Hygrothermal properties of extruded earth bricks

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SUMMARY

This article focuses on the study of hygrothermal properties of five extruded earth bricks produced by several French brickworks. The thermal conductivity, the water vapor permeability and sorption kinetics underline the highly anisotropic behavior of the bricks directly linked to the extrusion direction during the manufacturing process. The results confirm that the extrusion process has a major influence on the orientation of clay platelets and impacts the hygrothermal properties. The brick manufacturers could take advantage of these results to improve the hydrothermal performances of the walls by adapting the laying of the bricks and the geometry considering the extrusion direction.

INTRODUCTION

Earth is one of the oldest building materials still use [1]. The interest in traditional earth constructions, as rammed earth, adobe or compressed earth bricks, has grown in Europe since a few years; among other qualities, earth is a material having a low environmental impact and a good capacity for the hygrothermal regulation inside a building. With the recent keen interest in sustainable development, earthen construction shave become attractive and Frenchbrick manufacturers produce more and more extruded earth bricks widening their product range. One of the advantages of the extrusion process is that it enables fast production of large quantities of homogeneous bricks that are similar in shape and size. As it was observed or fired clay bricks, an alignment of the clay particles occurs during this process because of the frictions with the die [2-4]. Relatively few publications focus on extruded earth bricks and a majority of them deals with their mechanical properties [2,5-10]. Therefore, this article focuses on the hygrothermal properties of extruded earth bricks by measuring their thermal conductivity, their water vapor permeability and their water vapor sorption.

1. MATERIALS AND PROCEDURES

1.1. Materials

For this study, the five bricks tested (referenced B1 to B5) were produced by different French brick works. They are used for interior partition walls (Fig 1).In the case of extruded earth bricks, the soil mixed with water to approximately the plastic limit of the soil is extruded under a vacuum through a machined die. This produces a stiff column of clay, that is subsequently cut into single bricks. The dimensions, the dry densities and the clay content are summarized in the Table1.

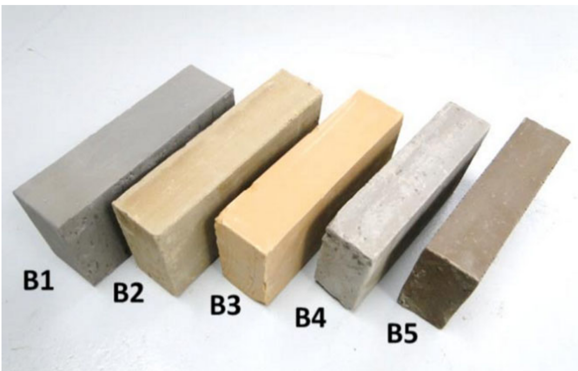

Fig.1: The five unfired clay bricks tested [9].

Table 1: Dimensions, dry density and clay content of the unfired clay bricks

Unit code	Length (cm)	Width (cm)	Height (cm)	ρ (kg/m^3)	<2,5 µm (%)
B1	22.5	10.5	6.0	1940	39.8
B2	22.5	11.3	5.4	2020	55.2
B3	22.0	11.1	5.4	2030	33.4
B4	21.6	10.6	5.0	2050	58.3
B5	21.5	10.5	5.0	2020	47.7

For these five bricks, the directions of extrusion are not the same: B2, B4 and B5 were extruded in lengthwise sense; B1 and B3 were extruded height wise. During this process, the clay platelets orientated themselves in the direction of extrusion and two directions can be considered: the perpendicular direction (Dperp) and the parallel direction (Dpara) (Fig.2). This phenomenom, little studied in the literature, is well known by brick manufacturers in fired clay bricks.

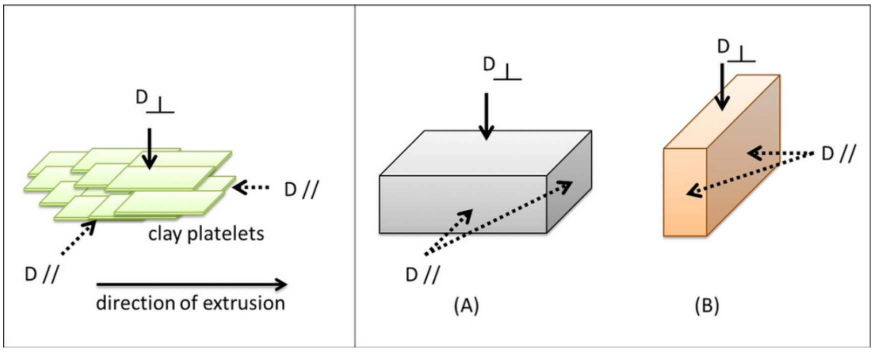

Fig. 2: Direction of extrusion for the bricks B2, B4, B5 (A) and the bricks B1, B3 (B) [9].

