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Hygrothermal properties of hollow brick masonry used in veneer

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Hygrothermal properties of hollow brick masonry used in veneer

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Abstract. The material properties of a brick masonry are important when modelling or comparing different veneers. The effect of mortar joint, however, is somewhat an unknown variable. In this study, two different firing batches of a hollow burnt-clay brick product were tested for thermal conductivity, water vapor permeability, water absorption coefficient and capillary moisture content. Brick and mortar materials were tested both exclusively and as masonry specimens. The effect of brick-mortar interface was within margin of error for the first brick batch with slightly lower density, while batch two water vapor permeability, water absorption coefficient and capillary moisture content were noticeably affected. The effect of brick-mortar interface seems to be dependent on brick properties. The differences in hygric properties between brick batches were large, but below 100 %. Accounting for mortar using area weighted properties can improve modelling accuracy, but other factors such as workmanship, degradation and brick batch differences are likely more important.

Keywords: Hygrothermal properties, brick veneer, masonry

1. Introduction

1.1. Background of the study

Wind driven rain (WDR) is significant source of moisture for external walls. Future analyses have shown that climate change will increase WDR in North temperate zone due to increase in both rainfall and wind magnitudes [1-3]. WDR is important factor in brick wall function due to the high porosity of the materials. As such, the ventilation of cavity walls has been increasingly common area of research [4-11]. More precise material properties are needed for quantifying the principles of cavity wall ventilation.

Hollow bricks are commonly used in cavity wall facades. Despite being a composite material, masonry walls are most of the time simplified to a one-dimensional brick layer. For hollow bricks, such a simplification introduces additional sources of error compared to solid bricks.

This study investigates the significance of masonry joints and mortar embedment for hygric properties perpendicular to the wall. Effective hygric properties of hollow bricks and masonry are compared using the properties of pure brick, pure mortar, and composite specimens. Brick and mortar properties are used to determine area weighted properties for masonry.

1.2. State of the art

In imbibition analysis [12] of massive masonry walls, large differences were found between composite masonry and a homogenous brick layer. Relevantly for single layer façades, the interface resistance was found to be largely irrelevant in the wetting and drying speed. Comparatively, a noticeable interface resistance has been observed in water absorption tests [13, 14], although it was not evident in drying speed. Ramirez et al. [13] hypothesizes that successive interfaces have an additive in-series effect on water penetration. As such, water transportation in single layer façade would be mostly limited to perpendicular movement.

Hollow brick masonry differs from solid brick masonry due to the ability to imbibe mortar in its hollows. As such, the material properties of hollow brick masonry are expected to differ from those of its components. Multiscale FEM analysis on masonry thermal conductivity by Alghamdi and Alharthi [15] found out that both mortar joints, and mortar penetration in hollows affect the effective thermal conductivity of a wall significantly.

Using separately defined material properties for masonry does not account for the interaction between materials. Darlyin, Janssen and Carmeliet [16] found out that dry cured mortar had lower capillary moisture content compared to mould cured mortar. Further sharp-font analysis [17] confirmed that the difference in capillary moisture content and absorption coefficient of differently cured mortars was related to the water extraction during curing.

2. Materials and methods

The testing was performed as a part of Future Spaces project, in which wooden and mortar façades along with ventilated roofs were studied. Wall and roof structures were built and tested in real world climate conditions. The material testing was performed to improve the modelling accuracy of test walls. Part of the walls were added later, using a new batch of the same brick product. As such, both batches of hollow veneer bricks were tested with the same mortar. Example of the brick specimen is shown in Figure 1.

