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Estimation of service life of coated brickwork mortar joint

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Abstract

This work reports an investigation into the permeation of chloride in brick masonry mortar joints in three different media (water from rain, runoff, and sea). The coated and uncoated (control) masonry prisms were subjected to 3% chloride solutions for periods of 1–5 weeks each, and the chloride concentration at depth of 20 mm was determined (ranging from 0.012 to 0.327 for immersion days of 7 to 35, respectively, for coated and uncoated prisms of 0.03 to 0.887, respectively). The results show that the service life of the coated brick mortar joint has been increased by 36 years for the sea water sample.

Keywords: Compressive strength; Corrosion; Diffusion; Chloride; Mortar

1. Introduction

The rapid progress over recent years in understanding of materials and the considerable advances in the methods of design have led to the increasing acceptance of load-bearing masonry as a structural material. Bricks are usually left unplastered and uncoated due to their naturally beautiful appearance. Apart from the use of brick masonry as a load-bearing element, other brickwork applications include drainage structures for the conveyance of sewage, industrial wastes, etc., industrial floor members, as well as chemical-resistant element.

Inability of any of the members of the masonry to meet the required function implies failure of such a structural element. Major causes of deterioration of brickwall include the change in material, opening that gives way for water and aggressive media, pressure beyond bearing capacity of the wall, as well as underscouring due to underground water. Some of the mechanisms of failure include rain penetration, thermal/moisture movement, loss of adhesion/cohesion, condensation, and rising damp that can lead to corrosion of metallic material. There are two main types of attacks when considering [1] durability of high-performance concrete (mortar): (1) expansion of concrete compound (cement paste and aggregate) by the action of aggressive water solutions and (2) expansion due to the crystallization of new compound, which causes structural damage.

The rate of diffusion of chloride ions is greater than that of CO_2 (in the air), and only when they reach the metallic material can they cause corrosion. According to Kilareski [2], the high pH (13) associated with the hydration of Portland cement is usually sufficient to keep the protective film stable. However, sufficient concentration of chloride ions can lower the pH.

The term *coating*, in this content, refers to such surface treatment that forms a film on the surface of concrete and that penetrates the mortar little or not at all. Coatings are natural, artificial, or synthetic materials applied in a thin (60–500 μm) layer upon a surface to be protected and forms impermeable films banded strongly to the surface [3].

In the design of reinforced brick masonry in tension, the minimum cover depends on the strength of the units, grout, and mortar as well as the environment [4]. Fire-burnt bricks, glazed at production, generally offer some degree of resistance to water penetration. Growth of microorganisms on the mortar joint is detrimental to human health, as well as creating openings through which reinforcement is exposed to attacks from the environment. Cements of improved qualities are restricted in their areas of application [5,6], while chloride ion and other aggressive chemical agents' penetration have been shown [1,7] to be two to five times greater in Portland cement-based materials than in those cement containing mineral blending additions.

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Table 1
Average compressive strength of mortar cubes

Day of curing	Loads at failure (kN)				Average compressive strength (N/mm^2)
	P_1	P_2	P_3	$P_{average}$	
7	52	48	45	48.333	19.33
8	75	72	80	75.667	30.27

This paper presents the results of an investigation into the permeation effect of chloride in brick wall mortar joints in sea-, runoff-, and rainwater. Water samples were tested for different chloride concentrations, while burnt brick masonry prism specimens were used in the experimental tests.

2. Diffusion equations and data analysis

Diffusion is defined [8] as a process that leads to an equalization of concentration in single phase. It involves movement of molecules from a region of higher concentration to lower concentration. Diffusion depends on: (a) coating characteristic constant, K, of the medium that relates to the quantity of substance passing through the material, (b) the concentration of the diffusing material, $C_{external}$, and (c) diffusion constant, D, of the diffusing substance, which is the perpendicular area it can cover per unit rate.

