Consolidation of ceramic bricks - Potential harmfulness assessment

Joana de Almeida Correia Beringuilho

May 2017

Civil Engineering, Architecture and Georresources Department, Instituto Superior Técnico, Universidade de Lisboa, Portugal

Abstract

Ceramic bricks have been used as a construction material since the most ancient civilizations and are still found, nowadays, in numerous buildings of great cultural and architectural value. However, the prolonged exposure to weathering phenomena leads to various forms of degradation, so that, in an attempt to restore the original properties of the material, the use of conservation technics resorting to consolidant products, became common practice.

The lack of information about consolidation treatments applied on ceramic bricks, justifies the development of the present work.

The experimental work consisted on a previous characterization of the existent ceramic material and, afterwards, the potential harmfulness of the consolidation treatment was assessed, resorting to an ethyl silicate. The characterization of the ceramic material revealed the existence of heterogeneity and anisotropic behaviour in the analysed sample. The potential harmfulness assessment of the consolidation treatment was made through a comparative analysis of non-treated and treated specimens.

The treatment promoted colour changes ($\Delta E^*>3$) and modifications related to water transport properties related to alterations of the porous space. In terms of global potential harmfulness assessment, the treatment revealed a moderate incompatibility degree.

Key words: Ceramic Brick – Consolidation Treatment – Ethyl Silicate – Potential harmfulness assessment

1 Introduction

Ceramic bricks have been used since the most ancient civilizations. Nowadays there are numerous buildings and monuments with brick masonry that still remain, proving the high resistance and durability of this excellent construction material. However, the progressive exposure to weathering processes (acid rain, salt crystallization, freeze-thaw) leads to the development of several degradation forms that threaten the durability of ceramic bricks. These degradation processes undergo increases in the open porosity and water absorption, that generally results in decrease of mechanical properties (Franzoni *et al.*, 2016). Consequently, the problematic of the conservation of ancient ceramic bricks is of extreme importance in restoration of cultural and architectural heritage of many countries like Portugal.

A lot of times, the replacement of degraded elements is not possible or not recommended, hence the justification for consolidation treatments, that promote cohesion and adherence to decayed materials, thus improving mechanical properties (Franzoni *et al.*, 2013). These improvements are obtained mainly through alterations in the porous structure, as decrease of open porosity.

Still, consolidation treatments are considered very risky due to their irreversibility and likeliness to cause harmful effects (Ferreira Pinto e Delgado Rodrigues, 2008). Regarding this matter, it is fundamental to evaluate if the changes promoted by the application of any consolidation treatment are acceptable or not. This process of evaluation is a complex and delicate one, because it is very difficult to define. Nevertheless, Franzoni *et al.* (2016) summarized the requirements that a stone consolidant should fulfil (applicable as well to any porous material, like ceramic bricks) (Franzoni *et al.*, 2016).

<u>Effectiveness</u>: The consolidant should penetrate deep into the substrate and increase mechanical resistance.

Compatibility: The treatment shouldn't cause alterations to the aesthetical aspect visible to the human eye, like darkening, change of colour or wet appearance. Moreover, the consolidant should not originate harmful by-products to the substrate or evaporation of toxic components. In terms of changes in physical properties, it is expected that the material suffers from reduction in open porosity and water absorption capacity. However, consolidants that clog pores or that drastically alter water transportation properties inside the material, should be avoided. A good consolidation treatment would be the one where the water vapour permeability is preserved, and the diffusion of water vapour through the material is maintained. These requirements become fundamental in conservation treatments that resort to consolidants, because in case liquid water and water vapour is blocked behind the treated layer, and the water is subject to freezing or salt crystallizations phenomenon's, serious degradation forms may take place. For the same reason, another factor to take into consideration is the drying rate of the treated material, which should be altered as little as possible. Lastly, the consolidation treatment should induce gradual variations as the consolidant penetrates deep into the material, minimizing the occurrence of harsh treated/non-treated interfaces. The transition should be gradual and there should be no superficial hard crust formed after the treatment.

Durability: The continuous exposure to environmental weathering over time should not lead to loss of effectiveness and the consolidant should not give rise to harmful products by itself.

The concept of compatibility substantially coincides with the concept of potential harmfulness (Delgado Rodrigues e Grossi, 2007). Those are the most complex concepts in the conservation field, because the parameters to be tested are not well defined, nor there are exact rules that define which results can be considered successful (Franzoni *et al.*, 2016).

However, Delgado Rodrigues e Grossi (2007) proposed a methodology on how to integrate results on a decision-making process to evaluate compatibility/ potential harmfulness of conservation treatments, which will be used for the purposes of the present work and it will be explained later on.

