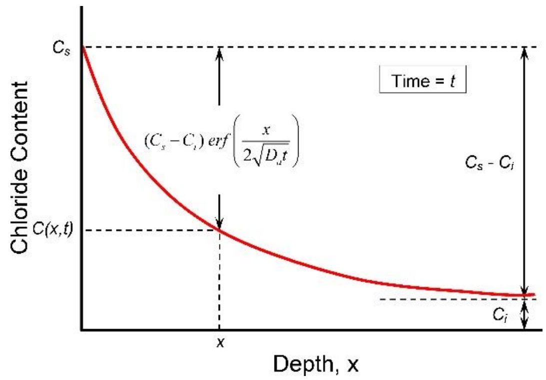
A high performance grinding bit, 18 mm in diameter, grinds the concrete to a fine powder at exact depth increments, which can be selected between 0.5 mm to 2.0 mm. The bit is attached to a grinding machine that is held against the surface by a support plate. Grinding is accomplished by rotating the grinder within the support plate so that the bit removes a circular portion of the surface. The grinding area is 73 mm in diameter and the maximum depth is 40 mm. For **in-situ testing**, the **Profile Grinder** can be attached to horizontal or vertical surfaces using the anchor bolts and clamping pliers shown in the image on the right. On horizontal surfaces, the powder produced at each depth increment is collected with a battery-operated vacuum cleaner (Dust Buster) containing a re-usable filter. On a vertical face, the powder at each depth increment is collected in a plastic bag attached to the grinding plate, as shown to the right. For every depth increment of 1 mm, approximately 9 grams of powder is obtained for analysis. It takes 4 to 6 minutes to obtain each sample and about 5 minutes to determine the chloride content using the **RCT Kit** (see **RCT** data sheet for details).

For **laboratory testing**, a grinding bench plate is available to permit profile grinding of small specimens, e.g. 100 mm in diameter. These can be specimens molded in the laboratory and used in diffusion testing such as ASTM C1556 of NT Build 443, or cores drilled directly from the structure.

Data Analysis

For laboratory tests in accordance with ASTM C1556 or NT Build 443, the chloride content profile obtained after a given period of immersion in the specified chloride solution is subjected to regression analysis to obtain the apparent chloride diffusion coefficient. The testing condition is assumed to result in one-dimensional diffusion and the chloride ion content as a function of depth is assumed to obey the following solution to Fick's second law of diffusion **(1)**:

$$C(x,t) = C_s - (C_s - C_i)\, erf\left(\frac{x}{2\sqrt{D_a t}}\right) \qquad (1)$$



where,

$C(x,t)$ = the chloride ion concentration at a depth x in mm from the exposed surface for an elapsed time t in years since the start of chloride exposure;

C_s = the chloride concentration at the surface, expressed as a % of concrete mass;

C_i = the initial (or background) chloride concentration of the concrete, expressed as a % of concrete mass;

erf = the error function (a special function related to the integral of the normal probability function); and

D_a = the apparent chloride diffusion coefficient in mm^2/year

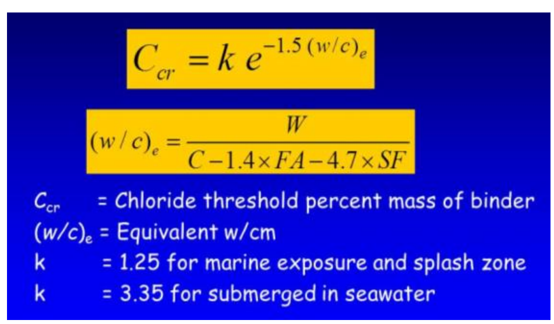
Equation (1) describes the variation of chloride ion content as a function of the distance x from the surface after an elapsed time t since initial exposure to a constant surface chloride concentration of C_s. This function is shown as the red curve in the above figure. The values of the equation parameters (C_s, C_i, and D_a) are determined using least-squares curve fitting, which can be implemented using for example the "Solver" function in Microsoft Excel or using statistical software that permits general non-linear regression analysis. The value of C_i would be zero (0) if there is no background chloride present initially in the concrete.

The diffusion coefficient in research reports is reported often in units of 10^{-12} m^2/s. To covert to units of mm^2/y, multiply by 3.15576×10^{13}. For good quality concrete, typical values of the chloride diffusion coefficient are 10 to 100 mm^2/y.