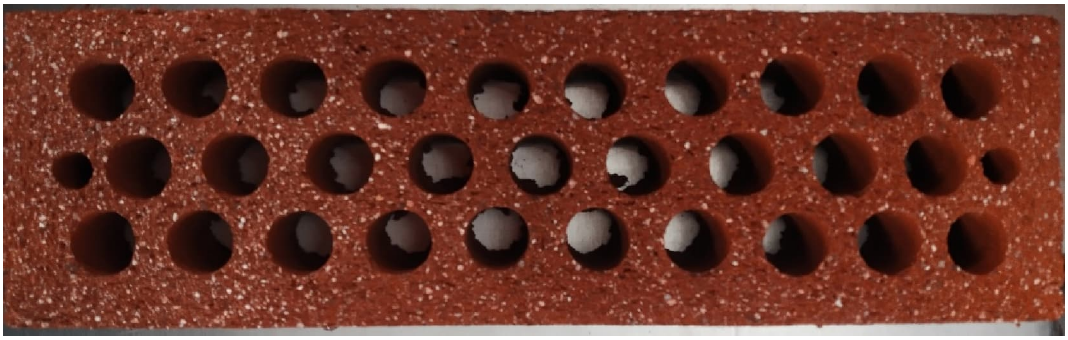

Figure 1. Cross section of the hollow brick.

Hollows in brick batches I and II account for 28 and 29 % of the bricks' total volume. Composite specimens were limited to testing the bed joint, which accounts for ¾ of the total joint length. The geometry of hollow bricks was not viable for most standard test systems using circular specimens. Rectangular half-brick specimens with face area of 75 x 140 mm^2 were used for measuring pure brick, and as a comparison group for circular specimens. Specimen shapes are shown in Figure 2. Material properties are presented in Tables 1 and 2.

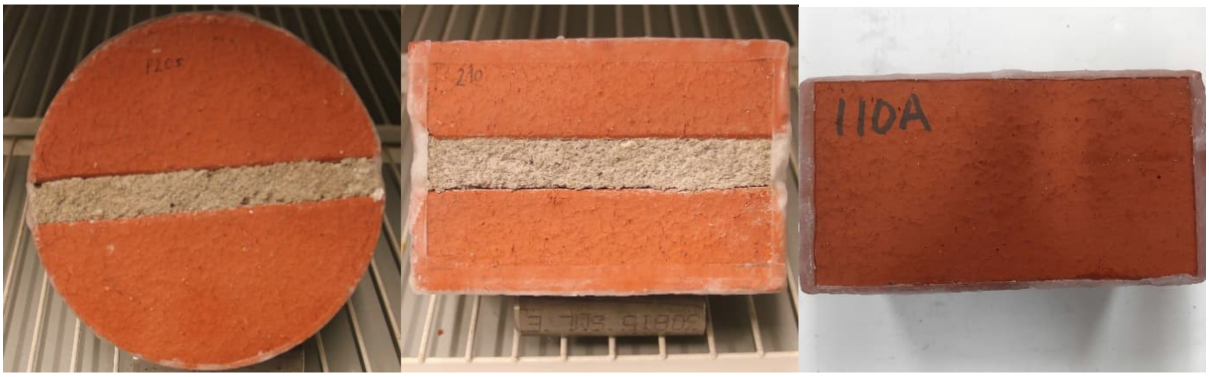

Figure 2. Specimen types used in water vapor permeability tests.

Table 1. Materials.

Material	Name	Producer	Details
Clay brick	MRT red	Wienerberger	75 x 85 x 285 mm^3
Masonry mortar	ML 5 M100/600	Weber	

Larger 300 x 300 mm^2 wall samples were used to measure masonry density and the proportion of brick to mortar in face area. On average, 21.3 % of the wall area was mortar. Comparatively, rectangular and circular specimens had mortar face areas of 21.7 % and 15.4 %. All walls and composite specimens used in Future Spaces project were made with dry cured mortar joints. Pure mortar specimens were cured in mould. Material densities are shown in Table 2.

Table 2. Material densities.