Solution for semi-infinite medium whose external concentration varies with the function of time is obtained by the Laplace transform of diffusion [9]. This is expressed as:

$$C_{x,t} = K\sqrt{t}\left[e^{(x^2/4D_c t)} - \frac{x\sqrt{\pi}}{2\sqrt{D_c t}}\left(1 - \operatorname{erf}\frac{x}{2\sqrt{D_c t}}\right)\right] \quad (1)$$

where C is the chloride concentration (in a single year, results reported that the concentration of 2.1 decreases to 0.1 kg/m^3 at a depth of 4.0 cm [10]), D_c is the effective chloride diffusion coefficient of concrete (mortar) and this depends on the types of cement and the water-to-cement (w/c) ratio and also on the boundary conditions and amount of chloride, t is the time, x is the chloride concentration depth from mortar surface, K is the coating characteristic constant. In the analysis, corresponding coating characteristic K_{field} has been modified to $K_{modified}$. This is expressed as in Eq. (2):

$$K_{modified} = \frac{K_{coated}}{K_{coated}} K_{field} \quad (2)$$

in which K_{coated} and $K_{control}$ are the coating characteristic constant for coated and control samples, respectively, while K_{field} is expressed as in Eq. (3):

$$K_{field} = \frac{C_{external}}{\sqrt{50}} \quad (3)$$

where $C_{external}$ is the field (external) concentration (kg/m^3), $K_{modified}$ is the K_{field} for the control mortar joint when $K_{coated} = K_{control}$. In the analysis, the minimum corrosion protection service life selected is 50 years. The exposure conditions are categorized [9] as:

1. low, where $C_{external} = 0–2.4$;
2. moderate, where $C_{external} = 2.4–4.8$;
3. high, where $C_{external} = 4.8–5.9$;
4. severe, where $C_{external} = 5.9–8.9$.

3. Experimental design

3.1. Crushing test on mortar

The average compressive strength of mortar was determined in accordance with the ASTM designation C-109. Mortar (1:6 cement/sand) specimens of 50-mm cube were produced. The specimens, which were placed in the mould in three layers and each received 25 blows, were placed in a moist closet for 24 h and later cured for 7 and 28 days, respectively. The compressive strength determination is shown in Table 1.

3.2. Density determination for mortar

The mortar density was determined in accordance with ASTM designation C905-79. Each mortar specimen was placed in the mould (which was initially weighed), tampered, and placed in the moist closet for 24 h. This was later cured for 7 days. Table 2 contains the density of mortar samples.

3.3. Prism specimens preparation

Mortar joint of 20 mm thick was used to form prism specimen (slenderness ratio of 2, i.e., $h/t = 2$, where h and t are the prism height and thickness, respectively). Fig. 1 shows preparation for the specimens. In this study, a generic type of paint (Ultimate Gloss): density of 0.9–1.2 g/cm^3, with coverage of 10–12 m^2/l, costing N32/m^2 ($\sim$US$0.38/m^2; N = naira equivalent) was used. Two coats with an allowance of 4 h between the coats were applied by brush. Some prism specimens were uncoated. The prisms were all subjected to 3% chloride solution.

Table 2
Density of mortar

Samples	Weight (g)			Volume of mould (cm^3)	Density of mortar (g/cm^3)
	Empty mould	Mould and mortar	Mortar		
1	17	230	213	90.29	2.36
2	17	226	206	90.29	2.31
3	18	234	216	90.29	2.39
4	18	225	207	90.29	2.29

Average density = 2.34 g/cm^3.

Fig. 1. Preparation for prism specimens.

3.4. Chloride content determination

3.4.1. Procedure for the preparation of filtrate solution for pulverized mortar

1. Water samples from the sea, rain, and runoff were taken and kept.

2. Samples were taken from a coated and uncoated mortar joints at the depth of 2 cm by breaking each prism, measured to the depth, and enough quantity from each of the samples was scrapped. This was done for 1-, 2-, 3-, 4-, and 5-week immersed samples. Each sample was pulverized and labeled for recognition.

3. In accordance with ASTM C-144 (Section 19), 10.0 g each of the pulverized mortar was weighed into a 250-ml beaker and 75 ml of distilled water was added. Twenty-five milliliters of dilute 1:1 v/v nitric acid (1 ml of HNO_3 to 1 ml of distilled water) was added immediately, while 3 ml of hydrogen peroxide (30% solution) was added and allowed to stand for 2 min. Few extra drops of 1:1 v/v nitric acid was added and stirred continually until yellow orange color appeared on top. The beaker was covered and heated with its content to boiling. It was removed and allowed to cool for 20 min. The suction apparatus was assembled and used to aid the filtration. The filtration was made by washing the residue with distilled water until the volume was 150 ml.

