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Hydric Resistance in Ceramic Samples with Contact Interfaces

Antônio Azevedo[1], Ricardo Sousa[2], Ana Sofia Guimarães[3]
Vasco P. de Freitas[4]

[1]Department of Civil Engineering, Faculty of Engineering University of Porto, Porto, Portugal (antonio.costaazevedo@fe.up.pt) ORCID 0000-0003-4530-9880; [2]INESC/LIAAD, Portugal (rtsousa@inesctec.pt) ORCID 0000-0002-8414-5826; [3]Department of Civil Engineering, Faculty of Engineering University of Porto, Porto, Portugal, (asofia@fe.up.pt) ORCID 0000-0002-8467-6264; Department of Civil Engineering, Faculty of Engineering University of Porto, Porto, Portugal (vpfreita@fe.up.pt) ORCID 0000-0003-3913-0868

Abstract

Knowledge of the humidity transport inside materials and building construction elements present a high role in the characterization of their behavior in service. It is a vary complex phenomena, where monolithic elements are considered since the existence of interface or layers contributes to the change of the moisture transport across the interface.

This work presents an experimental analysis of the moisture transport considering the interface ceramic bricks. This preliminary experimental work consists of quantifying, analyzing and deepening the knowledge of hydric resistance in the interface of "contact" through ceramic brick test samples with different densities.

In addition, this work also comprises an attempt to create a prediction model for the hydric resistance. The results describe the influence of hydric resistance in the interface as a function of the distance from the interface to the water plane.

Author Keywords. Hydric Resistence, Material Interfaces, Moisture

Type: Research Article

1. Introduction

In old buildings made by masonry walls with porous materials (e.g., red clay bricks, stone, plaster, mortar) the transport of moisture is an important problem. These walls are exposed to driving rain, night condensation and occasionally to rising damp. Wetting and drying of the masonry may result in moisture damage, such as algae and moss growth, staining due to salt efflorescence, or cracking and spalling due to freeze–thaw cycles or crystallization of salts (Derluyn, Janssen, and Carmeliet 2011). A common critical example in historic buildings is rising damp (Figure 1), a phenomenon that manifests itself when the building elements are in contact with water or with moist soil and occurs in scenarios of high capillarity materials and water permeability.

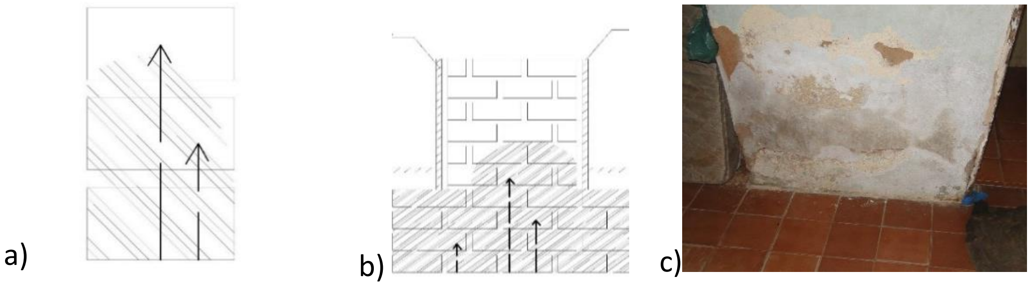

Figure 1: Humidity transport: a) Interface; b) Mansory; c) Real case

Building degradation due to moisture requires recovery procedures that are frequently expensive and invasive, for the users and for the executioners of the service. The techniques traditionally used to treat the problem, such as water cut - off, electro - osmosis, etc., present limitations in thick - walled buildings of heterogeneous composition related to treatment inefficiency or to the high costs associated with interactions (Teixeira 2011).

The heterogeneous materials leads to more complex moisture tranfer analysis due to their individual characteristics and the interface conditions that separates different bricks. Construction systems, masonry in particular, root their functional efficiency on the combination of materials with different.

In the technical and scientific areas remains a significant gap of knowledge about the influence of interfaces between layers. Some studies that have been carried out, such as Freitas (1992), Freitas, Abrantes, and Crausse (1996), Qiu (2003), Torres (2004) and Janssen, Derluyn, and Carmeliet (2012) conclude that in masonry, material interface analysis presents an important role.