2 Experimental characterization

2.1 Materials

The ceramic bricks used in the development of the present work have approximate dimensions of 4x5x20[cm] (Figure 1), and present some irregularities in form and punctual defects.

Figure 1 – Ceramic

The consolidant product used was Silres BS OH 100, which is an ethyl silicate manufactured by Wacker. It is a solventless, ready-to-use product for the consolidation of construction materials (Wacker, 2014).

2.2 Ceramic bricks characterization

Before engaging into the consolidation of the ceramic bricks, it is crucial to evaluate some physical and mechanical properties of this material in order to establish its degradation state and intrinsic characteristics. Therefore, the following characteristics were determined in ceramic bricks of approximate dimensions 4x5x20 [cm]:

- Porosity, bulk density, real density and maximum water content;
- Water content after 48 hours of immersion;
- Capillarity water absorption coefficient;
- Ultrasonic velocity;

Table 1 shows the average and standard deviation values of porosity and density (bulk and real) and maximum water content of the ceramic bricks tested.

Table 1 - Porosity, density and maximum water content.

n	Porosity [%]	Density [kg/m³]		Maximum water content [%]
		Real	Apparent	
53	19,1 (±1,8)	2585 (±26)	2092 (±28)	9,1 (±1,0)

Table 2 presents the results of maximum water content and after 48 hours of immersion and its respective saturation coefficient, for a smaller sample of ceramic bricks.

Table 2 - Porosity, maximum and 48h of immersion water content and saturation coefficient.

n	Porosity [%]	Water content [%]		Saturation coefficient [%]
		Maximum	48 hours of immersion	
19	19,5 (±1,7)	9,4 (±1,0)	7,5 (±1,0)	80,2 (±2,9)

The results showed a considerable variability in values, evidencing the heterogeneity of the ceramic bricks. Experimental data regarding ancient ceramic bricks was found in literature. Fernandes (2006) determined values of porosity and maximum water content of bricks originating from ancient portuguese monuments, and the results obtained in the present study are within that reference range, but under the higher incidence of results determined by the author [(Fernandes *et al.*, 2010) (Fernandes e Lourenço, 2016)]. Fernandes (2006) also determined apparent densities, and those values are lower than the ones presented on this work (Fernandes e Lourenço, 2016)]. The results of the saturation coefficient are high which reveals that the ceramic brick is easily saturated by immersion for 48h in water, consequence of the well-connected porous network inside the material.

The determination of water absorption by capillarity and of the ultrasonic velocity was performed according to three different directions (Figure 2) to assess the anisotropy of the bricks.

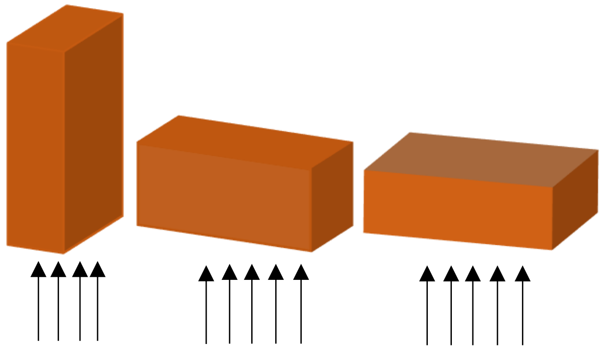

Figure 2 – Studied axial directions.

Table 3 presents the average and standard deviation values of the capillarity coefficient and asymptotic values for a sample of 11 bricks with porosity between the range of 19,9% and 21,9%.

Table 3 - Capillarity coefficients and assimptotic values.

n	Longitudinal		T1		T2	
	CC	VA	CC	VA	CC	VA
11	0,107 (±0,019)	32,8 (±1,5)	0,104 (±0,022)	8,0 (±0,4)	0,095 (±0,014)	6,6 (±0,3)

CC – Capillarity coefficient $[kg/m^2.s^{0.5}]$; *VA* – Assimptotic value $[kg/m^2]$.

The average values of the capillarity coefficient are rather similar for the three tested directions, which reveals little anisotropic behaviour of the ceramic brick. The average values of the Capillarity coefficients are, once again, within the reference range reported by Fernandes (2006) in his characterization study on ancient bricks, but the minimum results obtained in the present work are under the range of results presented by the author (Fernandes *et al.*, 2010). Assimptotic values depend on the capillarity direction analysed, meaning that Longitudinal direction presents higher assimptotic values because it has the highest absorption height.

The results of the ultrasonic velocity determined in ceramic bricks are presented in Table 4, according to their range of porosity.