Material	Density (kg/m^3)	CoV (%)
Wall sample 300 x 300 mm^2	1592	0.61
Whole brick - batch I[a]	1422	1.15
Whole brick - batch II[a]	1495	0.56
Sample of brick - batch I[b]	1952	1.08
Sample of brick - batch II[b]	2021	1.08
Masonry mortar[c]	1757	1.86
Mould mortar	1729	0.25

CoV: Coefficient of Variance.
[a] Includes voids inside brick to the total volume.
[b] Density without voids. Measured with thin discs cut from brick face.
[c] Mortar cut from a masonry wall.

Outer dimensions and joint height of composite specimens were measured to estimate the amount of mortar embedded in the brick hollows. The volume of brick and joint was calculated for each sample, and the material weight calculated based on the average density of brick and mortar. Average densities were measured separately for the materials. The weight of mortar in hollows was assumed to be the remainder of specimen weight after reducing brick and joint weights. Hollow volume filled was calculated by dividing the volume of mortar in hollows with the total hollow volume of the specimen.

Since the component weights are based on dimensions and average densities of materials, the measurement of mortar in hollows is not very accurate. Especially the interface between materials seems to have voids that are not accounted for. In addition, the maximum penetration depth of mortar in hollows was measured for rectangular specimen. Mortar penetration depth could not be defined for circular specimens due to the specimen shape. Composite specimen content by weight is shown in Table 3.

Table 3. Average weights of the materials in composite specimens.

Specimen type	Weight (g)	Brick (g)	Joint (g)	Mortar in hollows (g)	Hollow volume filled (%)	Penetration up/down[a] (mm)
Batch I masonry (R)[b]	1624	1198	321	104	25	16.6 / 20.0
Batch I masonry (C)[c]	1885	1483	307	96	-	-
Batch II masonry (R)	1585	1218	317	50	12	14.4 / 21.6
Batch II masonry (C)	1870	1538	294	39	-	-

[a] Penetration depth of mortar in hollows above and below the joint.
[b] Rectangular joint specimen.
[c] Circular joint specimen.

2.1. Thermal resistance

Thermal resistance of pure materials was tested according to SFS-EN 12664 [18], using a guarded hot plate apparatus. 10 cylindrical specimens with a diameter of 52 mm and thickness of 9-12 mm were tested per variation. Specimens were leveled and the brick face was ground even. The thermal conductivity of composite specimens could not be measured due to the relatively small measuring area (400 mm^2) of the apparatus.

2.2. Hygric properties

Circular specimens had a diameter of 135 mm, and ten were tested for each variation. Water vapour permeability was tested according to SFS-EN 12572 [19], using dry cup method at 22 °C and 0/50 % relative humidity. Water absorption coefficient A_w [$kg/m^2s^{0.5}$] and capillary moisture content W_{cap} [kg/m^3] were determined according to standard SFS-EN 15148 [20]. In addition, water penetration coefficient B_w [$m/s^{0.5}$] was calculated according to SFS-EN 15801 [21]. All samples were conditioned at 22 °C and 50 % RH before testing.

3. Results

Thermal conductivity of bricks was lower than mortar. Due to the high variance of all test series, no difference can be ascertained between batches or mortar hardening methods. Thermal conductivity results are shown in Table 4.

Table 4. Thermal conductivity

Material	λ (W/mK)	CoV (%)
Batch I pure[a]	0.47	20
Batch II pure[a]	0.44	13
Masonry mortar	0.59	11
Mould mortar	0.57	11

λ: Thermal conductivity, CoV: Coefficient of Variance.
[a] Measured using thin discs from brick surface, without voids.

Area weighted effective properties were defined for all masonry specimens. The relative difference between measured and area weighted properties of specimens is shown in result tables as RD column. Water vapor permeability of brick batch I is 79 % higher than batch II, while mortar's permeability is mid between the brick types. Water vapor permeability is presented in Table 5.

Table 5. Water vapor permeability.