The wall material can be red clay, concrete, granite, etc. In the construction of masonry, the contact of the block with another block (a type of the interface) is a practice. Therefore, when this wall comes in contact with moisture it is necessary to check the actual flow of water transport in this interface, the existence of interruption or decrease of the passage that may depend on the thickness of the materials, the type of interface, etc. The Study of the Transport of Moisture Within the materials and their elements, it is very important to characterize their behavior in terms of durability, watertightness, appearance degradation and thermal performance. Thus, research on this topic is important for a better understanding of materials potentially useful in preventing damage from moisture and good construction performance.

This work aims to study the moisture transport through multi-layered porous elements in building walls. To achieve this purpose, several objectives were defined:

- Analyze the influence of the interface type on the transport of liquid water in the vertical direction;
- Quantify the hydric resistance at the interface of contact between layers, determinable experimentally and of high importance for the use of advanced hygrothermal simulation software programs;
- Elaborate an experimental framework to obtain a significant set of hydric resistance values for the contact interface;
- Measure the moisture content and the influence of the interface between layers in the transport of liquid water using gamma radiation;
- Create a database of hydric resistance and develop a model that allows the estimation of this parameter whenever no experimental results are available.

This paper is organized as follows. Section 2 presents a review on the main methods of moisture study. Section 3 describes the material and methods of the experimental set. Section 4 presents and discuss the results. Finally, the main conclusions are summarised in Section 5.

2. State of the art

The progression of the wet front through the layers in building element characterizes the moisture transport. Several studies have been carried out with the purpose of analyzing the moisture transport in porous building material. The main conditions and conclusions regarding the influence of the interfaces in the transport of moisture in porous material are presented below.

In Freitas (1992), different mechanisms of moisture transport in walls of buildings were analyzed, considering the experimental analysis of the moisture transport in walls of multiple layers as main objectives. For this purpose, a device for the determination of moisture content was designed and constructed using a non-destructive technique and allowing a continuous dynamic analysis - HUMIGAMA-VF - which allows the measurement of moisture content based on the attenuation of gamma rays.

In addition, the experimental characterization of the continuaty conditions in the interface according to different contact configurations was developed. A simplified calculation software program for FLUMAX calculation was developed which was used for humidification and drying of walls studies.

A database was created with the values of the phenomenological coefficients that influence in the transport equations for some materials used in Civil Engineering. The database contains records of the hygrothermal properties of two porous materials, concrete and red clay, indispensable for the numerical simulation of moisture transport phenomena.

It was evaluated the building walls are composed multiple layers with three different continuity conditions:

- "Contact" - contact of two materials without interpenetration of the porous structure. There is no continuity of capillary pressure and there is a maximum flow transmitted - FLUMAX - function of the hydric resistance of the interface that conditions the transport;
- The interface between layers affects the kinetics of imbibition and the drying of the building elements;
- The interface between layers delays the soaking process in a much more pronounced way, the lower the maximum flow transmitted. This flow translates the hydric resistance of the contact between layers;
- The interface between layers generally causes an acceleration of the drying of the outer layer due to a lack of moisture source.

Wilson (1995) studied the movement of water in porous building materials. The method proposed by the researchers describes the equations of the rate and volume of water absorption, which were compared to experimental data. The tests were performed in composite samples of mortar and mortar mix with sand, with 50 mm of square section and 250 mm of depth, divided in two materials with different hydraulic properties and the lower layer with the highest suction.

The results disregard the gravitational forces since in the building materials, the capillary forces are much more important due to the thin pores. The experimental results validated the numerical model used to describe the process of water absorption in multilayer materials. Thus, the absorption passes through the high suction material reaching the low suction material, decreasing the rate of absorption as soon as the water reaches the interface between the two materials, the properties of the second material controlling the rate of absorption of the second material and the water absorption of the entire element.

Janssen, Derluyn, and Carmeliet (2012) presented a new experimental and analytical study of the water behavior through mortar interface with masonry samples, focusing on the fixing conditions.

The water absorption by capillarity in masonry was evaluated using the X-ray projection method and assumed the sharp-front theory.