Table 4 - Ultrasonic velocity.

n	Porosity [%]	Ultrasonic velocity (m/s)					
		Longitudinal		T1		T2	
		dry	saturated	dry	saturated	dry	saturated
5	15,6 (±0,9)	3475 (±108)	3633 (±88)	3249 (±110)	3449 (±206)	2896 (±296)	3246 (±297)
3	20,4 (±0,4)	3291 (±128)	340 (±126)	3040 (±78)	3261 (±89)	2631 (±98)	2711 (±80)

The highest values correspond to the Longitudinal direction. On the contrary, the lowest values match the T2 direction, and the intermediate values correspond to the T1 direction. The ultrasonic velocity values are rather distinct and vary according to the analysed direction, so it's concluded that the bricks present an anisotropic behaviour quite strong. The ultra-sonic velocity values obtained in saturated bricks are slightly higher than those determined in dry bricks, which points out for the presence of porous space constituted by an open and interconnected porous network, partially composed by fissures.

3 Consolidation Treatment

3.1 Consolidation Procedure

The consolidation treatment was applied by brushing in samples with average dimensions of 3,7x7,6x5,0 [cm], along the "treatment face", which corresponds to the face of the brick that, in brick masonry, would be visible and exposed to weathering.

Specimens were treated approximately until half of the sample's height and, depending on the sample in question, between 13 and 16 applications steps were made. Each application step had the duration of approximately 5 minutes and the breaks between them were, respectively, 5 minutes, 10 minutes, 15 minutes and from then on, every 20 min until the last application step. The total duration of the procedure varied from 4h35min to 5h50min.

In order to reduce the heterogeneity of the samples, each pair of treated and non-treated specimens belonged to the same brick.

Table 5 presents the average and standard deviation values of the final amount of consolidant product consumed and absorbed, for the treated samples.

Table 5 – *Amount of product consumed and absorbed, for the treated samples.*

n	Amount of consumed product (kg/m²)	Amount of absorbed product (kg/m²)
6	4,82	4,18

After the application of the consolidation treatment, the specimens were maintained in laboratory conditions (HR = 56±15% e T= 24±4ºC) for about 128 days, and the control of the specimens' mass was carried out through that time gap (Figure 3).

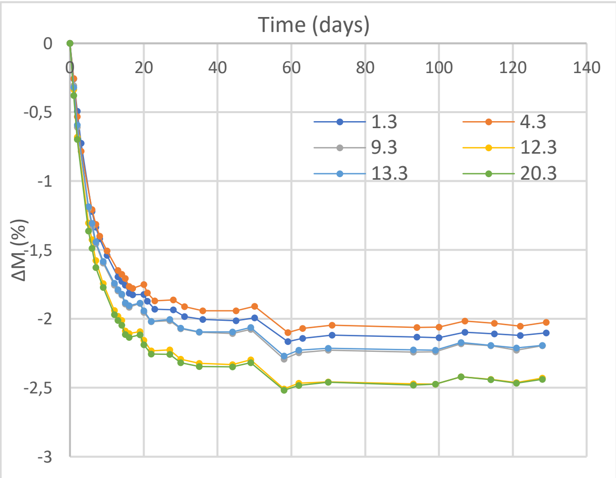

Figure 3 - Control of treated samples weight loss after treatment.

The same type of consolidation treatment was also executed in scope of another investigation associated with the effectiveness assessment of consolidation of ceramic bricks (Ribeiro, 2016). The used consolidation procedure was very similar to the one presented on this work, thereby the results presented by Ribeiro (20016) will be summarized later on, in order to integrate the complex process of potential harmfulness assessment.

3.2 Potential harmfulness assessment

The evaluation of the potential harmfulness of any consolidation treatment comes as a step downstream to effectiveness and it should only be introduced in the process when the effectiveness of the given treatment is guaranteed within acceptable limits (Delgado Rodrigues e Grossi, 2007).

On that note, the Ribeiro (2016) pursued the thematic of effectiveness assessment resorting to several experimental tests, performed on non-treated and treated samples, including:

- Ultrasonic velocity test (samples size: 2,5x4x20 [cm]);
- Compressive strength test (samples size: 2,5x4x20 [cm]);
- Bending strength test (samples size: 2,3x2,4x3 [cm]);
- Microdrilling test (samples size: 2,3x2,4x3 [cm]);

Those results will be exposed later, in chapter 5.3 – Results Analysis.

For purposes of evaluating the potential harmfulness of the consolidation treatment, in the present work, the following characteristics were analysed, in treated and non-treated samples:

- Colorimetric changes (samples size: 3,7x7,6x5,0 [cm]);
- Porosity and maximum water content (samples size: 3,7x3,7x5,0 [cm]);
- Water absorption by capillarity (samples size: 3,7x3,7x5,0 [cm]);
- Drying behaviour (samples size: 3,7x3,7x5,0 [cm]);
- Water vapour permeability (samples size: 3,7x3,7 [cm] and thickness between 6 and 9 mm);

3.2.1 Colorimetric Changes

The colorimetric analysis was performed on samples, before and after treatment, with the aid of a spectrocolorimeter, and analysed according to the colour system CIELAB, L*, a* e b*. Table 6 presents the average colorimetric changes obtained through the differences in colorimetric coordinates (ΔL*, Δa*, Δb*) and differences in chroma (ΔC*) and in total colour difference (ΔE*).

