A CRITIQUE ON CHARACTERISING INTERFACE RESISTANCES WITH MAXIMUM MOISTURE FLOWS

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ABSTRACT

In February 2018, this journal published the article “Interface influence on moisture transport in buildings”. This critique firstly establishes that the reported ‘hydraulic resistance’ values overestimate the impacts of the material interfaces for the brick-mortar ‘hydraulic contact’ samples. It is shown that the actual flows after crossing the brick-mortar interface are 2 to 5 times higher than indicated by the article’s ‘hydraulic resistance’ values. This critique secondly demonstrates that the article’s main idea of characterising material interfaces with a maximal post-interface-flow is not dependable nor generalisable. This flow is not necessarily constant in time, and may depend on the interface’s actual location, the surrounding materials’ properties and the imposed boundary conditions, hence defying all generalisation. The conclusion of this critique is therefore that the processing methods and results of the disputed article are not reliable.

KEYWORDS

Interface resistance; hydric resistance; hydraulic contact; brick-mortar interface;

HIGHLIGHTS

- A recent article overestimates the impacts of the brick-mortar interface resistance
- Its post-interface flows are too low, they do not reproduce the moisture absorption
- Characterisation of material interfaces by post-interface flows is moreover queried
- Inherently, these flows may depend on surrounding material and interface location
- This limits their usability to the same structure only, thus foiling generalisation

1. INTRODUCTION

In February 2018, this journal published the article “Interface influence on moisture transport in buildings” [1], wherein an enquiry into the impact of material interfaces on moisture absorption in building materials is documented. This article continues previous research of this group on this topic [2-6], which was originally initiated with the seminal paper of de Freitas et al. in 1996. In all of these studies, the interface impacts are characterised with maximum moisture flows over the interface, contrary to the much more widely employed characterisation with interface resistances though [7-14]. The investigation in [1] targets three types of material interfaces: ‘air space’ (two brick samples separated by an air space), ‘perfect contact’ (two brick samples in direct contact) and ‘hydraulic contact’ (bonded brick-mortar samples). The material interface impact is quantified as the maximal moisture flow right after the moisture front passes the interface, which is labelled as ‘hydraulic resistance’. Introductorily, it should be noted that presenting moisture flows as hydraulic resistances is strongly counterintuitive: low moisture flows correspond to high hydraulic resistances and vice versa. This label, only recently formally introduced [1,6], should therefore be reconsidered.

This being said, this critique aims at two much more critical defects in [1] though. Firstly, temporarily accepting [1]’s maximum-flow-based characterisation, it is shown below that their post-interface flows for the ‘hydraulic contact’ cases cannot be correct, as they significantly underestimate the moisture absorptions after the brick-mortar interface. To further verify that, this critique digitally extracts and linearly regresses [1]’s moisture absorption data, giving (far) higher slopes of the moisture absorption curves. Secondly, it is established beneath that the prime idea of the maximum-flow-based characterisation of material interfaces is basically defective, as its results may directly depend on the configuration they have been determined for, thus nullifying their generalisability. This is demonstrated via calculations with the sharp-front model for moisture absorption in composites [11,14]. The conclusion of this critique is hence that [1]’s processing methods and results are not reliable. With respect to the former, characterisation of material interfaces with interface resistances [7-14] should be preferred instead, as this approach is inherently less phenomenological in nature.

2. INCORRECT HYDRIC RESISTANCE VALUES

This section focuses on [1]’s findings for the ‘hydraulic contact’ cases, wherein two types of brick (brick A and B) and two types of mortar (cement and lime mortar) are brought together to form 10 cm high bonded samples. The brick is always at the bottom, and hence in contact with water during the moisture absorption. Three different lengths of brick are used (2, 5, 7 cm), thus yielding three different heights for the brick-mortar interface. The main results for the ‘hydraulic contact’ cases are gathered in [1]’s Figures 7 and 8 and Table 2, reproduced in Figure 1 and Table 1 here for ease of reference. Figure 1 indeed demonstrates that the moisture absorption slows down after crossing the brick-mortar interface, and that material interface impact is quantified in Table 1 by the hydric resistances, i.e. the post-interface flows.