3.4.2. Procedure for chloride determination

Chloride content was determined by the mercuric nitrate titration, while buret method and digital titrator methods were used for low and high concentrations, respectively. These two methods are explained briefly:

1. Buret method: One diphenylcarazone reagent powder pillow was added and mixed into 100 ml of the filtrate (Section 3.4.1) sample in a conical flask. This was titrated with mercuric nitrate standard solution (0.0141 N) in the buret until the color changed from yellow to light pink. The chloride content in milligrams per liter in 150 ml was obtained and the result was shown in Table 3, which was the average chloride content of three specimens for each of the three media.

2. Digital titrator method: The sample was prepared as in the buret method and a delivery tube was attached to a 2.256-N mercuric nitrate titrator cartridge, which was set to zero, and this delivery tube was flushed by turning its knob to eject a few drops of titrate into the flask until the color from yellow to light pink. The concentration in milligrams per liter was read and the results were recorded in Table 3.

Table 3
Average chloride content in water samples (three specimens each)

	Average chloride concentration	
Water sample	mg/l	kg/m^3
Sea	4724.23	4.72
Runoff	1.54	0.002
Rain	0.59	0.001

4. Data and results of analysis

Let C_a and C_b be the chloride concentration in milligrams per liter of the filtrates of the immersed and background mortar, respectively. Let C be the gain in chloride

Table 4
Chloride measurement at 2.0 cm depth of the prism mortar joint

Days of immersion	Number of specimens	Average chloride concentration, C_a (mg/l)		Chloride content, C_b (mg/l)	Average chloride gain of mortar (kg/m^3)	
		Control	Coated		Control	Coated
7	3	7.000	6.333	6.0	0.035	0.012
14	3	7.000	6.333	6.0	0.035	0.012
21	3	22.000	12.000	6.0	0.560	0.210
28	3	30.000	15.660	6.0	0.850	0.338
35	3	31.333	15.333	6.0	0.887	0.327

content (kg/m^3) of the filtrate solutions of the immersed pulverized mortar. Given a typical calculation for chloride gain: mass of chloride in 150 mm filtrate = (chloride concentration) $\times 150 \times 10^{-3}$, so that the volume

$$V = \frac{10}{2.3}$$

$$= 4.27 \text{ cm}^3 \ (= 4.274 \times 10^{-3} \text{l})$$

The average chloride gain is equal to $(C_a - C_b) \times 150 \times 10^{-3}$ g, then:

$$C = \frac{(C_a - C_b) \times 150 \times 10^{-3}}{4.275 \times 10^{-3}} \text{ mg/l}$$

Therefore,

$$C \text{ (kg/m}^3) = 0.035(C_a - C_b)$$

$$= 0.035 \times 6$$

$$= 0.21 \text{ kg/m}^3$$

Table 4 shows the average chloride measurement of the specimens at 2.0 cm depth each, while Fig. 2 shows the average chloride content in kilograms per cubic meter, against time, for the control and coated samples.

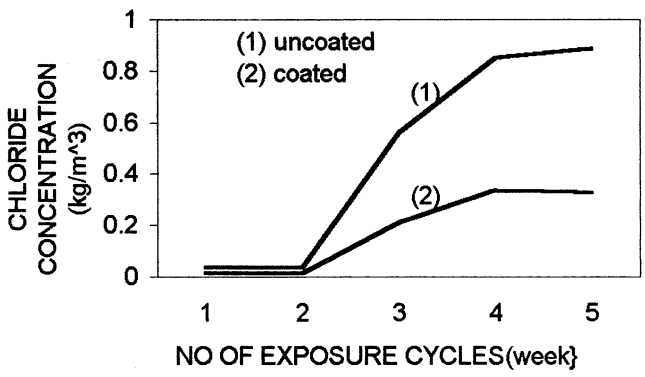

Fig. 2. Average chloride contents vs. time.