Table 6 - Colorimetric changes induced by the consolidant.

n	ΔL*	Δa*	Δb*	ΔC*	ΔE*
6	-4,09 (±0,70)	1,61 (±0,76)	3,93 (±0,79)	4,03 (±1,07)	5,91 (±1,20)

The negative values of ΔL* obtained mean that the treatment originated a darkening of the surface. Δa*, Δb* values are positive, which corresponds to changes to the more red (a*) and yellow (b*) extreme, respectively. The difference in chroma (ΔC*) is positive, which translates into a more saturated colour.

The consolidation treatment originated, in average, a total colour difference (ΔE*) of 5,91, thereby it is possible to conclude that the treatment was responsible for alterations in colour visible to the human eye (ΔE*>3) [(Franzoni *et al.*, 2016) (Lou *et al.*, 2015)].

3.2.2 Porosity and maximum water content

Table 7 shows the average and standard deviation values of porosity and maximum water content for non-treated and treated samples.

Tabela 7 - Porosity and maximum water content, on non-treated and treated samples.

Non-treated samples		
n	Porosity [%]	Maximum water content [%]
12	20,7 (±0,2)	9,9 (±0,2)
Treated samples		
n	Porosity[%]	Maximum water content [%]
12	18,7 (±0,3)	8,8 (±0,2)

A decrease in the average values of porosity and maximum water content is noticeable on treated samples. These variations are due to the fact that the consolidation treatment originated a reduction of the void volume, once that the product, after precipitation, filled in part of the porous space of the samples.

3.2.3 Water absorption by capillarity

Figure 4a) and Figure 4b) present the curves of water absorption by capillarity, obtained from non-treated and treated samples, according to the capillarity direction T1.

The purpose of testing the T1 direction is related to the need to study the behaviour of the face where the consolidation treatment was applied. On that note, the face of the sample in contact with the water blade corresponded to the "treatment face".

The initial segment of non-treated samples curves shows greater slope than the initial segment of treated samples curves, which corresponds to a higher initial water absorption velocity by capillarity. The water absorption by capillarity was much slower on treated samples so that, in many cases, the initial segment of the treated samples curves did not end on the same day that the test was initiated.

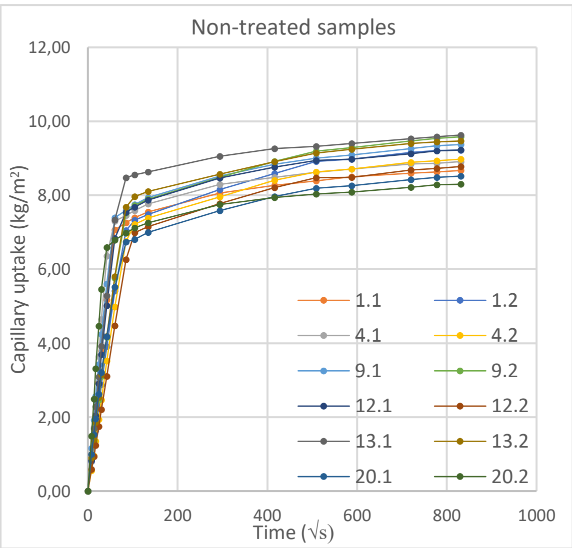

Figure 4 a) - Capillarity water absorption curves on non-treated samples.

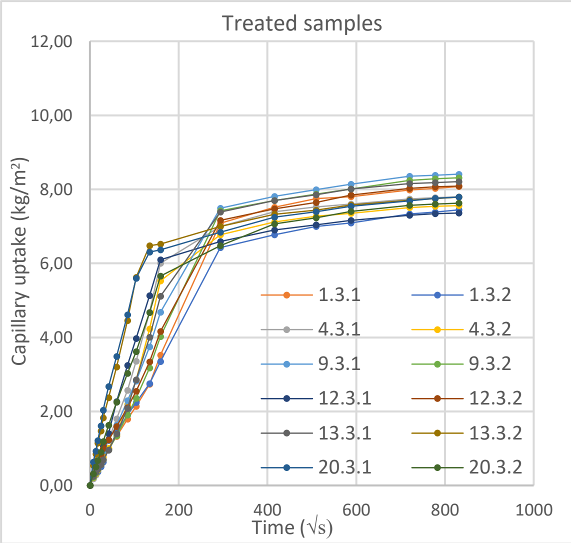

Figure 4 b) - Capillarity water absorption curves on treated samples.