Service Life Estimation

A common application of the **Profile Grinder** is to obtain powder samples from existing structures to establish the exiting chloride profile. If the structure has been exposed to moist conditions so that diffusion has been the primary transport mechanism for chloride ions, Eq. (1) can be fitted to the data to obtain an apparent chloride diffusion coefficient. If it is assumed that the surface chloride concentration and diffusion coefficient do not change in the future, Eq. (1) can also be used to estimate the chloride ion content at the depth of the reinforcement at a particular time in the future. Thus it is possible to determine at what time t, the chloride content at the depth of the reinforcement would reach the **chloride ion threshold** for initiation of corrosion.

Chloride Ion Threshold



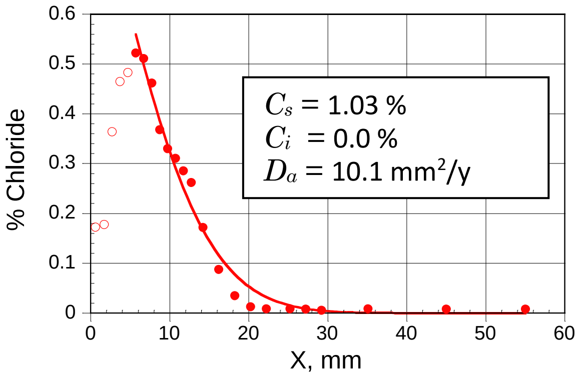
There is no single unique value for the amount of chlorides in concrete that will breakdown the protective oxide film and initiate corrosion of steel reinforcement. The value depends on many variables, among others, the exposure conditions, the water-cementitious materials ratio, the types of cementitious materials in the concrete, etc. **(1, 2, 3)**. The figure to the right shows a proposed equation for estimating the chloride ion threshold based on the exposure condition and the amounts of cement (C), water (W), fly ash (FA), and silica fume (SF) in the concrete **(1)**. For example, for a concrete with w/cm = 0.4, with 15 % of the binder being fly ash and 5 % being silica fume, and exposed to a splash zone, the chloride ion threshold is estimated to be about 0.23 % of the mass of the binder.

In the literature, the threshold chloride ion content may be expressed in different units. In the U.S., it is commonly expressed in terms of mass of chloride per unit volume of concrete. In Europe, it is commonly expressed as a mass percentage of chloride per mass of binder (the cementitious materials). The chloride ion content measured with the **RCT Kit** (see data sheet) is in terms of mass percentage of chloride per mass of concrete. To convert from a threshold value expressed as a mass percentage of binder to a value expressed as a mass percentage of concrete, it is necessary to multiply the former by the ratio of binder content (in kg/m^3) to the density of the concrete. For example, if the binder content is 450 kg/m^3 and the concrete density is 2250 kg/m^3, a threshold chloride ion content expressed as 0.23 % of binder would be 0.23 (450/2250) = 0.046 % of the mass of concrete, or approximately 0.05 %.

Testing Example

The following example illustrates the analysis of the chloride profile obtained from a structure exposed to marine environment for 5 years. The **Profile Grinder** was used to obtain powder samples at approximately 1-mm depth increments. As the powder samples were obtained, chloride content was determined on site using the **RCT Kit**.

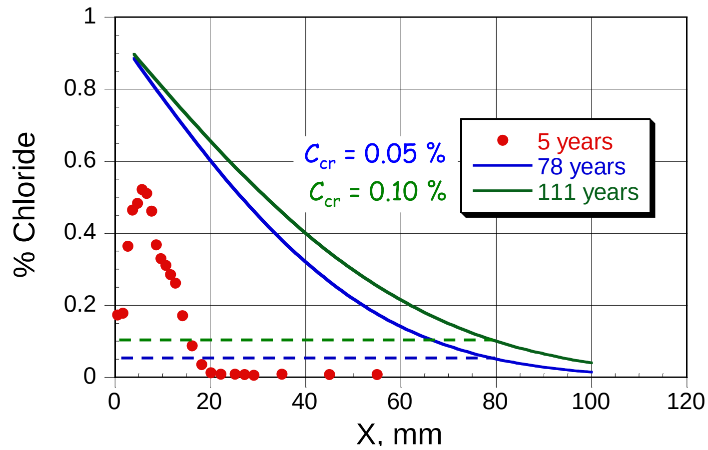
The data points in plot on the right show the measured chloride content profile expressed as % mass of concrete. It is seen that the first points within the outer 5 mm show less chloride than expected based on the diffusion model given by Eq. (1). Several explanations have been proposed for this behavior, such as washout by exposure to rain and an interaction effect due to carbonation. In any case, the data points shown as open circles were neglected in doing the least-squares regression analysis to obtain the best-fit values of the three parameters in Eq. (1), which are shown within the box. It is seen that background chloride content is 0 % and the apparent chloride diffusion coefficient is 10.1 mm^2/y.



