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# Influence of mortar rendering on chloride penetration into concrete structures

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ABSTRACT

This experimental work studied the influence of mortars used as external rendering on chloride transport in concrete. Prismatic concrete specimens were cast with dimensions of 80 × 80 × 80 mm and water to binder ratio of 0.55. Three different mixtures of mortar were used to cover these specimens, after making a thin layer of spatter dash treatment. Reference concrete specimens were also cast. After a curing period in wet chamber and in laboratory environment, five of the six faces of the specimens were coated with epoxy resin to simulate unidirectional flux of chloride during the test. The specimens were subjected to natural diffusion tests for 49 days and, afterwards, samples were extracted and analysed to obtain chloride profiles. Results show that mortar renderings directly influence chloride penetration into concrete and this influence is more pronounced for mortars with higher contents of cement and less porosity. This shows that, although mortars have higher porosity than concrete, they can provide an additional protection to concrete structures, delaying chloride penetration into bulk concrete.



## 1. Introduction

A significant number of concrete structures have been damaged by steel reinforcement corrosion around the world. Among the factors that contribute to this kind of damage, the aggressiveness of chloride ions is one of the main reasons for damage to ordinary concrete structures due to reinforcement corrosion [1]. These ions penetrate into concrete mainly by capillary absorption and diffusion [2,3]. This takes place through the direct contact with sea water or, in a significant number of cases, by exposure to marine aerosol [4–7].

Material characteristics affecting chloride ingress into concrete include material porosity [8–10], fissures characteristics [11,12], chloride binding ability of the cementitious matrix and its effect on accelerating or delaying chloride transport in concrete [13,14]. Environmental characteristics and concrete changes due to its environmental interaction that affect chloride ingress include temperature [15,16], concrete carbonation [14,17] and saturation degree of concrete porous network [18,19].

The majority of the works on these subjects took place in laboratory environments, where the variables are more easily controlled. Either in laboratory or under natural exposure, these works take into account the materials individually, either being concrete, mortar or cement paste [4–9,12–22]. The combined influence of concrete and mortar taken together, as a layered composite, has rarely been experimentally studied. Nevertheless, the rendering of concrete structures by a mortar layer is common in many countries.

Crank [23] presented a mathematical approach for mass transport in double layered systems considering mass transport by diffusion. Taking into account the skin effect, Andrade et al. [24,25] proposed Eqs. (1)–(3) as a solution for the chloride transport by diffusion in materials with different transport characteristics between the surface and bulk. In these equations, $C_1$ is the chloride concentration in the external layer, $C_2$ is the chloride concentration in the internal layer, $D_1$ is the diffusion coefficient in the external layer, $D_2$ is the diffusion coefficient in the internal layer, $C_s$ is the surface chloride concentration, $e$ is the thickness of the external layer (skin), $R$ is the resistance, if any, between the two layers (external and internal), $x$ is the depth studied and $t$ is the time demanded in the study.

$$C_1 = C_s \sum_{n=0}^{\infty} \alpha^n \left( erfc\left[\frac{2ne + x}{2\sqrt{D_1 t}}\right] - \alpha erfc\left[\frac{(2n+2)e - x}{2\sqrt{D_1 t}}\right]\right) \tag{1}$$

$$C_2 = \frac{2kC_sR}{k+1} \sum_{n=0}^{\infty} \alpha^n erfc\left[\frac{(2n+1)e + k(x-e)}{2\sqrt{D_1 t}}\right] \tag{2}$$

$$K = \sqrt{D_1/D_2}; \quad \alpha = (1-k)/(1+k); \quad C_1 = RC_2 \tag{3}$$

This approach carries some limitations like not taking into account the non-linearity of binding capacity of cement-based materials

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[26], the time dependence of chloride diffusion coefficient [8,27] or the influence of multi-species interactions on ionic transport [28–31]. More sophisticated models can embody these aspects for more reliable service-life predictions [28–33]. However, these models usually require a large number of input parameters. The simplified approach using Eqs. (1)–(3) can provide useful information for the case of double layered systems without the requirement of many input parameters, of which some are difficult to obtain.