Table 8 presents the average and standard deviation values of the capillarity water absorption coefficient and assimptotic values tested on non-treated and treated samples.

Table 8 - Capillarity coefficients and assimptotic values.

Non-treated samples		
n	T1	
	CC $[kg/m^2.s^{0.5}]$	VA $[kg/m^2]$
12	0,112 (±0,031)	9,1 (±0,4)
Treated samples		
n	T1	
	CC $[kg/m^2.s^{0.5}]$	VA $[kg/m^2]$
12	0,033 (±0,010)	7,9 (±0,3)

The analysis of Table 8 reveals a very significant reduction of the capillarity water absorption coefficient on treated samples. Assimptotic values are also lower for treated samples, which equivales to less capillary water uptake (kg/m²).

3.3.4 Drying behaviour

For the studying of drying behaviour, the samples were sealed with epoxy resin SIKADUR 32N, to induce one-directional migration of moisture towards the top surface during drying. Afterwards, the specimens were saturated in vacuum conditions and let too dry under laboratory conditions (HR=60±21% e T=18±5ºC).

Figure 5a) and Figure 5b) shows the drying curves of non-treated and treated samples, resulting from periodical weighing of the specimens.

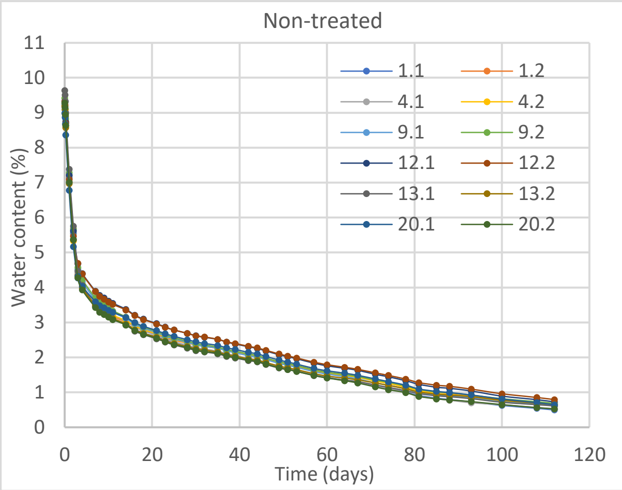

Figure 5 a) – Drying curves on non-treated samples.

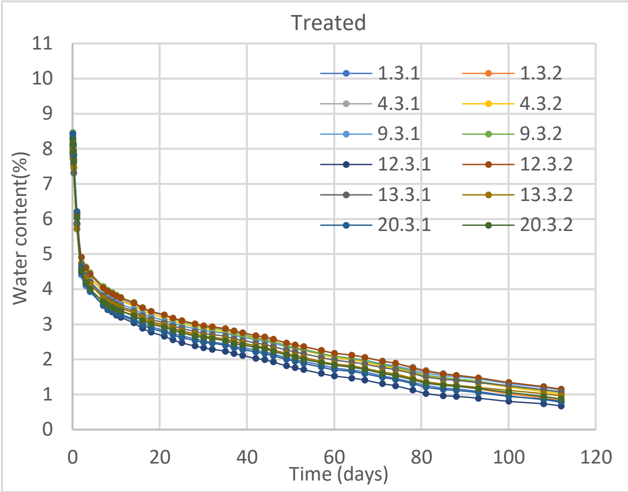

Figure 5 b) – Drying curves on treated samples.

The obtained drying curves show that the consolidation treatment originated changes on the drying kinetics of the ceramic samples. In every curve, there is an initial straight segment that corresponds to a constant drying rate, and it is possible to identify the inflexion point from which on the drying rate starts to be decreasing (critical moisture content).

Table 9 presents the average and standard deviation values of water content in the beginning and at the end of the test, the critical moisture content and the drying index, of non-treated and treated samples.

Table 9 - Water content in the beginning and at the end of the test, critical moisture content and drying index.

Non-treated samples				
n	Water content in the begging of the test (%)	Water content at the end of the test (%)	Critical moisture content (%)	Drying index
12	9,38 (±0,19)	0,63 (±0,15)	4,43 (±0,15)	0,205 (±0,022)
Treated samples				
n	Water content in the begging of the test (%)	Water content at the end of the test (%)	Critical moisture content (%)	Drying index
12	8,18 (±0,15)	0,96 (±0,08)	4,66 (±0,15)	0,271 (±0,013)

An increase in the drying index of treated samples is verified, which confirms the tendency for the consolidation treatment to decelerate the drying process. The critical moisture content is similar for both non-treated and treated samples. However, this parameter was obtained 72h after the test was initiated, for non-treated samples, and only 48h after, in case of treated samples.