Introductorily, the analysis here studies two specific cases, 7 cm of brick B with lime mortar and 5 cm of brick B with cement mortar. The measured moisture absorption for these cases can be found in the bottom graph of Figure 1, indicated with the full diamonds and hollow squares respectively. Unfortunately, these graphic results do not allow to reliably identify the time points at which the moisture front passes the interface, nor does [1] ever report these. A digital extraction of both data sets – for as much as possible – is presented in Figure 2, wherein now a linear time scale is used instead of the square root of time applied in Figure 1. Based on these, these time points can be estimated at about 12000 s and 5000 s for the first and second case respectively, and the absorbed moisture masses at these times are roughly 17.0 kg/m² and 12.5 kg/m², both growing to around 25 kg/m² at 90000 s. For these configurations, Table 1 reports post-interface flows of $4.2 \cdot 10^{-5}$ kg/m²s and $4.8 \cdot 10^{-5}$ kg/m²s. These values are oddly low, as they would lead to absorbed moisture masses of merely 20.3 kg/m² and 16.6 kg/m² at 90000 s, when starting from the indicated time points and related moisture masses. Obviously [1]’s values for these two ‘hydraulic contact’ cases do not replicate their moisture absorptions after passing the interface, and therefore must be incorrect.

Figure 1: Moisture absorption curves for 'hydraulic contact' cases, brick A at the top, brick B at the bottom; reproduced from [1].

Table 1: Maximal moisture flows for 'hydraulic contact' cases; partially adopted from [1].

Brick type	Mortar type	Interface height [cm]	[1]'s results [10 ⁻⁵ kg/m ² s]	this critique [10 ⁻⁵ kg/m ² s]	ratio [-]
A	CM	2	9.7	16.4	1.7
A	CM	5	7.1	14.0	2.0
A	CM	7	4.2	19.7	4.7
A	LM	2	7.9	14.9	1.9
A	LM	5	5.8	12.3	2.1
A	LM	7	5.4	19.4	3.6
B	CM	2	7.9	27.0	3.4
B	CM	5	4.8	17.7	3.7
B	CM	7	3.2	5.6	1.7
B	LM	2	7.9	28.9	3.7
B	LM	5	4.2	15.2	3.6
B	LM	7	4.2	14.8	3.6

Since [1] does not clearly state how and when the post-interface flows are computed – it merely mentions that they are calculated from "the slope of the mass variation curve as function of time, ..., after reaches the discontinuity" –, the cause of this flawed values cannot be identified. More correct values can be obtained via a linear regression of the temporal evolution of the absorbed moisture mass, the slope of which defines the post-interface flow. For these regressions, only a selection of the extracted data points are applied: the early points, before passing the interface, are left out, as well as the final points, beyond 80000 s, because these expose that the moisture front has reached the top of the overall sample. The resulting post-interface flows are $16.2 \cdot 10^{-5}$ kg/m²s and $19.8 \cdot 10^{-5}$ kg/m²s respectively, which are roughly 4 times higher than [1]'s outcomes, see Table 1.

Figure 2: Moisture absorption curve for both exemplary cases. Hollow markers represent all extracted data, full markers the data used in the regression. The regression lines are given by the dashed lines, and their describing equations are included as well.