Complementary to several numerical studies of double layered systems, one contribution in the experimental field was done by Kreijger [34]. This study identified the formation of a more porous surface layer that had different transport characteristics in comparison with the bulk material, which characterises the skin effect [24,25]. Nevertheless, as commented before, although there are many experimental works focused on durability performance of concrete and mortar individually, the combined behaviour of these materials as a double layered system has not been extensively studied.

The present work addresses this gap in knowledge by experimentally studying the influence of chloride transport in mortar renderings on chloride penetration into the concrete substrate, simulating the performance of this double layered system in buildings. The theoretical model represented by Eqs. (1)–(3) is fit to the experimental data and used to analyse the possible protective effect of mortar renderings on chloride penetration into concrete. The effects of material composition and rendering thickness are studied.

## 2. Experimental work

The specimens used in this research were made in three stages. First of all, concrete substrates were cast. On it, a thin layer of bonding spatter dash treatment was executed and, finally, a mortar rendering layer was added. These specimens are called here as layered specimens. Reference concrete specimens (without mortar layer) were also cast for comparison.

Cubic concrete specimens (substrates) were cast with the dimensions $80 \times 80 \times 80$ mm, using a Brazilian Portland cement with high early strength (ASTM type III), whose physical and chemical characteristics are presented in Table 1. The water to binder ratio was set at 0.55 and the mixture composition of concrete is detailed in Table 2. The slump of fresh concrete and the compressive strength of concrete at 28 days are also presented in the same table. After being removed from the moulds, the concrete substrates remained in laboratory environment up to 120 days to simulate a delay that usually occurs in real building process between casting concrete elements and execution of rendering layers. This condition was also followed by reference concrete specimens.

**Table 1**
Chemical composition and physical properties of cement and hydrated lime.

| Composition/property | | Portland cement | Hydrated lime |
|---|---|---|---|
| $SiO_2$ (%) | | 20.06 | 0.44 |
| $Al_2O_3$ (%) | | 5.99 | – |
| $Fe_2O_3$ (%) | | 2.18 | 0.08 |
| CaO (%) | | 60.48 | 67.76 |
| MgO (%) | | 3.82 | 2.82 |
| $Na_2O$ (%) | | 0.94 | 0.18 |
| $K_2O$ (%) | | 1.09 | 0.05 |
| Insoluble residue – IR (%) | | 0.46 | 0.12 |
| Loss on ignition – Li (%) | | 2.65 | 27.49 |
| Potential composition (Bogue equations) | $C_2S$ (%) | 19.49 | – |
| | $C_3S$ (%) | 50.40 | – |
| | $C_3A$ (%) | 12.18 | – |
| | $C_4AF$ (%) | 6.63 | – |
| Blaine ($cm^2/g$) | | 4815 | – |
| Specific density ($g/cm^3$) | | 3.09 | 2.42 |
| Compressive strength – 28 days (MPa) | | 34.94 | – |

**Table 2**
Mixtures and properties of concrete and mortars.

| Material | Concrete | Mortar 1:3* | Mortar 1:1:6* | Mortar 1:2:9* |
|---|---|---|---|---|
| *Relative proportions* | | | | |
| Cement (kg) | 1 | 1 | 1 | 1 |
| Hydrated lime (kg) | – | – | 0.30 | 0.59 |
| Sand (kg) | 2.52 | 3.53 | 7.05 | 10.58 |
| Coarse aggregate (kg) | 2.41 | – | – | – |
| Water to binder ratio | 0.55 | 0.6 | 0.83 | 1.11 |
| Cement ($kg/m^3$) | 370 | 437 | 250 | 173.5 |
| *Property* | | | | |
| Air content (%) | – | 2 | 2 | 4 |
| Slump/consistency level (mm) | 7 ± 1 | 262 | 264 | 262 |
| Compressive strength (MPa) – 28 days | 30.43 | 23.59 | 11.82 | 5.65 |
| Capillary absorption ($g/cm^2$) | 1.43 | – | – | – |
| Water absorption after immersion (%) | 4.86 | 8.24 | 10.40 | 11.33 |
| Dry specific density ($g/cm^3$) | 2.25 | 2.21 | 2.13 | 2.09 |
| Total porosity (%) | 10.95 | 18.19 | 22.13 | 23.72 |

* This identification refers to the mortar proportions in volume (cement: sand or cement: lime: sand).