5. Evaluation of service life

The service life was evaluated by the iterative solutions to Eq. (1). This was achieved by using QUICKBASIC computer software (QB45). The results for the field external concentration of between 0.40 and 0.84 kg/m^3 are shown in Table 5, while the graph of service life (t_s) of brick wall mortar joint against field concentration (0.85–8.9) is in Fig. 3. It could be noted that the service life is in time equivalent, assuming no major deterioration of paint itself, as paint has its own deterioration period. The results of the iteration made it possible to compare the service life of both the coated and uncoated mortar joints. Diffusion equation (from Eq. (1)) for K_{modified} is expressed as:

$$C_{x,t} = K_{\text{modified}} \sqrt{t} \times \left[e^{(x^2/4D_c t)} - \frac{x\sqrt{\pi}}{2\sqrt{D_c t}} \left(1 - \text{erf} \frac{x}{2\sqrt{D_c t}} \right) \right]. \quad (4)$$

Eq. (4) was solved to get the service life for $D_c = 0.58$ cm^2/year, $x = 4.1$ cm, $C_{(x,t)} = 0.71$ kg/m^3, and $K_{\text{modified}} = 0.057$, 0.019, 0.022, ... 8.9 kg/m^3, respectively. In Fig. 3, it can be seen that the chloride content of the runoff and rain samples are too low to cause any offshore with C_{external} of 4.7 kg/m^3

Table 5
Coating characteristic constant and time equivalent of brickwork mortar joint

Field external concentration (kg/m^3)	K_{modified} (kg/(m^3 year$^{0.5}$))		Time equivalent (years)	
	Control	Coated	Control	Coated
0.40	0.057	0.019	329	1893
0.45	0.064	0.032	279	1479
0.50	0.071	0.024	243	1271
0.55	0.078	0.027	213	1045
0.60	0.085	0.029	181	928
0.65	0.092	0.032	172	791
0.70	0.098	0.034	157	717
0.75	0.106	0.036	145	657
0.80	0.113	0.038	134	580
0.84	0.119	0.041	126	536

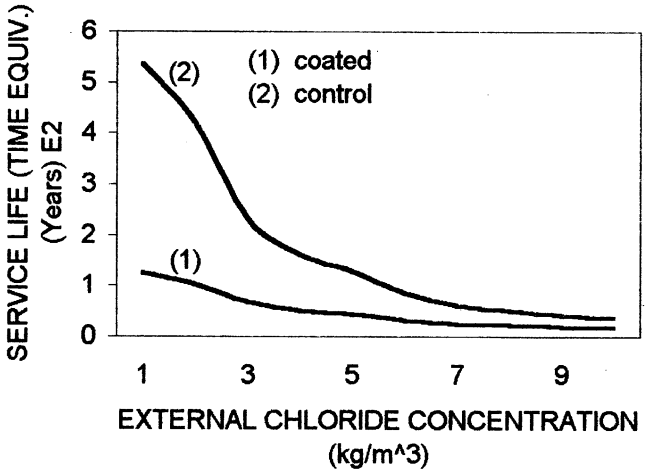

Fig. 3. Service life vs. chloride concentration.

gives the service life of 27 and 63 years for the uncoated and coated mortar joint, respectively.

6. Conclusion

From the results of this work, the initial low value of chloride concentration has been observed for a considerable period of time (0.4 exposure). Coated specimens show a fall of concentration (against the control ones) at a point in exposure time.

Taking the coating characteristic constant into account, the iterative solutions show that the service life of the brickwork mortar joint decreases with time.

The coating (Ultimate Gloss) increased the service life of the wall mortar joint to 36 years, when compared with the control.

7. Recommendation

Since 50 years is taken as maximum corrosion protection service life for any structure, the brickwork with its joint coated with Ultimate Gloss should not be used in an immersed medium where the field external concentration is more than 6.0 kg/m^3.

The loss of chloride solution, due to boundary conditions, should be looked into due to interface contact between brick units and the mortar joint. Various effective chloride diffusion coefficients (D_c) of the mortar joints of different types of cements should be examined.

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