This observation comes back across the board for all ‘hydraulic contact’ cases, see the last two columns of Table 1. It should be noted that some simplifications were implemented in the digital extraction and linear regression of these cases. For the digital extraction, only the values from 10000 s to 45000 s were retained, as the later points are affected by the moisture front reaching the top of the sample, while the earlier points could not easily be identified clearly on the original graphs. For the linear regression, for the 2 cm, 5 cm, 7 cm brick samples respectively, only the values after 10000 s, 20000 s, 30000 s were employed, to clearly exclude all time points before the passing of the interface. Please note that more data points were used for the regressions in Figure 2, and hence the different flow values in Table 1 for the two exemplary cases. These differences indicate however that the new post-interface flows in Table 1 are most probably somewhat conservative still. All in all, the post-interface flows obtained in this critique are consistently higher than [1]’s values, with factors ranging from 1.7 to 4.7. This implies that [1] severely overestimates the effect of the material interfaces, since its post-interface flows highly underrate the actual moisture absorption after the interface.

It should also be noted that these new post-interface flows have been calculated quite long after the moisture front passes the interface, while [6] asserts that flows are calculated right after that passing. When limiting the regression for the 5 cm brick B and cement mortar case to the initial three bold data points, see Figure 2, then the post-interface flow would become $30.9 \cdot 10^{-5} \text{ kg/m}^2\text{s}$, which is much higher still than new value in Table 1. The smooth moisture absorption curvature for this case, see Figure 2, in fact demonstrates that the post-interface flow decreases with time, raising more critical concerns on quantifying the impact of material interfaces by a post-interface flow. These general concerns on this main idea are the topic of the next section.

3. SHORTCOMINGS OF THE ‘FLOW’ APPROACH

Other publications on the theme of material interfaces [7-14] have consistently opted to describe their impact with an interface resistance, the flow through which hence is controlled by the difference in capillary pressure over that interface. The critiqued publication [1], as well as its related articles [2-6], chooses for another approach, by characterising the interface impact via the more direct post-interface flow. This is a peculiar decision, since this strongly restricts the generalisa-

bility of the findings, because these post-interface flows may depend on the analysed configuration, as is shown below.

Initially, one can best understand this by thinking about the thermal analogon. Let us assume a half-infinite conductive medium, with a sudden change in temperature imposed at its surface. At a certain location in that medium, a negligibly thin insulating layer is present. The impact of that layer on the thermal response of the configuration is uniquely defined by its thermal resistance: knowledge of that resistance allows to quantify the thermal response of the configuration, independent of the boundary condition, the surrounding material and the layer location. This implies that inverse identification of that resistance from an experiment with a particular boundary condition, surrounding material and layer location gives a generalisable result: the acquired resistance can reliably be used in simulating configurations with a different boundary condition, surrounding material and/or layer location. This generalisability is completely lost though if the impact of the layer is characterised via the heat flow through it. It is general knowledge that this heat flow depends on the boundary condition, surrounding material and layer location: it is higher for a larger change in the surface temperature, for a more conductive half-infinite medium, and/or for a layer located closer to the surface. And last but not least, the heat flow through the layer is often not a constant, but may decline over time [15]. It is demonstrated below that these matters similarly relate to the impact of material interfaces in moisture transfer.

The primary proposal for characterising the impact of material interfaces on moisture transfer in building materials with the maximal flow through the interface originally stems from [2], inspired by experiments on ‘perfect contact’ configurations of ceramic brick and aerated concrete. The measurement results for the ceramic brick cases were presented in [2]’s Figure 5, which is reproduced here in Figure 3. Quoting from [2]: “when the moisture reaches the interface, there is a slowing of the wetting process due to the interface’s hydric resistance. If we place the interface at different distances from the wetting plane ($x = 2$, $x = 5$ or $x = 7$ cm), the beginning of the slowing of the wetting occurs in different time periods, as expected; however, from that moment onwards, there is an increase in mass that is constant for all cases. This behaviour clearly supports the existence of a hydric resistance linked to a maximum transmitted flow”. These findings and deductions are confirmed in [3], where comparable experiments are documented. It should be noted though that [3] also reveals the first faults in the maximum-flow-based characterisation concept. Firstly, different maximal flows are found for the ‘ceramic brick + aerated concrete’ and ‘aerated concrete + ceramic brick’ configurations, while both configurations are the same, albeit reversed. Secondly, the focused observer may note that the post-interface absorptions depicted in [3]’s Figure 4 are not increasing linearly in time, see e.g. the curved post-interface absorption for ‘clay brick with a joint at 2 cm’ or for ‘clay brick with a joint at 5 cm’. These observations thus invalidate the assumption of a location-independent and time-constant post-interface flow. The maximum-flow-based characterisation in [2,3] was derived from and applied to ‘perfect contact’