Afterwards, the concrete substrates had one of their faces cleaned by manual brushing and received a thin layer of bonding spatter dash treatment. After three days, mortar rendering layers were executed with 25 and 40 mm thickness resulting in three different geometries for the layered and reference specimens (Fig. 1). For this purpose, three different mortar mixtures were used, which are represented by their proportions in volume as mortars 1:3, 1:1:6 and 1:2:9 (cement:sand or cement:lime:sand), as presented in Table 2. The physical and chemical characteristics of the used hydrated lime are presented in Table 1. The thickness and mixtures chosen in this research for mortar renderings were based in a previous research carried out in João Pessoa city, Brazil, which shows a high variability in mortar characteristics used in this city [35].

Three specimens were used for each experimental condition. All of them had five of their six faces painted with epoxy resin 28 days after the execution of the mortar rendering layer. A unique free face was used for the penetration of chlorides into concrete with the objective of simulating a unidirectional flux. The main steps in preparing the layered specimens are shown in Fig. 2.

The specimens were then subjected to diffusion tests. During these tests, the specimens remained 49 days immersed in one molar sodium chloride solutions in laboratory environment. The choice of this exposure period happened with the objective of adjusting the differences on chloride transport velocity in mortar and concrete, as these materials have significant differences on their mass transport characteristics. This was a consequence of preliminary tests carried out with mortars and concrete specimens subjected to different exposure periods. The reference specimens were subjected to the same conditions imposed to the layered specimens.

When the exposure period was over, the specimens were marked according to each sample depth and were continuously powdered at each 5 mm from surface to bulk. Close to the interface between mortar and concrete, the thickness was reduced to 2.5 mm, which had the objective of improving the resolution of chloride measurements in this region. Fig. 3 schematically shows the samples extraction from the specimens. After this extraction, total chloride content in each powered sample was measured using the potentiometric titration method, according to ASTM C114 [36].