The results show that the hardening of the mortar between the bricks modifies the water properties and presents a resistance at the mortar-brick interface, with effect proportional to the water absorption of the mortar during the curing process. Thus, three different types of water absorption treatment in a mortar were studied: mortar molded separately in "mold", a mortar applied later with wet curing and a mortar with dry cure.

The validation of the results confirm the viability of the chosen approach. The main advantage of this method is the simple application in the interpretation since X-ray visualizations are sufficient as input data.

The results of this work allow to draw the following conclusions:

- The differences in water interface properties and strengths were related to water absorption during curing, being zero for molded mortar, low for wet mortar and high for dry mortar.
- The entire analysis was performed on the basis of the sharp-front theory, which illustrates the minimum amount of additional data required, as well as the simple development of analytical expressions for the evaluation of the measured results. However, the sharp-front method does not allow the description of the current moisture content profiles, nor does it allow the quantification of moisture transport under real conditions.
- This experience demonstrated that the sharp-front theory provides a reliable approximation of the overall moisture absorption during the capillary absorption of water in masonry samples.
- The consistency of the results was confirmed by validating the water properties and interface resistances with the obtained results.

Rêgo (2014) evaluated the influence of two salts, potassium chloride (KCl) and sodium sulphate (Na_2SO_4), and three interface types (contact, air space and hydraulic continuity) in the absorption processes in brick samples. This experimental study allowed to conclude that:

and the interface samples are due to the thickness of the layer, where this coefficient increases porportionately to the thickness of the layer;

- In the three interface types test samples, a hydric resistance is observed which reduces the flow of water transmitted at the interface;
- The presence of sodium sulphate in test samples with a contact interface results in a decrease in the maximum flow transmitted against the reference value. The inverse is observed in relation to potassium chloride;
- Both salts cause a very significant decrease of the maximum flow transmitted at the interface in air gap samples in comparison to the tests carried out with water. The maximum transmitted flows calculated for the two salts are similar;

- There is a decrease in the transmitted water flow for test samples with hydraulic contact interface.

3. Materials and Methods

The properties of old building materials are difficult to analyze. Thus, in order to increase knowledge about old bricks used in Portugal, the research by Fernandes and Lourenço (2007) concluded that the most important physical properties for the characterization of the state of bricks conservation are density, porosity and water absorption.

The interface is a separation between two bricks and the contact is a type of interface in which there is no mutual filling between the two material pores (Figure 2).

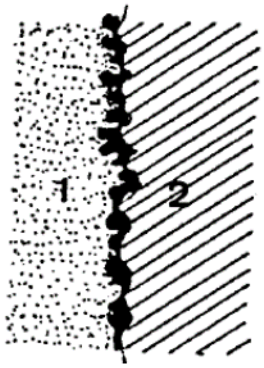

Figure 2: Contact

For the construction of the samples with contact, two types of ceramic materials were used in order to perform unidirectional capillary absorption tests: Red clay type "A" and Red clay type "B". For the tests of the samples considered the interfaces in contact – Figure 3.