3.2.5 Water vapour permeability

The water vapour permeability test was performed resorting to the "dry cup" method. The following methodology was used: the sample was placed above a cup with a solution of calcium chloride, to generate an HR of approximately 0%, and the assemblage was placed inside a chamber, containing a supersaturated solution of sodium chloride, that provided an HR of approximately 75%. In this "dry cup" method a unidirectional vapour flux was induced through the sample, from the outside to the inside of the cup. The weight gain of the assemblage and the conditions of the chamber were periodically measured throughout the test.

The samples used in this test were obtained through the cut of each larger samples into two less thicker specimens, designated P1 and P2, as illustrated through the example in Figure 6.

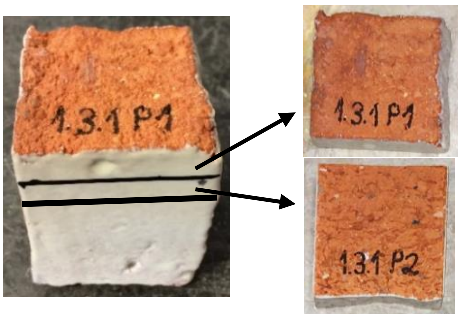

Figure 6 - Cut and designation of samples P1 and P2.

Table 10 shows the average and standard deviation values of the permeability coefficient ($\prod$) and the diffusion-equivalent air layer thickness (Sd), of non-treated and treated samples.

Table 10 - Permeability coefficient (∏) and the diffusion-equivalent air layer thickness (Sd), on non-treated and treated samples.

Non-treated samples				
n	∏ x $10^{-8}[kg.m^{-1}.h^{-1}.Pa^{-1}]$		Sd [m]	
	P1	P2	P1	P2
2	1,28	1,83	0,41	0,26
	1,09	1,70	0,43	0,30
Treated samples				
n	∏ x $10^{-8}[kg.m^{-1}.h^{-1}.Pa^{-1}]$		Sd [m]	
	P1	P2	P1	P2
6	0,93 (±0,12)	1,38 (±0,12)	0,57 (±0,08)	0,36 (±0,03)

The consolidation treatment originated a decrease of the permeability coefficient and an increase of the diffusion-equivalent air layer thickness, in both specimens P1 and P2. Specimens P1, revealed to be less permeable than specimen P2 by showing lower values of permeability coefficient.

3.3 Results Analysis

In previous sub-chapters a comparative analysis of the results obtained in non-treated and treated samples was made, but, in terms of potentially harmful effects of the changes occurred, not very significant conclusions were laid out. In a study presented by Delgado Rodrigues e Grossi (2007), the authors proposed a multicriteria system to evaluate the incompatibility risk of any given conservation action. Such system constitutes a valid instrument for potential harmfulness assessment, in regard of the present work.

The multicriteria system consists of qualifying the position of a given parameter (compatibility indicator) in a rating between 0 and 10, according to its potential as inducer of harmful effects. The rating of 0,5 and 10 refers to low, medium, or high risk of incompatibility (Delgado Rodrigues e Grossi, 2007).

Table 11 presents the rating scale proposed by Delgado Rodrigues & Grossi (2007). It is important to point out that the system was created regarding a consolidation treatment for stone surfaces. Nevertheless, it constitutes mere guide lines, and may also be applied in case of ceramic materials.

Delgado Rodrigues e Grossi (2007) stress that not every compatibility indicator identified needs necessarily to be used when there is lack of supporting data. Thereby Table 11 is an adaptation of the original one, and does not mention compatibility indicator which were neither tested in the present work nor presented by Ribeiro (2016).

Table 11 – Incompatibility risks associated with a consolidation treatment (Delgado Rodrigues e Grossi, 2007).

Criteria	Compatibility indicator	Incompatibility risks (rating scale)
Visual properties	Total colour difference (ΔE*)	Less than 3 → 0 Between 3 and 5 → 5 Higher than 5 → 10
Mechanical properties	Bending strength Compressive strength Drilling resistance	Values vary less than 10% → 0 Values vary between 10 e 25% → 5 Values vary more than 25% →10
Hydrophilic behaviour	Water absorption coefficient Drying index Water vapour permeability	Values vary less than 10% → 0 Values vary between 10 e 25% → 5 Values vary more than 25% →10

The authors also point out that the rating system can also be complemented with other parameters considered relevant, so Table 12 presents the average and standard deviation values for the compatibility indicator determined both in the course of the present work as in the work developed by Ribeiro (2016).