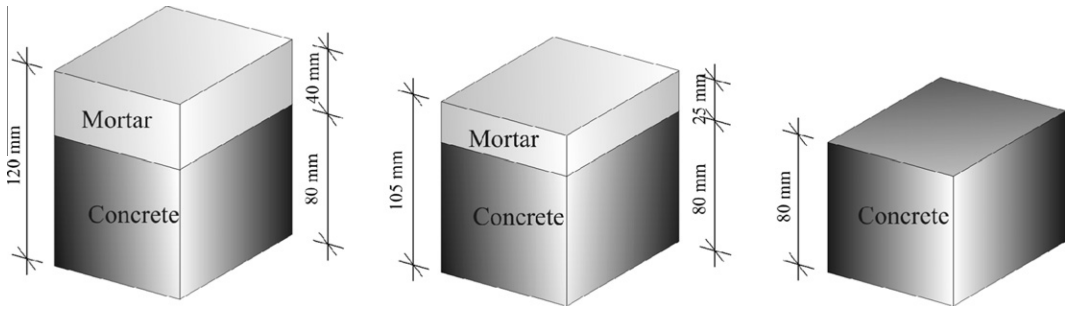


**Fig. 1.** Geometric characteristics of specimens used in the work.

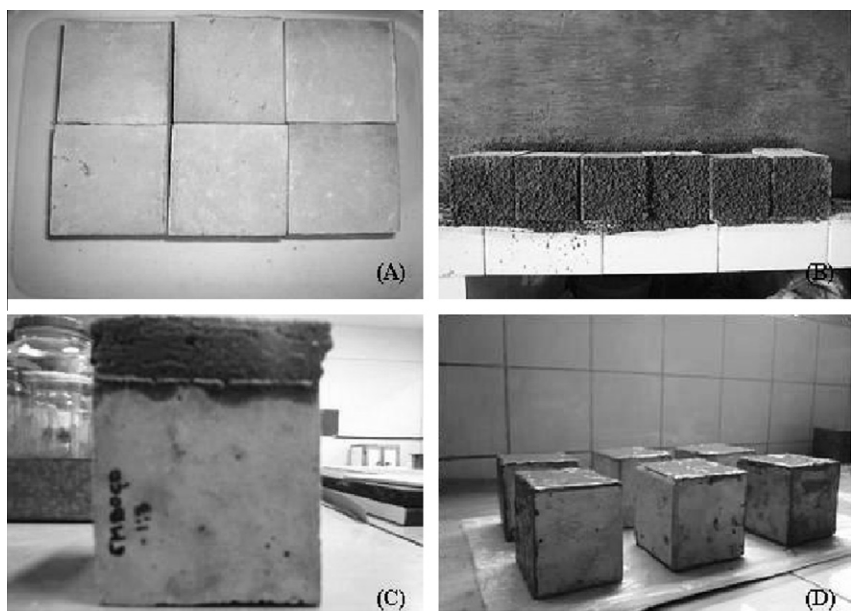


**Fig. 2.** Some stages of making layered specimens: clean surface of specimens (A), spatter dash treatment (B), mortar rendering layer (C) and epoxy resin layer (D).

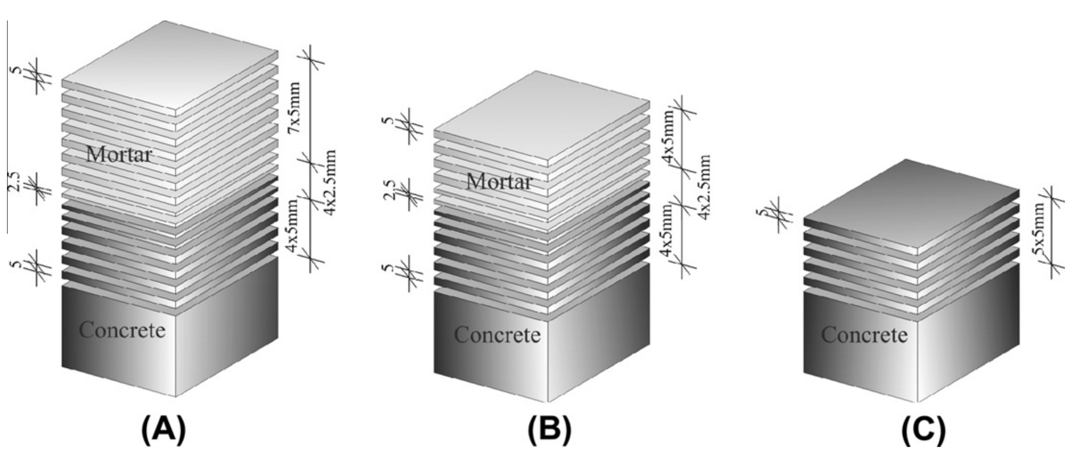


**Fig. 3.** Schematic representation for obtaining samples: layered specimens with 40 mm thickness of mortar rendering (A), layered specimens with 25 mm thickness of mortar rendering (B), and reference concrete specimens (C).

These results were used for drawing chloride profiles for the layered and reference specimens. As there were three specimens for each experimental condition, each chloride profile data represent the average of chloride content in three powdered samples.