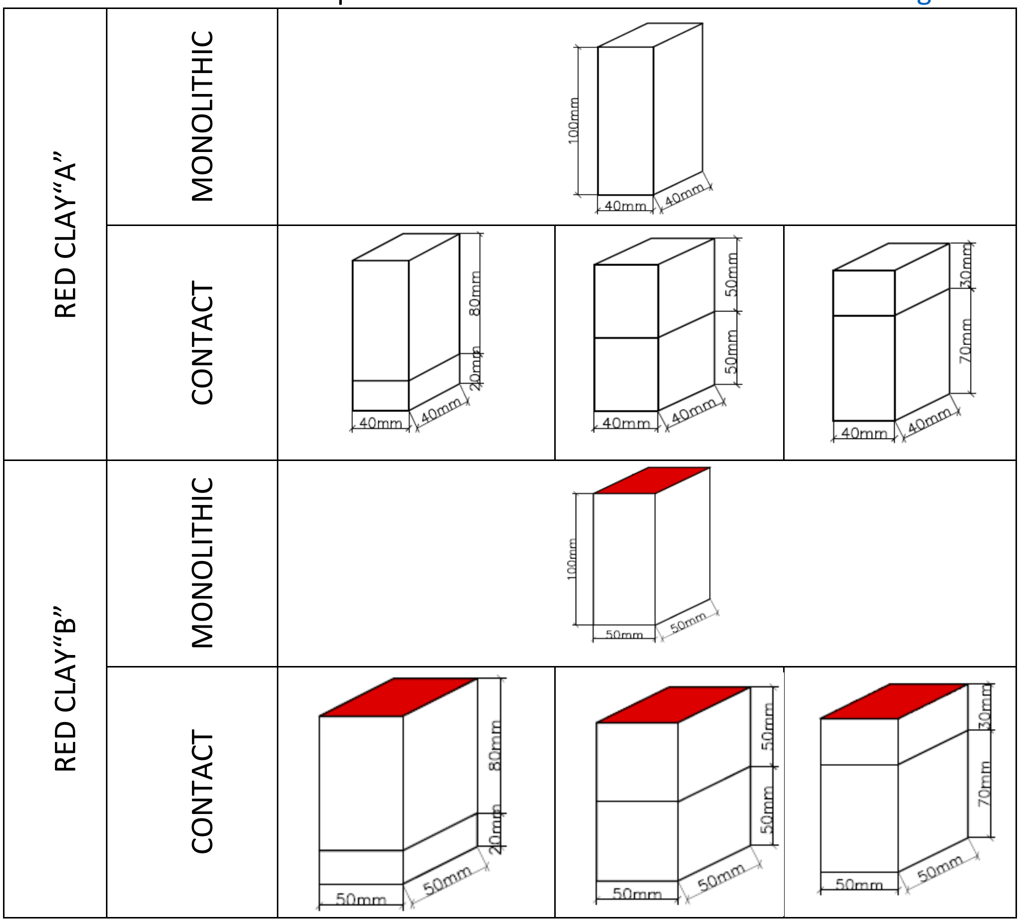

Figura 3: Geometry used for the test of red clay type A and B

The absorption of liquids in structural red clay blocks and primordial components of structural masonry occur by capillary suction. The porosity of the red clay block is an intrinsic property of the constituent material of the construction and the determination of this porosity is important to gauge the amount of water that this block absorbs. This information can be obtained by performing laboratory tests on rectangular prismatic samples, which allows studying the product and improving its characteristics. These improvement may avoid diseases due to moisture and capillarity rise or absorption of rainwater, such as stains, efflorescence and mortar.

In the contact, the samples were cut into 40 x 40 mm for Red Clay "A" and 50x50mm for Red Clay "B"base blocks and were joined face-to-face with adhesive tape to form a single block. These dimensions are justified by the fact the original bricks made of ceramic A and B 40 mm and 50 mm, respectively.

Tests on contact samples, although similar to monolithic samples, show that the behavior was different since there was discontinuity of the porous structure at the interfaces. As a consequence of the porous irregularity, the water flows slower. The contact blocks with different interface positions, 20mm, 50mm and 70mm, were tested.

The waterproofing of the samples was performed only on the lateral sides, since the water/moisture absorption and evaporation process is exclusively by the upper and lower faces (unidirectional). To waterproof the blocks, for used Sika Icosit k-101 N epoxy resin was. This is a composition composed of two components (A and B) and a correct application of the resin assumes a mixture of 13 grams of component A and 87 grams of the component B in a vessel, mixed for 3 minutes. Two coats of paint were given, with two opposing longitudinal faces being waterproofed and after drying the other two, so that it was possible to hold the sample at the time of painting.

For the contact interface, the two faces of the contact were considered together and a water sandpaper was used to remove any existing material in the sample that could prevent contact between the interfaces and to avoid an air space. The blocks were also fixed with self-adhesive tape (Figure 4) of aluminum to ensure a connection between the sample parts, making it impossible to evaporate at the same time.

Figure 4: Aluminum self-adhesive tape

The experimental procedure was based on the gravimetric method which consists of the selection of a material sample, later weighed before and after the drying process. This method allows to calculate, by difference of mass, the amount of water contained within the material (Lanzinha 1998). Among availabe techniques, the gravimetric method is the simplest since (ISO 2002) only predicts for vertical absorption tests. This water absorption test is measured using prismatic geometry samples of the analyzed material under regular atmospheric pressure conditions. After drying to constant mass, one side of the sample is immersed in 5 to 10 mm of water for a specific period of time and the mass increase is determined (Figure 5).