Material	δ_v (m^2/s)	CoV (%)	RD (%)
Batch I	2.13E-06	5.9	-
Batch I masonry (R)[a]	1.97E-06	8.0	-3
Batch I masonry (C)[b]	1.93E-06	6.0	-6
Mortar	1.68E-06	2.8	-
Batch II	1.19E-06	4.0	-
Batch II masonry (R)	1.85E-06	5.9	43
Batch II masonry (C)	1.56E-06	7.2	23

δ_v: Water vapor permeability, CoV: Coefficient of Variance, RD: Relative difference to area weighted properties.
[a] Rectangular joint specimen.
[b] Circular joint specimen.

Variance in capillary properties was higher than in vapor permeability. Water penetration coefficients of masonry specimens, especially for batch II, have variance high enough to cover the RD % (relative difference compared to area weighted properties). Since water penetration coefficient measures the height of water front migration, it is likely incorrect for vertically layered materials that can have different water front heights for each layer.

Masonry specimens were expected to have slightly higher capillary moisture content compared to area weighted properties. The calculated average penetration of mortar in hollows (72 g) equals to roughly 6 kg/m^3 increase in capillary moisture content. Batch I masonry had a negligible increase in capillary moisture content, while batch II masonry specimens had an increase of 35 kg/m^3 and 21 kg/m^3 respectively. Interestingly, batch II masonry also had less mortar in hollows based on specimen weights and dimensions. This increase in capillary moisture content could be caused by water accumulation in the brick hollows.

Table 6. Water absorption by partial immersion.

Material	A_w ($kg/m^2s^{0.5}$)	CoV (%)	RD (%)	B_w (mm/s^2)	CoV (%)	RD (%)
Batch I	0.106	12	-	0.90	6	-
Batch I masonry(R)[a]	0.090	7	-1	0.80	6	5
Batch I masonry(C)[b]	0.083	10	-13	0.78	6	-2
Mortar	0.035	5	-	0.25	10	-
Batch II	0.084	9	-	1.51	15	-
Batch II masonry(R)	0.107	10	48	1.10	16	-10
Batch II masonry(C)	0.079	8	4	1.01	12	-23

A_w: Water absorption coefficient, B_w: water penetration coefficient, RD: Relative difference to area weighted properties.
[a] Rectangular joint specimen.
[b] Circular joint specimen.

Table 7. Water absorption by partial immersion – Capillary moisture content.

Material	W_{cap} (kg/m^3)	CoV (%)	RD (%)
Batch I	142	8	-
Batch I masonry(R)[a]	155	4	4
Batch I masonry(C)[b]	146	5	-1
Mortar	170	5	-
Batch II	84	9	-

Batch II masonry(R)	138	6	33
Batch II masonry(C)	118	8	22

W_{cap}: Capillary moisture content, RD: Relative difference to area weighted properties.
[a] Rectangular joint specimen.
[b] Circular joint specimen.

Figure 3 shows examples of the graphs measured in free water intake test. Brick and masonry specimens were full wall thickness, having a height of 84 mm on average. Mould mortar specimens had a height of 29 mm to keep the duration of the test reasonable.