1.2. Procedures

1.2.1. Preparation of the samples

For the thermal conductivity and the water vapor permeability, cylindrical samples (Ø = 50 mm, thickness = 10 mm) were cored directly into the brick, without water, on two sides depending on the clay layer orientation: perpendicular (Dperp) and parallel (Dpara). Each face of the samples was rectified using a grinding machine to obtain a plane surface.

1.2.2. Thermal conductivity

Thermal conductivity measurements of the samples were carried out using the heat flow meter method according to ISO 8301 with a Lasercomp Fox 50 at 30°C (with a "hot" plate at 40°C and the "cold" plate at 20°C) [11]. Samples were previously dried at 105°C for 48h.

1.2.3. Water vapor permeability

To determine the water vapor factor resistance (µ), water vapor permeability tests were carried out following standard EN ISO 12572 [12]. Tests were run at 23°C; the "dry" cup conditions were 0% RH inside the cup containing a salt, $CaCl_2$, and 50% RH inside the climatic chamber where the samples sealed on the cup were placed.

1.2.4. Water vapor sorption isotherm

The water vapor sorption measurements were performed according to the standard EN ISO 12571 [13]. For each reference, two cubes of 50 mm were cut from the brick and then dried at 105 ° C during 48 hours. Then, four of the faces of each cube are coated with a mixture of wax and paraffin as follows: for the cubes (Dperp), the two free faces are perpendicular to the direction of extrusion; for the cubes (Dpara), the two free faces are parallel to the direction of extrusion. The cubes were weighed before and after the deposition of the wax/paraffin mixture. The cubes are placed in a climatic chamber at 23°C and 40% RH until a constant weight was obtained. The relative humidity (RH) was varied in steps at 60, 80, and 95% RH. The samples were weighed regularly to determine the weight evolution curves as a function of the time. The relative humidity of the climatic chamber was changed when the weight of samples became constant. To obtain the desorption curves, the same procedure was followed with decreasing levels of relative humidity from 95 to 40% RH. The moisture content of each samples, denoted θ, was determined from the mass curve recorded which was calculated at each equilibrium step of humidity following the equation: θ = 100 x (humid mass – dry mass)/dry mass.

2. RESULTS AND DISCUSSION

2.1. Thermal conductivity

The Table 2 shows the thermal conductivities of the earth bricks measured in two directions (λDperp and λDpara). The values are the average of three samples and the anisotropy ratio is obtained by dividing λDpara by λDperp.

Table 2: Thermal conductivity of unfired clay bricks (average of 3 samples).

Unit code	λ D⊥ ($W.m^{-1}.K^{-1}$)	λ D// ($W.m^{-1}.K^{-1}$)	Ratio λ D// / λ D⊥
B1	0.66 ± 0.05	1.10 ± 0.02	1.67
B2	0.66 ± 0.06	0.93 ± 0.05	1.41
B3	0.69 ± 0.04	1.24 ± 0.02	1.80
B4	0.57 ± 0.08	0.86 ± 0.08	1.51
B5	0.62 ± 0.04	0.72 ± 0.04	1.16

The thermal conductivity values differed depending on the sample Dpara or Dperp. For all the bricks, the values Dperp are lower than that the samples Dpara, and the anisotropy ratio being scattered from 1.2 (B5) and 1.8 (B3). As shown by Laurent [14], the density is one of the main physical parameter that affects the thermal conductivity: in our study, the densities of the five bricks were the same that is coherent with the low variations observed on the values of thermal conductivities. The significant difference of the thermal conductivity values between the samples Dperp and the samples Dpara shows that extruded earth brick can be considered as an anisotropic material. As explained earlier, during the extrusion process, the clay layers oriented themselves following the direction of extrusion. The thermal properties were thus dependent on the direction considered (perpendicular or parallel to the orientation of clay platelets). In the perpendicular direction, the clay particles inhibit the heat flow and the thermal conductivity is thus lower. On the contrary, in the parallel direction, the heat flow is favored by the orientation of clay platelets and the thermal conductivity is higher.