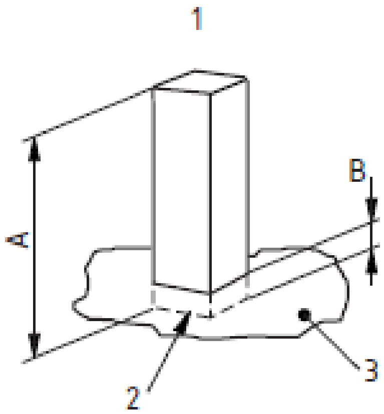

Figure 5: Diagram of a ceramic sample taken from EN, 1) Specific sample. 2) Sample top face. 3) Water surface. A) High that depends on a standard. B) Water immersion of 5 a 10 mm

Despite being a direct and apparently accurate technique, gravimetric method presents the disadvantage of being destructive. It should be noted that the cutting of the bound materials necessary for observation of the wet front in the specimen produces its heating and consequently disruption in the distribution of moisture.

3.1. Prediction Model

In order to create a prediction model, decision trees were used. Decision trees method is a decision support tool which is based on a tree-like model of decisions and their possible consequences. These types of models are frequently used in research, specifically in decision analysis, decision making, planning, strategy development and reserve determination which depend on models produced by data analysis (Kubat 2015). Figure 6 depicts an example of a decision tree.

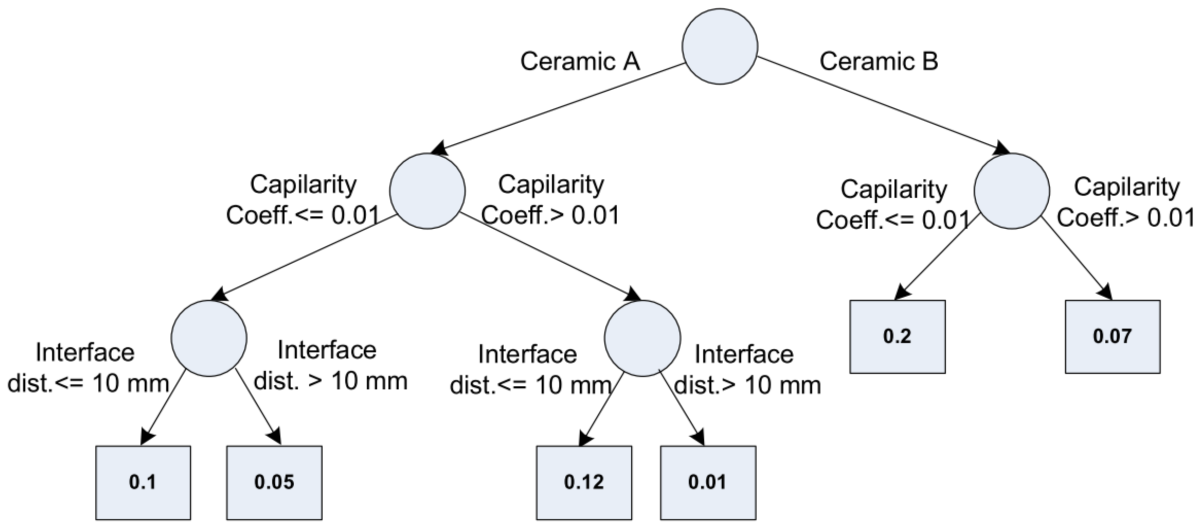

Figure 6: Illustrutive example of a decision tree

The decision tree is composed by nodes (represented by circles) where conditions (based on parameters) are tested. Each node presents two or more branches associated to a condition. If the condition is satisfied, the respective branch is chosen. This procedure is performed until reach an end node (represented by a square). Each end node is associated to a real value (regression) or a label (classification). This value or label is the final prediction of the model. In more advanced context, decision trees can present a regression or a classification model in each end node. In order to build the decision tree, several algorithms (learning algorithms) are available in the literature, such as CART and ID3 (Kubat 2015). This work used the Matlab toolbox, where the learninng algortihms are available. In this work, the decision tree consists of a regression model. This model is used to predict a measure (hydric resistence) according to physical measures and properties of the ceramic samples (distance, ceramic type, ...).