Figure 3: Left: moisture absorption curve for ‘perfect contact’ in ceramic brick, with interface at 2, 5 and 7 cm; Right: basic model for determining ‘hydraulic resistance’; reproduced from [7] and [2]. and ‘air layer’ configurations only, where often large interface resistances can be expected. The approach was though abstractly expanded to ‘hydraulic contact’ configurations in [4,5] and really applied for ‘hydraulic contact’ configurations in [1,6], without verifying however whether the premise of location-independent and time-constant post-interface flows still applies for their typically smaller interface resistances. The flow values in Table 1 actually disclose that the location-independent assumption has been abandoned, as distinct values are reported for interfaces at different heights. The time-constant assumption, on the other hand, still appears to scaffold [1]’s investigation, given Figure 4.5 in [6] (reporting the same data as [1]), reproduced here in Figure 3. This graph presents the basic model for determining the hydric resistance or post-interface flow, and evidently presumes that this flow remains constant after passing the interface. On the other hand, by stating that this flow is determined “immediately after the knee point” [6], one can start to doubt whether this premise is actually still accepted. These doubts are confirmed by a recent publication [16], where these post-interface flows, and hence the hydric resistances, are indeed considered as evolving in time. These two concessions of course vastly restrict the generalisability of [1,6]’s post-interface flows to other configurations, as their findings may become entirely phenomenological, only valid for the specific configuration they are measured for.

It can indeed be shown that the response seen in Figure 3, a post-interface flow that is location-independent and time-constant, is only obtained when the material interface is the dominant factor in the post-interface flow; but such is most certainly not generally the case. To illustrate this, calculations with the sharp-front model of [14,11] are executed. It has been confirmed previously that the moisture absorption in a two-layer composite, with or without interface resistance, can be reliably assessed with the sharp-front model [11]. The relevant equations were originally formulated in terms of ‘absorbed moisture volume i ’, ‘sorptivity S ’ and ‘porosity f ’ in [14], but were replaced with their analogons ‘moisture mass m ’, ‘capillary absorption coefficient A_{cap} ’ and ‘capillary moisture content w_{cap} ’ in [11], more proper to building physics:

$$m = A_{cap,1} t^{0.5} \quad t \leq (L_1 w_{cap,1} / A_{cap,1})^2 \quad (1)$$

$$m = A_{cap,2} \tau^{0.5} + w_{cap,1} L_1 - w_{cap,2} L_E \quad t > (L_1 w_{cap,1} / A_{cap,1})^2 \quad (2a)$$

$$L_E = K_2 \left(\frac{L_1}{K_1} + R_{IF} \right) \quad \tau = t + \left(\frac{w_{cap,2} L_E}{A_{cap,2}} \right)^2 - \left(\frac{w_{cap,1} L_1}{A_{cap,1}} \right)^2 \quad (2b)$$

where 1 and 2 signify the top and bottom material respectively, m [kg/m²] is the absorbed moisture mass per unit surface area, A_{cap} [kg/m²s^{0.5}] the capillary absorption coefficient, w_{cap} [kg/m³] the capillary moisture content, t [s] and τ [s] the actual and a shifted time, K [s] the front permeability, L [m] the length, R_{IF} [m/s] the interface resistance, and L_E [m] the equivalent length, the hydraulic resistance of material 1 and the interface resistance expressed as a length of material 2. The moisture flows can be calculated via the temporal derivative of these equations.