The nominal depth of cover for the structure is 80 mm. Based on the assumption that the surface chloride ion concentration and chloride diffusion coefficient do not change with time, calculations can be done to estimate the remaining service life, which is defined as when the chloride content reaches the threshold value at the reinforcement depth. Two values of threshold chloride concentration were used 0.05 % and 0.10 %. By trial and error, the exposure time, t, was determined when the chloride content at x = 80 mm would reach the threshold values. The results are shown in the graph on the next page. Thus it is concluded that the remaining service life is in the range of 80 to 110 years. Keep in mind that these estimates of remaining service life are approximate values and based on several simplifying assumptions:

- Chloride migration is governed by diffusion
- The apparent diffusion coefficient does not change with time
- The concentration of chloride at the surface remains constant
- Effects of temperature and chloride binding are not considered

In practice, the chloride profile in the structure should be reevaluated at regular intervals in the future. This will allow updating the effective chloride ion diffusion coefficient and calculating a new expected service life.



The curves in green and blue are the chloride ion profiles calculated using Eq. (1) for the times that would result in the threshold chloride content at a depth of 80 mm

References

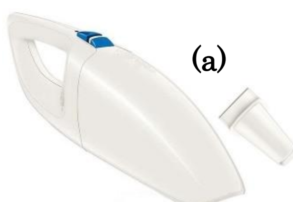
(1) Poulsen, E. and Mejlbro.L., **Diffusion of Chlorides in Concrete, Theory and Application**, Modern Concrete Technology Series, Taylor and Francis, 2006, ISBN13: 9-78-0-419-25300-6

(2) Nilsson, L.O., Sandberg, P., Poulsen, E., Tang, L.M. Andersen, A. and Frederiksen, J.M., "A System for Estimation of Chloride Ingress into Concrete: Theoretical Background," HETEK Report 83, 1997, http://www.hetek.teknologisk.dk/english/16507

(3) Frederiksen, J.M. and Poulsen, E. "Chloride penetration into concrete—Manual," HETEK Report 123, 1997, http://www.hetek.teknologisk.dk/english/16507

Profile Grinder Specifications

- No-load speed: 2,500 – 8,700 rpm
- Rated input power: 950 W
- Output power: 510 W
- Thumbwheel for speed selection
- Electronic overload protection
- Electronic safety motor shutdown in case of unexpected stop
- Grinding diamond bit diameter: 18 mm
- Depth increments: 0.5 to 2.0 mm (± 2 %)
- Maximum grinding depth: 40 mm
- Grinding area: 4,185 mm² (73 mm diameter)
- Powder sample: ≈ 9 g per each mm of grinded depth



(a)

(b)

Profile Grinder Kit (PF-1100) Ordering Numbers

Item	Order #
Grinder unit consisting of grinding machine, housing, handle cover with flange and counter nut, two handles and grinding diamond bit	PF-1101
Grinding support plate with green felt	PF-1102
Grinding bench plate with screws and nuts	PF-1103
Attachment ring and two bolts	PF-1104
Allen key, 4 mm	CC-25
2 adjustable clamping pliers	C-102-3
Set of anchoring tools	CC-30
2 seating rubber rings	PF-1105
Plastic bags, 50 pcs	PF-1106

Item	Order #
Brush	PF-1107
Measuring tape	RCT-1028
14 and 17 mm wrenches	C-155/151
Sponge	PF-1108
Dust mask	PF-1109
Silicone oil bottle	L-24
Spare green felt	PF-1111
User Manual	PF-1112
Optional Items	**Order #**
Dust Buster, portable vacuum cleaner (a)	PF-1200
PF-1110 Spare grinding diamond bit (b)	PF-1110