4. Discussion

In this section, the results of the study concerning the influence of materials on the kinetics of imbibition, hydric resistence and the prediction model are addressed.

4.1. Influence of materials on the kinetics of imbibition

In order to evaluate the effect of the different materials on the imbibition kinetics with brick samples, the water absorption coefficients by capillarity were calculated in monolithic samples. A macroscopic approach to the transport of liquid water was required for porous materials. The amount of water absorbed and the height of water rise to the scale of the porous building materials. The coefficients A (kg.m^{-2}.s$^{-1/2}$) and B (m.s$^{-1/2}$) represent the capillary absorption coefficient and capillarity penetration coefficient, respectively. Therefore, these coefficients characterize the water carrying capacity of the materials. Figure 7 show the water absorption average curve by capillarity as a function of the square root of time obtained in the tests with water-immersed monolithic test samples.

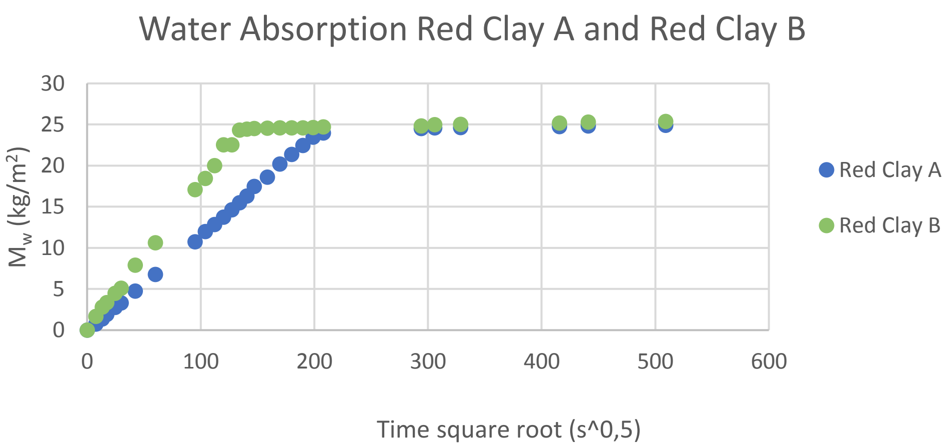

Figure 7: Capillarity absorption curves, based on the root of time, of the red clay type A, 40 x 40 mm and of the red clay type B, 50 x 50 mm, monolithic samples partially immersed in water

The capillarity coefficient was calculated for the five samples of each of the materials. The capillary coefficients obtained for A mean value 0.10 kg.m^{-2}.s$^{-1/2}$, deviation 0.02 kg.m^{-2}.s$^{-1/2}$, 19.69% coefficient of variation and for B mean value 0.19 kg.m^{-2}.s$^{-1/2}$, deviation 0.02 kg.m^{-2}.s$^{-1/2}$, 14.89% coefficient of variation.

In the tests with the red clay type A, the five values were dispersed (not consistent). For red clay type B, the capillary coefficient were very cosnsistent and present low dispersion. Here, the red clay B absorbs water faster than the red clay type A. This analysis assumed that the data follow the normal distribution and the range that contains 95% of the data values.

This water absorption increase was expected since the red clay B presents a lower density (1583 kg/m³) than the red clay A (1800 Kg/m ³). The results calculated for two samples are significantly different.

The results with the red clay material are favourable. Different porous characteristics of each type of brick used in literature may be the source of observed differences. Table 1 presents different values of capillary coefficients of solid brick partially immersed in water obtained by several researchers. The values obtained in the present study are within the ranges of values already registered.

Author	Material	Capillarity Coefficient (kg/(m².s$^{1/2}$))
Freitas, Abrante, and Crausse (1996)	Red clay	0.050
Azevedo (2013)	Red clay	0.145
Pereira (2005)	Red clay	0.142
Mukhopadhyaya et al. (2002)	Red clay	0.084
Rêgo (2014)	Red clay	0.068
Afanador Garcia, Guerrero Gomez and, Monroy Sepulveda (2012)	Red clay	0.155
Afanador Garcia, Guerrero Gomez and, Monroy Sepulveda (2012)	Red clay	0.294
Roels et al. (2004)	Red clay	0.160
Azevedo (this research)	Red clay “A”	0.113
Azevedo (this research)	Red clay “B”	0.197

Table 1: Coefficient of capillarity of solid brick in water obtained by other authors

4.2. Hydric resistence

In the transport of water in multilayer porous materials, a discontinuity may be present due to the existence of an interface between the materials. There are different interface types, each of them contribute differently to a change of water transport, compared to a monolithic sample scenario.