2.2. Water vapor factor resistance

The water vapor factor resistance values are summarized in the Table 3 (each value is the average of 5 samples). The more this factor is high, the more the vapor permeability is low, contrary to thermal conductivity, the anisotropic ratio was calculated by dividing µDperp / µ Dpara to compare the ratios between them.

Table 3: Water vapor factor resistance of the extruded earth bricks.

Unit code	μ D⊥	μ D//	Ratio μ D⊥ / μ D//
B1	24.0 ± 2.1	16.0 ± 0.9	1.50
B2	44.0 ± 4.1	23.1 ± 1.6	1.90
B3	19.0 ± 0.9	10.6 ± 0.2	1.79
B4	32.6 ± 3.5	18.8 ± 1.3	1.73
B5	21.8 ± 2.4	16.6 ± 1.3	1.31

As shown with the thermal conductivity, there is a significant difference between the samples Dperp and Dpara. For all the bricks, the values of the samples Dpara are lower. As previously, the anisotropy ratios are scattered, but there is no direct correlation with the thermal conductivity ratios except for the reference B5 which had the two lowest ratios. The values obtained are close to those measured by Cagnonet al. On extruded bricks; their "drycup" values ranged between 7 and 19 without taking into account the anisotropy and underlined a high vapor permeability for these materials too [8].

2.3. Water vapor sorption isothermand kinetic of sorption

The water vapor sorption measurements have shown that, at equilibrium, the difference between the samples Dperp and Dpara is weak. Thus, only the results obtained with the sample Dperp are presented on the Figure 3. The highest moisture contents (θ) are attributed to the bricks B2, B4 and B5 which contain the higher amount of fine particles(<2μm), respectively 55, 58 and 47 %. These results underline that the earth bricks have a high potential for the hydric regulation in a building.

The values of the moisture content reached at equilibrium are comparable but the kinetics of sorption are different between the samples Dperp and Dpara which reveal again an anisotropic behavior especially marked for B2 and B4, the two references having a high amount of fine particles (>50%) (Figure 4). During the sorption phase, a significant difference was observed progressively at each step between both samples Dperp and Dpara particularly at the last stage at 95% RH. For the sample Dpara, the moisture content (θ) increased faster than that of the sample Dperp. During the desorption phase, the moisture of the sample Dpara decreased more quickly and the stabilization was reached before that of the sample D perp. Moreover the gap between the both curves is more marked than during the desorption phase indicating the different behavior of the water vapor flow linked to the microstructure of the brick. As observed with the water vapor permeability test, parallel to the orientation of the clay platelets (i.e. to the direction of extrusion), the water vapor flows more easily. However, once equilibrium is reached, the samples Dperp and Dpara contain the same amount of water.

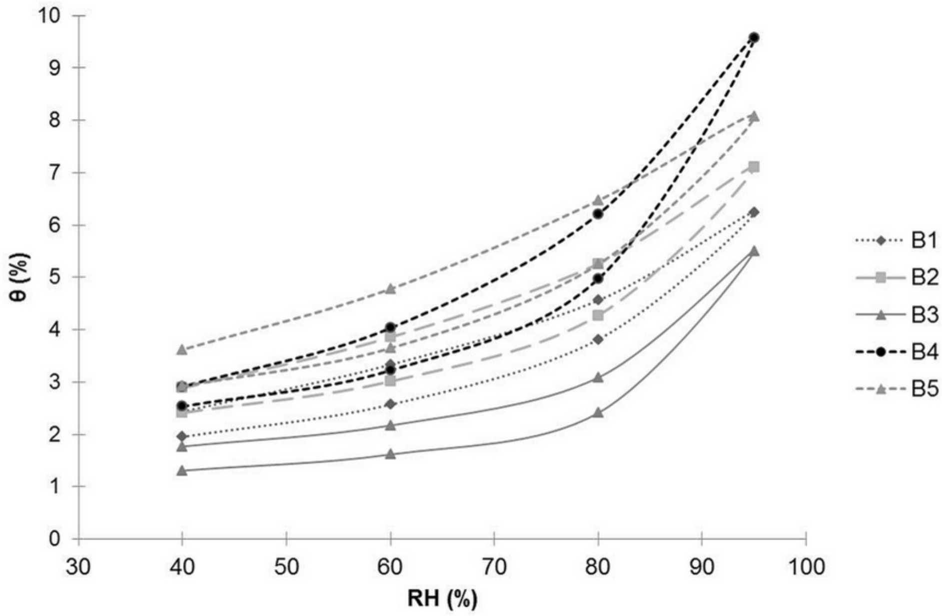

Fig. 3: Sorption and desorption curves of the unfired clay brick (Dperp) at 23°C.