Delgado Rodrigues e Grossi (2007) proposed a mathematical formulation to integrate the ratings into a overall incompatibility degree of a given conservation treatment:

$$ID_n = \sqrt{\frac{C_1^2 + C_2^2 + \cdots + C_n^2}{n}}$$

ID_n – incompatibility degree;
C_1 ... C_n – ratings of the compatibility indicators (1 to n);
n – number of indicator used in the computation ID_n.

Integrating all the ratings presented on Table 12, it has:

$$ID_n = \sqrt{\frac{10^2+0^2+0^2+10^2+10^2+10^2+5^2+0^2+0^2+5^2}{10}} = 6{,}71$$

Where:
$ID_n = 0$ corresponds to a perfectly compatible action;
$ID_n = 10$ corresponds to a perfectly incompatible action;

The calculated value ($ID_n = 6{,}71$) is situated between an intermediate situation of compatibility and the extreme of perfectly incompatible, but closer to an intermediate classification (ID_n= 5).

Delgado Rodrigues e Grossi (2007) refer that the rules suggested for the rating system are a first approach to the compatibility assessment of conservation actions and although some of them are supported by experimental data, available in literature, others are just merely based on logical thinking. This means that further research is needed to validate and calibrate the system in order to build a strong and supported methodology.

Table 12 - Values for the compatibility indicator determined in the course of the present work and in the study developed by Ribeiro (2016).

Criteria	Compatibility Indicator			Average and standard deviation values		Percentual Variation (NT vs T)	Incompatibility risks (rating scale)
				NT	T		
Visual Properties	Total colour difference (ΔE*)			5,91		-	10
Mechanical Properties	Ultrasonic velocity (m/s) Direct method	Dry	L	2552 (±91)	2703 (±89)	5,92%	0
			T1	1216 (±87)	1301 (±54)	7,0%	
		Saturated	L	2652 (±76)	2766 (±86)	4,30%	
			T1	1259 (±76)	1344 (±42)	6,75%	
	Bending resistance (MPa)			1,6 (±0,3)	1,7 (±0,3)	6,25%	0
	Compressive resistance (MPa)			18,2 (±2,4)	19,5 (±2,6)	7,14%	0
	Drilling resistance (N)			20 (±5)	31 (±7)	55,0%	10
Hydrophilic behaviour	Porosity (%)			20,7 (±0,2)	18,7 (±0,3)	9,66%	0
	Maximum water content (%)			9,9 (±0,2)	8,8 (±0,2)	11,11%	5
	Water absorption coefficient $[kg/m^2.s^{0.5}]$			0,112 (±0,031)	0,033 (±0,010)	70,54%	10
	Drying index			0,205 (±0,022)	0,271 (±0,013)	32,20%	10
	Water vapour permeability $\prod$ x $10^{-8}[[Kg.m^{-1}.h^{-1}.Pa^{-1}]$		P1	1,19 (±0,10)	0,93 (±0,12)	21,85%	5
			P2	1,76 (±0,07)	1,38 (±0,12)	22,03%	

With that being said, the obtained results should be critically analysed, in order to rethink the rating conferred to certain compatibility indicator.

Relatively to the total colour difference (ΔE*), the registered value is found to be the on the threshold of what is considered acceptable (ΔE*<5), thereby the rating of 10 might be to penalty. The visual inspection made in the ceramic samples, before and after the treatment, did not reveal an extreme visual difference (Figure 7).

Figure 7 – Samples before and after treatment – colorimetric analysis.

Evidently, some darkening of the treated samples occurred, but not to the point to assign high risk of incompatibility to this parameter. On that note, a new rating scale is proposed (Table 13).

Table 13 – Proposal for a new rating scale for the compatibility indicator ΔE.*

Criteria	Indicador de compatibilidade	Riscos de Incompatibilidade (escala de classificação)
Visual Properties	Total colour difference (ΔE*)	Less than 3 → 0 Between 3 and 6 → 5 Higher than → 10

Based on the new rating scale proposal for the incompatibility indicator ΔE*, the incompatibilidty degree was once again determined:

$$ID_n = \sqrt{\frac{5^2+0^2+0^2+10^2+10^2+10^2+5^2+0^2+0^2+5^2}{10}} = 6,12$$

The obtained result ($ID_n = 6,12$) is found to be closer to an intermediate level of incompatibility, which constitutes an upgrade compared to the first ID_n calculation ($ID_n = 6,72$).

Another approach would be to perform an arithmetic mean of the ratings given to each compatibility indicator, instead of a quadratic mean, as proposed by Delgado Rodrigues & Grossi (2007). This suggestion is made once the quadratic mean "amplifies" the more severe ratings (10) and devalues the favourable ones (0). Meanwhile, the arithmetic means weights equally all the ratings, as follows:

$$ID_n = \frac{5+0+0+10+10+10+5+0+0+5}{10} = 4,5$$

The obtained result ($ID_n = 4,5$) is found between the perfectly compatible extreme and an intermediate level of compatibility.