As a consequence of the discontinuity of the porous structure in the materials, the interface causes a hydric resistance that limits the transmitted moisture. Therefore, the hydric resistance (RH) is defined by the greater or lesser propensity of moisture transport, expressed in kg / (m².s), calculated experimentally through the curve of the mass variation as a function of time, during a water absorption test. This measure corresponds to the slope of the curve after reaching discontinuity. Figures 8 and 9 present a comparison between the monolithic samples and the samples with the interface in contact.

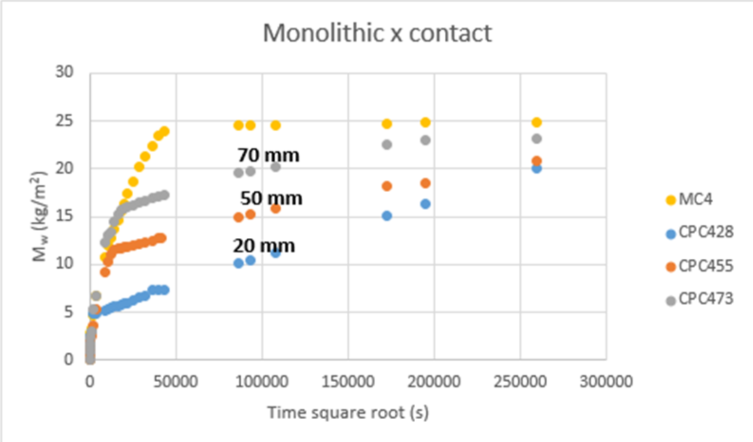

Figure 8: Monolithic x contact, red clay "A". Hydric resistence for monolithic, 2cm, 5 cm and 7cm of distance

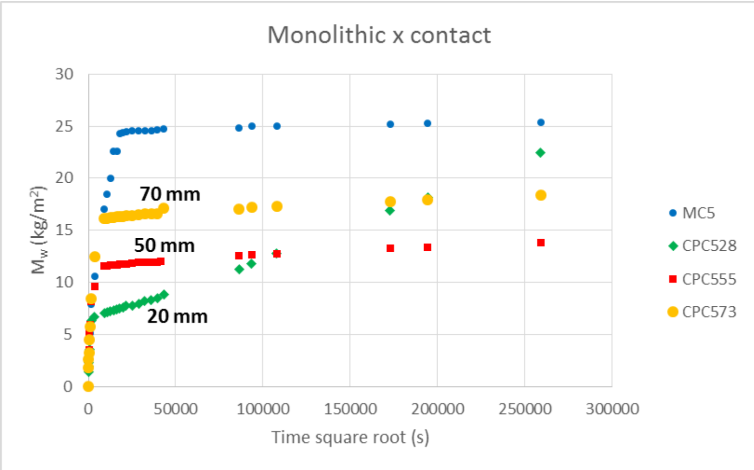

Figure 9: Monolithic x contact, red clay "B". Hydric resistence for monolithic, 2cm, 5 cm and 7cm of distance

Figures 8 and 9 show that the water absorption before reaching the contact interface behaves similarly to the water absorption on a monolithic sample. When water reaches the interface (at 20 mm, 50 mm and 70 mm in height), hydric resistance is verified, reducing the rate of absorption. Table 2 presents the hydric resistance, expressed in kg / (m^2.s).