## 3. Results

Chloride profiles obtained from the experimental work are presented in Figs. 4 and 5, for layered specimens. Taking into account

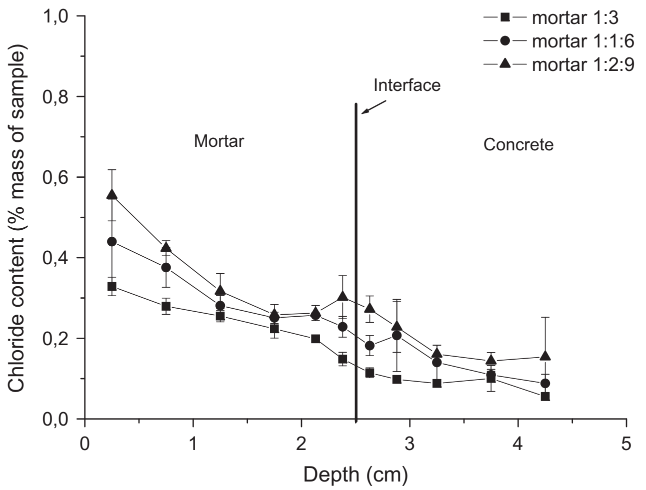


**Fig. 4.** Chloride profiles obtained from natural diffusion tests for specimens with 2.5 cm thickness of mortar rendering.

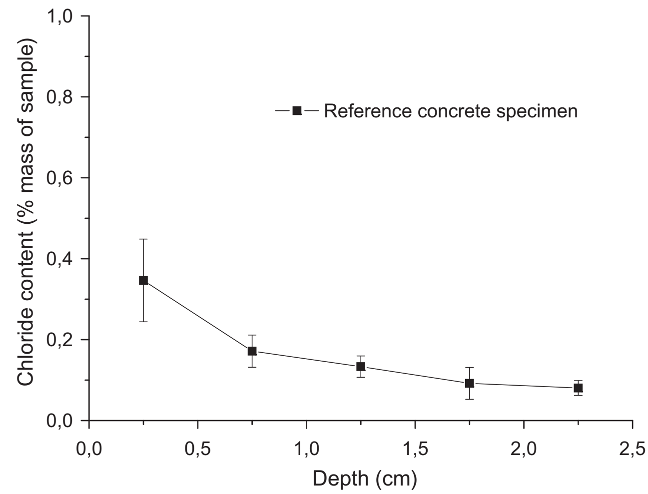


**Fig. 6.** Chloride profile obtained from natural diffusion tests for reference concrete specimens.

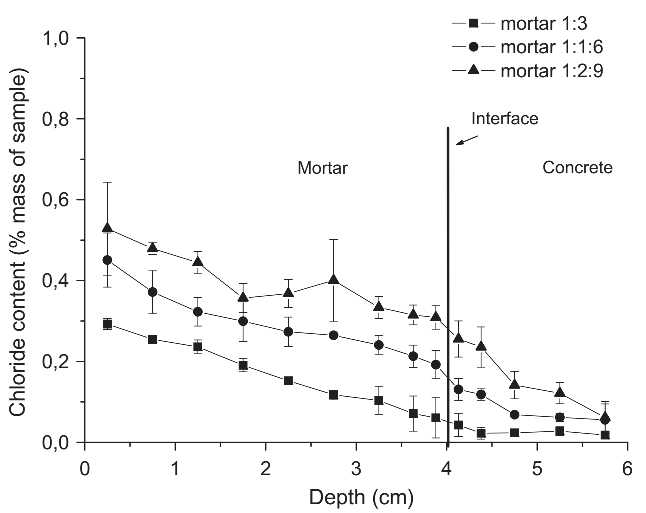


**Fig. 5.** Chloride profiles obtained from natural diffusion tests for specimens with 4.0 cm thickness of mortar rendering.

the differences in materials composition, percentage of sample mass was chosen to represent the results instead of percentage of cement mass. The depicted points represent average values for each depth analysed and their respective standard deviations. The deeper sample in concrete zone is not represented in Figs. 4 and 5.

Chloride profiles in Fig. 4 show that there is an increase in chloride contents with the mortar porosity increase and an accumulation of chlorides in the region just before the interface between mortar and concrete. This accumulation tendency can be observed thorough the more horizontal parts of profiles in the region closer to the interface between the different materials, which seems to be more pronounced for higher porosity mortars. A sharp decrease in chloride content just after the interface (i.e., in the outer region of concrete) can also be observed. All these aspects taken together provide evidence that there is a resistance to chloride penetration into concrete, which happens as a consequence of the differences in mass transport ability between mortars and concrete.