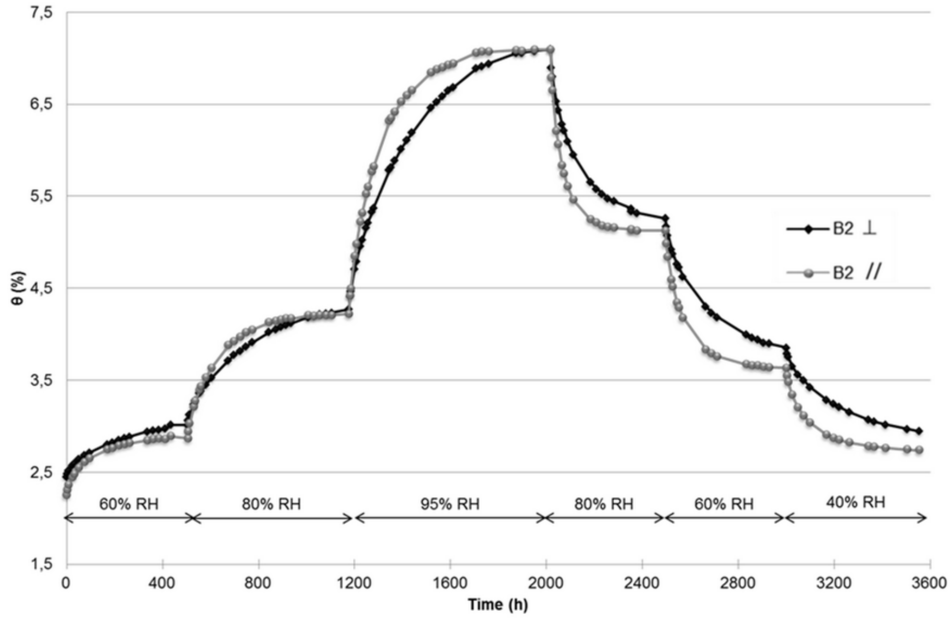

Fig. 4: Evolution of the moisture content (θ) of the samples Dperp and Dpara for the brick B2.

CONCLUSION

In this study, five extrude dearth bricks were characterized and the thermal conductivity, the water vapor factor resistance and the water vapor sorption were measured. The bricks came from several French brick works, the densities and the dimensions were similar. For each reference, the properties were studied in two directions: perpendicular and parallel to the direction of extrusion.

The results underlined that the hygroscopic properties are anisotropic and directly linked to the direction of extrusion and thus to the clay platelets orientation. The extrusion process generates stresses on the clay paste, the clay platelets tend to move in the direction of extrusion. In the perpendicular direction, the thermal conductivity and the kinetic of sorption are lower; the water vapor factor resistance is higher compared to the parallel direction. The heat flow and the water vapor are slowed down by the clay platelets. In contrast, in the parallel direction, the heat flow and the water vapor are facilitated: the thermal conductivity and the kinetic of sorption are higher, the water vapor factor resistance is lower. The effects of the anisotropy are important with an anisotropy ratio ranged from 1.2 to 1.9.

In the future, it will be interesting for the brick manufacturers to consider these results to improve the characteristics of their products. Depending on the desired effect, they could extrude their bricks in the direction of the length or the height, or adjust the direction of the laying bricks. These first results should be completed by additional studies including microstructure studies to correlate the hygrothermal properties with the microstructure of the brick (amount of clay, clay nature, porosity, etc.).

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BIOGRAPHICAL NOTICE

Pascal Maillard is a R&D Project Manager. After a PhD in chemistry of materials (2006, Rennes), he joigned the CTMNC to work on fired clay bricks in 2008. Now based in the laboratory of Limoges, he especially studies the extruded earth bricks and developed tests to characterize this material (mechanical, thermal and hygric properties).

Jean-Emmanuel Aubert is a Professor at the University of Toulouse and has performed his research activities in the LMDC since 2003. His main topics of research concern the eco-efficient materials used in building and road construction, especially the use of earth as construction materials.