SAMPLES	SYMBOL	WATER RESISTANCE (KG/m^2.s)	STANDARD DEVIATION	VARIATION COEF. (%)
PERFECT CONTACT AT 20 mm AND BASE OF 40 X 40 mm (A)	CPC428	6.1 X 10^{-5}	7.7 X 10^{-6}	11.5
PERFECT CONTACT AT 50 mm AND BASE OF 40 X 40 mm (A)	CPC455	4.3 X 10^{-5}	1.2 X 10^{-5}	27.2
PERFECT CONTACT AT 70 mm AND BASE OF 40 X 40 mm (A)	CPC473	2.4 X 10^{-5}	3.8 X 10^{-6}	15.6
PERFECT CONTACT AT 20 mm AND BASE OF 50 x 50mm (B)	CPC528	7.3 X 10^{-5}	1.4 X 10^{-5}	19.4
PERFECT CONTACT AT 50 mm AND BASE OF 50 x 50mm (B)	CPC555	4.9 X 10^{-5}	3.9 X 10^{-6}	7.9
PERFECT CONTACT AT 70 mm AND BASE OF 50 x 50mm (B)	CPC573	9.3 X 10^{-6}	2.5 X 10^{-7}	2.7

Table 2: Hydric resistance mean and dispersion measures for the test samples

Hydric absorption tests were performed on 40 samples, in which each sample was weighed 28 times. For each type of red clay (red clay A and red clay B), 20 samples were made, with 3 different typologies of interfaces and 5 samples for each typology. Thus, taking an average value of each typology, with the average value for each typology observable in the respective Figures 8 and 9 and Table 2.

4.3. Prediction Model

This section shows the results of the decision tree construction. Figure 10 shows the decision tree that results from the study. Each end node is associated to a hydric resistence value.

The values on the decision tree are very similar to the mean values presented in Table 2. This decision tree shows that the capilarity coefficient is the most descriminative parameter. The hydric resistence increases with the distance. Despite this observations, this approach presents the limitation of presenting small amount of samples. The increase of sample would improve the precision of this model.

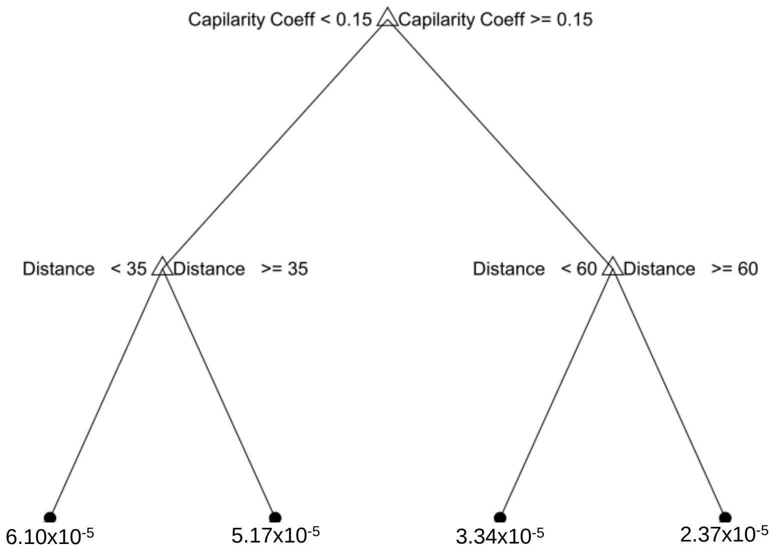

Figure 10: Decision tree. The nodes are associated to hydric resistance measure. The values in the leafs are in kg / (m².s), the distance in mm and capilarity coefficient kg.m-2.s-1/2

5. Conclusions

This work consolidates and deepens the scientific hygrotermic knowledge, more specifically in the influence of the interface in the transport of water through walls of buildings. Considering the scientific community's knowledge about this research topic, studies on the transport of moisture in porous materials have been increasingly performed. In the case of highly complex phenomena, monolithic constructional samples are frequently considered since the existence of interface or layers contributes to the change of moisture transport along the respective constructive element, which will contribute to the change of the law of mass transport.

In order to make a contribution, capillarity absorption tests were proposed according to the existent standard methods. With this work, we introduce the use decision tree to model and to facilitate the pratical use of these experimental results. This is an innovative work since it constitutes the first attempt to provide a set of values of hydric resistance in masonry walls of buildings.

In this work, to collect a wide range of hydric resistance values for imbibition also initializes a process of correlation analysis of these same values. This work is essentially of an experimental nature, with a relevant analytical component. As future work, the number of samples can be increase so that the prediction model becomes more accurate.

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