The analysis of the three determined ID_n show that the first two calculations, respectively, $ID_n = 6,71$ and $ID_n = 6,12$, are situated between an intermediate level of compatibility (ID_n= 5) and the perfectly incompatible extreme (ID_n= 10), even though both are closer to an intermediate classification. The last determined ID_n, corresponds to an incompatibility degree closer to the perfectly compatible extreme (ID_n= 0), when compared to the last two. Even though the previous calculations present some scattering of results, in terms of global assessment of the potential harmfulness, it can be concluded that the consolidation treatment with the ethyl silicate Silres BS OH 100, applied to ceramic samples, originated a moderate degree of incompatibility.

The redefinition of the rating scale attributed to the compatibility indicator ΔE* and the alternative proposal for the metaethical calculation of the ID_n (arithmetic mean), consist on calibration attempts of the methodology proposed by Delgado Rodrigues e Grossi (2007), but to validate any new methodology, it would be necessary further investigation and more experimental data. In scope of future development proposals, the study of new application methods and more consolidant products may contribute to de development of a strongly supported methodology, applicable to ceramic materials.

4 Conclusions

The characterization of the existent sample revealed the heterogeneity of the ceramic bricks, once the open porosity values and maximum water content determined showed significant variability. The saturation coefficient results were quite high, thus revealing interconnected porosity of the sample bricks. The capillarity water absorption test and the ultrasonic velocity revealed some amount of anisotropic behaviour through three different directions, and the differences between ultrasonic velocity determined on dry and saturated samples point out the presence of a porous space partially constituted by fissures.

The potential harmfulness assessment of the consolidation treatment was made through a comparative analysis of the results of non-treated and treated specimens. The treatment promoted colour changes visible to the human eye (ΔE*>3), and a darkening of the treated surface. The consolidant also originated a decrease of open porosity and maximum water content, consequence of the reduction of porous space through the precipitation of product inside the pores of the ceramic. The water absorption test by capillarity revealed that the treatment led to a very high reduction of the capillarity coefficient, and some decrease of capillary water uptake (kg/m²). This type of occurrence may be justified by a decrease of interconnected porosity in treated samples. The quantification of the modifications induced by the consolidation treatment, in terms of drying kinetics and water vapour permeability, presented similar information regarding the harmful effects induced, promoting reduction of the "breathing" capacity of the treated samples.

In terms of global potential harmfulness assessment, and resorting to the rating system proposed by Delgado Rodrigues e Grossi (2007), the consolidation treatment using Silres BS OH 100, applied to ceramic samples, originated a moderate incompatibility degree.

5 References

Delgado Rodrigues, J. e Grossi, A. (2007). "Indicator and ratings for the compatibility assessment of conservation actions". Journal of Cultural Heritage, 8, 32-43.

Fernandes, F. e Lourenço, P. (2016). "Caracterização de tijolos antigos". Kéramica, N339, 26-36 (in Portuguese).

Fernandes, F., Lourenço, P. e Castro, F. (2010). "Ancient Clay Bricks: Manufacture and Properties". Em Materials, Technologies and Practice in Historic Heritage Structures editado por Maria Bostenaru Dan, Foundation ERGOROM, Richard Prikryl e Akos Torok, 29-48.

Ferreira Pinto, A. e Delgado Rodrigues, J. (2008). "Stone consolidation: The role of treatment procedures". Journal of Cultural Heritage, 9, 38-53.

Franzoni, E., Leemann , A., Pigino, B. e Lura, P. (2013). "Use of TEOS for fired-cly bricks consolidantion". Materials and Structures, 47, 1175-1184.

Franzoni, E., Sassoni, E. e Graziani, G. (2016). "An innovative phospate-based consolidant for limestone. Part 1: Effectiveness and compatibility in comparison with ethyl silicate". Construction and building materials,102, 918-930.

Luo, Y., Xiao, L. e Zhang, X. (2015). "Characterization of TEOS/PDMS/HA nanocompisites for application as consolidant/hydrophobic products on sandstones". Journal of Cultural Heritage, 16, 470-478.

Ribeiro, L. (2016). "Estudo de tratamentos de consolidação de materiais cerâmicos – Avaliação de eficácia". Tese de Mestrado em Engenharia Civil, Instituto Superior Técnico – Universidade de Lisboa (in Portuguese).

Wacker. (2014). "Technical data sheet for Silres BS OH 100". Wacker Chemic AG, 1-3.