The same chloride accumulation in the interface region followed by an abrupt decrease in chloride content just after the interface can also be observed in Fig. 5. However, lower chloride contents in profiles obtained from specimens with 4 cm rendering thickness can be observed. This is clearer for layered specimens with less porous mortars and has the contribution of a longer pathway traveled by the ions before reaching concrete.

Fig. 6 presents a chloride profile for reference concrete specimens, which shows higher chloride contents than those obtained for layered specimens. This makes evident the complementary role of mortar rendering in protecting concrete structures against chloride penetration.

## 4. Discussion

### *4.1. Influence of mortar characteristics on chloride penetration into concrete*

Chloride profiles presented in Figs. 4–6 show that the studied mortars presented differences in their behaviour related to chloride penetration. Lower chloride contents can be observed in the mortar region when the mortar is richer in cement and less porous (Table 2). This relationship takes place for both rendering thicknesses and is closely related to the porosity reduction of higher cement content mortars and their consequent higher $C_3A$ content.

Considering the porosity reduction in higher cement content mortars, the results show a porosity decrease tendency from mortar 1:2:9 to mortar 1:3, which is also related to water to binder ratio and can be seen through the decrease in total porosity values from 23.7% to 18.2%, respectively (Table 2). This influences the chloride profiles presented in Figs. 4 and 5, as higher porosity means a faster transport of chlorides. Considering the $C_3A$ content, higher cement content means higher $C_3A$ content available to fix chlorides in the cementitious matrix [13–15]. This stronger ability for fixing chlorides tends to reduce the amount of free chlorides, which are the ones able to take part in mass transport and, consequently, this contributes to generate chloride profiles with lower concentrations.

The differences on chloride transport in mortar influence its transport in concrete. Figs. 4 and 5 show that there is a good harmony between the part of chloride profiles in mortar region and that in concrete region. It means that if fewer chloride ions reach the interface between both materials, even fewer ions are transported into concrete. Analysing Fig. 6 combined with Figs. 4 and 5, the positive effect of mortar rendering can be seen through a chloride content decrease in concrete. This influence is more accentuated for less porous mortars, which indicates that mortar rendering can contribute to protect reinforced concrete structures. However, this protective effect depends on mortar characteristics, such as its porosity and its chloride binding ability.

### 4.2. Influence of mortar thickness on chloride penetration into concrete

Curves based on Eqs. (1)–(3) were fitted to chloride profiles data presented in Figs. 4–6 with the objective of analysing the influence of mortar rendering thickness on chloride penetration into concrete. To do this, a diffusion coefficient of $4.9 \times 10^{-7}\ cm^2\ s^{-1}$ was used for concrete. It was obtained from diffusion tests carried out with reference specimens. The results obtained from these fittings are presented in Fig. 7, which compares the behaviour of fitted profiles in concrete region for different mortar rendering thickness.

The fitting based on Eqs. (1)–(3) represent an approximation to real conditions, as commented in Section 1. Nevertheless, regarding that the objective of this section is only to analyse the influence of mortar thickness on chloride penetration into concrete and that determination coefficients showed a good proximity to experimental data, this procedure was adopted in this work.

By Fig. 7, it can be seen that the thickness of mortar rendering is a property that significantly influences chloride transport in concrete. This influence is clearer for less porous mortars (Fig. 7b and c). For higher porosity mortars, there are no significant differences on chloride amounts that reach the interface between mortar and concrete and thus chloride profiles in concrete region represent this closer condition. In the context of the studied mortars, chloride content reductions at the level of 40% and 55% can be observed in the interface region for mortar 1:1:6 with rendering thickness of 2.5 and 4.0 cm, respectively (Fig. 7b). These values strongly increase for mortar 1:3 (Fig. 7c). On the other hand, they fall to only 10% in the case of mortar 1:2:9 (Fig. 7a).