Two materials are assumed, with the following capillary absorption coefficient, capillary moisture content and front permeability respectively: material 1 0.2 kg/m²s^{0.5}, 200 kg/m³, 2·10⁻¹² s, material 2 0.1 kg/m²s^{0.5}, 200 kg/m³, 1·10⁻¹² s. These are combined into four configurations, with material 1 always at the bottom and material 2 always at the top, with their interfaces at 10 cm, 7.5 cm, 5.0 cm and 2.5 cm. For the last three cases, an interface resistance is assumed present, for which values of 10¹¹ m/s and 10¹⁰ m/s are taken. For the first case, no interface resistance is present, here an ideal contact between the two materials is presumed.

The results of the different simulations are collected in Figure 4, with evolutions of the moisture mass and moisture flow at top and bottom respectively, and the cases with interface resistance 10¹¹ m/s and 10¹⁰ m/s at left and right respectively. The case with the 10 cm interface without interface resistance comes back twice, as this is considered a reference illustration. Its primary intent is to exhibit that even without an explicit interface resistance there can be a reduced post-interface flow, when the top material is less sorptive than the bottom material. Using such declining post-interface flow as indicator for the genuine presence of an interface resistance is hence

not as dependable as assumed in [1-6]. The graphs on the left in Figure 4 portray the impact of a dominant interface resistance: the post-interface flow is significantly reduced, it is relatively lo-

Figure 4: Top: moisture mass evolution; Bottom: moisture flow evolution; Left: 10^{11} m/s interface resistance; Right: 10^{10} m/s interface resistance.

cation-independent and it remains virtually constant in time. These graphs hence readily concur with [2]'s Figure 5 and [6]'s Figure 4.5, and furthermore resemble the behaviour observed for the 'perfect contact' and 'air space' cases of [1], see [1]'s Figures 5, 6, 9 and 10. The impact of a far less important interface resistance is illustrated with the graphs on the right in Figure 4: the post-interface flow is still strongly reduced – which should be largely attributed to the lower sorptivity of the top material though – but it is highly dependent on the interface location and it substantially decreases over time. The concrete post-interface flow values are 1.10 g/m²s, 0.71 g/m²s and 0.55 g/m²s for the interfaces at 2.5 cm, 5.0 cm and 7.5 cm respectively. These graphs look like the responses witnessed for the 'hydraulic contact' cases, but they thus no longer align with [2]'s Figure 5 and [6]'s Figure 4.5. All in all hence, it has to be concluded that identifying and characterising a material interface with the post-interface flow is neither dependable nor generalisable. The obtained values may not represent the further decrease of the moisture flow, and, more importantly, may highly depend on the interface location (illustrated here), the surrounding material (not illustrated here) and the boundary condition (not illustrated here). Conclusively, it has to be assumed that the resulting outcomes can only be used in the configurations that they have been measured for and even then solely for the time interval directly after the passing of the interface. The hydric resistances of [1,6] for the 'hydraulic contact' cases – the most relevant for moisture transport in building components – are hence purely phenomenological, and thus have no general value of any kind.

4. CONCLUSION

In February 2018, this journal published the article "Interface influence on moisture transport in buildings" [1], wherein an enquiry into the impact of material interfaces on moisture absorption in building materials is documented. This discussion has firstly shown that [1]'s hydric resistances for the 'hydraulic contact' cases are incorrect, as they significantly underestimate the post-interface flows. Secondly, it has been established that its concept of a maximum-flow-based charac-

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terisation of material interface impacts is essentially defective, as such post-interface flows may be highly dependent on the employed configuration, and not necessarily are constant over time. The conclusion of this critique is hence that [1]'s processing methods and results are not reliable. With respect to the former, a characterisation of material interfaces with interface resistances [7-14] should be preferred, given that this approach is inherently less phenomenological in nature.

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