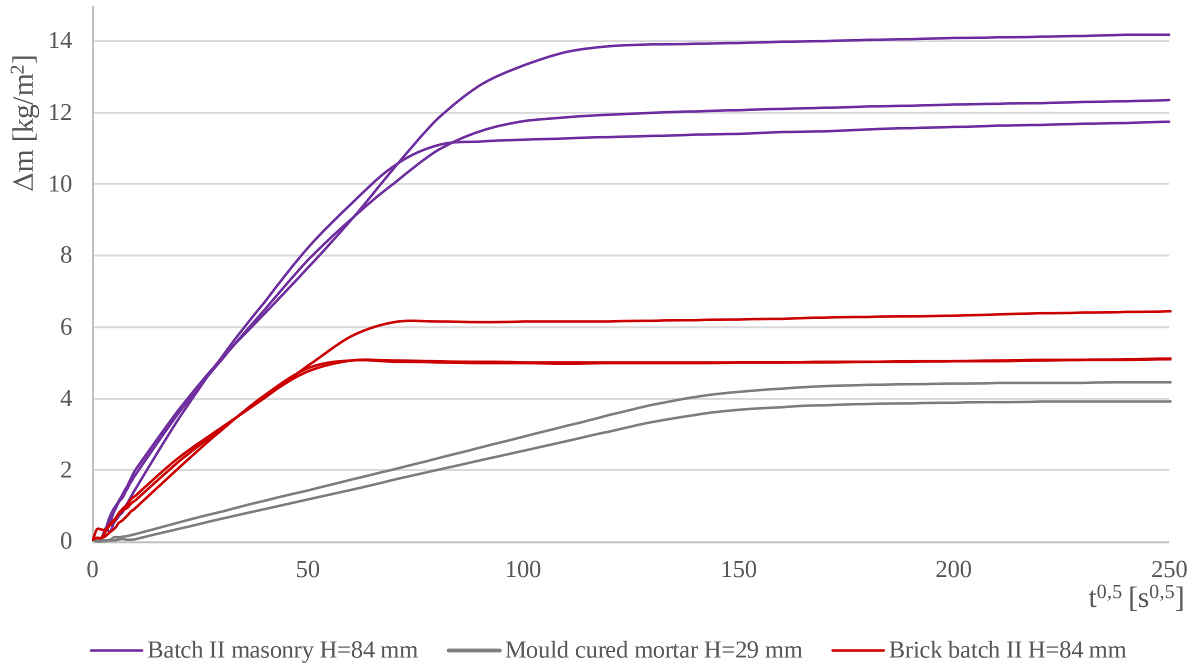

Figure 3. Water absorption graph for certain specimen types.

Comparison between masonry and a brick layer is shown in Table 8. Brick properties were defined using rectangular specimens. As such, Table 8 results for masonry only include results for rectangular specimens.

Table 8. Difference in effective wall properties compared to a brick layer.

Method	δ_v (%)	A_w (%)	W_{cap} (%)	Avg[a] (%)
Batch I area-weighted	4	17	-4	8
Batch I masonry	8	19	-8	12
Batch II area-weighted	-8	15	-19	14
Batch II masonry	-36	-22	-39	32
Average[b]	14	18	18	-

[a] Average difference in material properties for each test method.
[b] Average difference for each material property across the methods.

4. Discussion

The sampling of brick wall – especially in the case of hollow bricks – incurs a lot of new error sources. Bed- and headjoints have different surface types, orientation and brick laying techniques applied to them. Something et al Brick voids can have different alignment and volume based on sample location and shape. Newly made test walls that have never been under mechanical or weather stress will differ from real world structures. As such, these results are mainly used to estimate the significance of more precise measurements.

The impact of specimen shapes can be observed in all tests. Circular specimens have 3-44 % lower results, averaging 6.8 and 22 % for batches I and II respectively. For brick batch I, the relative difference between masonry and area weighted properties is within margin of error regardless of specimen shape. The relative difference was meaningful for both specimen shapes of batch II. For the most part, results for masonry and area weighted properties were in similar direction when comparing to a simplified brick layer. Only in water absorption coefficient of batch II were the results divergent.

On average, using masonry or area weighted properties had a difference of 14, 18 and 18 % respectively in water vapor permeability, water absorption coefficient and capillary moisture content. Comparatively, the difference in these properties between the brick batches was 79, 27 and 69 %.

5. Conclusion

The effect of brick-mortar interface and mortar penetration in hollow bricks is largely irrelevant in the hygric performance of brick façade. Area weighted material properties can be used to improve modeling accuracy. The effect of workmanship, degradation and leakage in head joint might however be even more relevant. In addition, the difference between brick batches used in this study was greater than the effect of mortar. Based on the results in capillary water content, there is a possibility that the voids inside a hollow brick might fill with water. This could be even more likely in real world climate, where the capillary suction doesn't have to work against gravity.

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