The cross-over observed in Fig. 7 between fitting curves for specimens without mortar and with 2.5 cm of mortar rendering layer is a particular aspect that can be explained as a consequence of the following points. Data dispersion and the proximity of chloride content observed at inner layers (where lower values take place), which can be expected for levels close to the initial chloride content in specimens, helped to approach fitted curves at depths deeper than 2 cm (this is close to the depth where samples were collected). Furthermore, there was also a larger difference between chloride content at the concrete surface and those at inner layers for concretes without mortar layer in comparison with layered specimens, which defined higher curve slopes for the first case. This tendency was extended for layers which are deeper than the ones where samples were collected, which contributed to cross-over the related curves. However, this does not interfere with the analysis carried out in this section.

Taking into account less porous mortars, the increase of rendering thickness from 0 to 2.5 cm and from this to 4.0 cm leads to significant reductions in chloride concentrations in concrete. Aiming to resume this behaviour, Table 3 shows equivalent depths where chloride contents observed at 1 and 2 cm depth in concrete region for layered specimens with 2.5 and 4.0 cm of mortar rendering thickness are reached in reference concrete specimens. For this case, only mortars with significant influence on chloride transport in concrete were taken into account. It means that only layered specimens with mortars 1:1:6 and 1:3 were analysed. Results from this analysis show that, on studied depths, a 2.5 cm mortar rendering thickness can mean an equivalent concrete thickness between 0.35 and 0.90 cm. Furthermore, a 4.0 cm mortar rendering thickness can mean an equivalent concrete thickness between 1.10 and 2.25 cm. This way, depending on the characteristics of mortar and rendering thickness, its presence on concrete surface can be analysed as an equivalent additional concrete thickness.

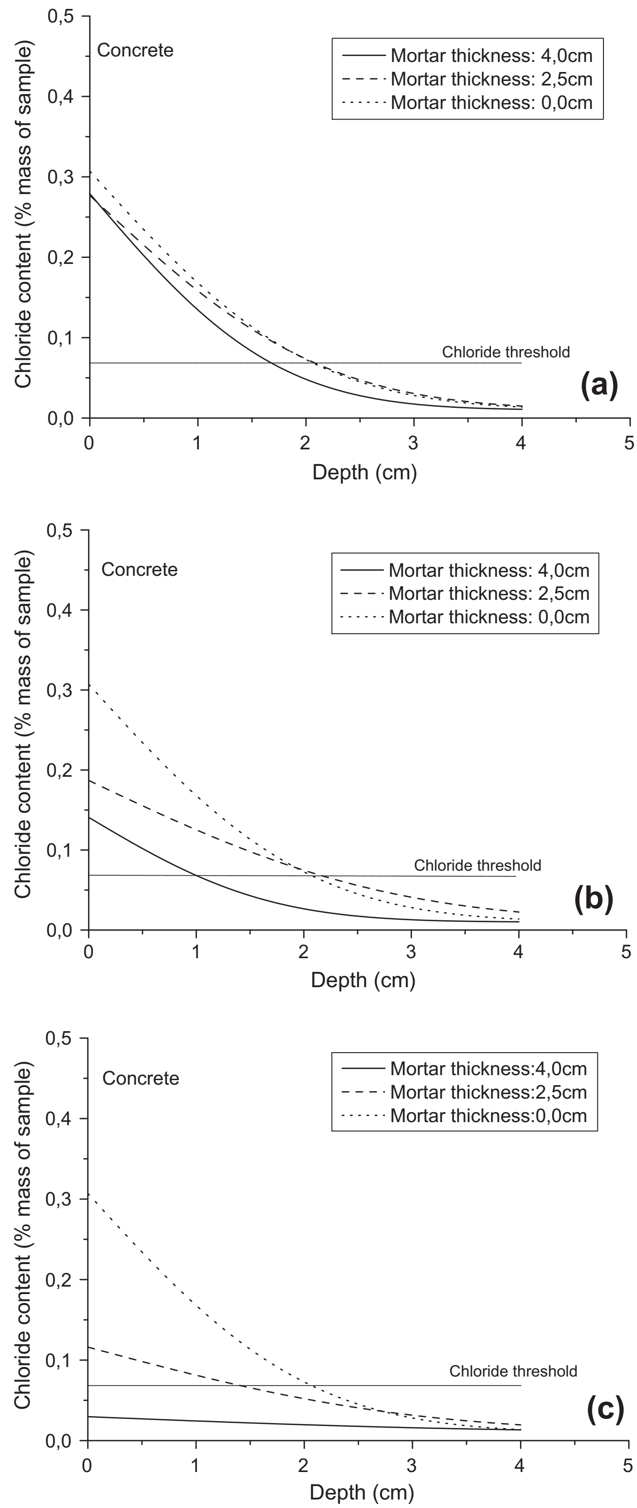


**Fig. 7.** Fitted chloride profiles in concrete region, obtained from Eqs. (1)–(3), for mortars 1:2:9 (a), 1:1:6 (b) and 1:3 (c).

Analysis of the depth in which the critical chloride content necessary to start corrosion process is reached in chloride profiles is another way for studying the influence of mortar rendering on chloride ingress into concrete. Considering the chloride threshold of 0.4% with respect to cement mass as a well accepted value [37,38], which means 0.065% respect concrete mass in the present case, it can be seen, by Fig. 7, that this critical content is reached at higher depths for concretes without rendering. This behaviour

**Table 3**
Influence of mortar thickness on chloride content in concrete.

| Mortar | Rendering thickness (cm) | A (% mass of concrete) | B (cm) | C (% mass of concrete) | D (cm) |
|---|---|---|---|---|---|
| 1:3 | 2.5 | 0.080 | 1.90 | 0.054 | 2.35 |
| | 4.0 | 0.025 | 3.25 | 0.020 | 3.35 |
| 1:1:6 | 2.5 | 0.125 | 1.40 | – | – |
| | 4.0 | 0.070 | 2.15 | 0.025 | 3.10 |

A – Chloride content at 1 cm depth in concrete – layered specimens.
B – Depth in which chloride content at 1 cm depth in concrete region of layered specimens is reached in reference specimens.
C – Chloride content at 2 cm depth in concrete – layered specimens.
D – Depth in which chloride content at 2 cm depth in concrete region of layered specimens is reached in reference specimens.

leads to significant differences when increasing rendering thickness, which can be clearly seen for layered specimens with mortars 1:3 and 1:1:6 and demonstrate the positive effect of mortar rendering on retarding the beginning of corrosion process in reinforced concrete structures.

## 5. Conclusions

The experimental work carried out in this study shows that mortar renderings positively act in relation to chloride penetration into concrete structures. However, this behaviour depends on material characteristics and on rendering thickness. Regarding material characteristics, those with higher cement content and less porosity more strongly contribute to retard chloride ingress into concrete and, consequently, to retard the start of steel reinforcement corrosion. Poor mortars (with low cement content and high water to binder ratio) do not significantly contribute to this effect and thus may not be taken into account.

Rendering thickness is another variable that influences the protection of reinforced concrete structures, with consequences on time taken for chlorides to cross the mortar layer and reach concrete. Nevertheless, this influence may be analysed simultaneously with material characteristics, as this positive effect is only significant for higher quality mortars.

These aspects taken together show that, although mortars usually have higher porosity than concrete, they can contribute to protect reinforced concrete structures against chloride penetration and this additional protection can be considered as an equivalent additional concrete thickness. This way, it is important to say that this work does not defend the position of increasing rendering thickness for increasing its protection action on concrete structures, but analyses this effect and shows that it takes place even for usual mortars, like mortar 1:1:6 and usual rendering thickness, like 2.5 cm. For this reason, this complementary effect should be taken into account when analysing service life of concrete structures.

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