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Mechanical behavior of an assembly of wood–geopolymer–earth bricks

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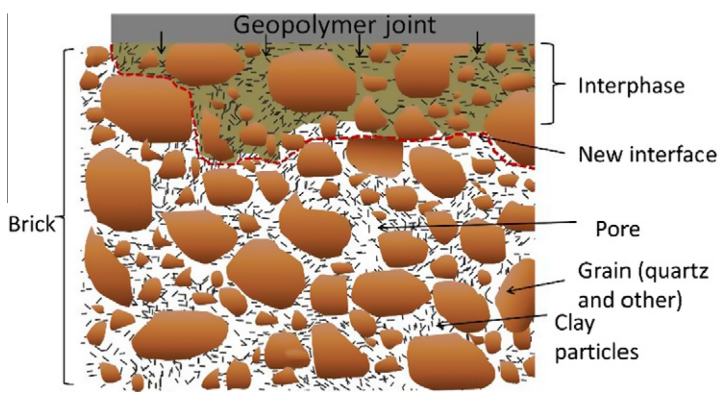
HIGHLIGHTS

- ▶ Geopolymer binder gives good adhesion between wood and earth.
- ▶ Shear results are similar to thus obtained on fired brick with cement mortar masonry.
- ▶ The Brick nature has an important effect on the mechanical behavior of masonry samples.
- ▶ The binder penetrates inside the earth creating a new phase.

GRAPHICAL ABSTRACT



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ABSTRACT

Timber frame construction with earth brick infill is a sustainable design that is promising in the building construction field. However, cracks form at the interfaces of the bricks and frame with temperature and humidity fluctuations. A geopolymer binder can create stronger bonds between these two materials than traditional mortar, potentially preventing crack formation. This study focuses on the pull-out and shear mechanical behavior of laboratory assemblies of wood, geomaterial binder and two different types of earth brick. The full-field displacements of double-shear test samples were also obtained by digital image correlation (DIC) to better describe and understand the mechanical behavior of the system. The results show that the geopolymer binder provides good adhesion of approximately 1.5 MPa or 2 MPa, depending on the type of brick. Failure localization is also different for each assembly, occurring inside the brick and binder or only inside the binder. This result is confirmed by DIC analysis. The microstructure of the brick has been correlated with the mechanical behavior of the assembly. First results show that the geopolymer binder can be used as a joint in wood and earth masonry.

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1. Introduction

The reduction of CO_2 emissions has become a global concern [1,2], and the investigation of environmentally friendly materials has become increasingly important [3]. The use of construction materials that less energy, such as the wood and earth materials that have been used for several millennia all over the world, seems to be relevant [4–6]. Earth materials offer several advantages, including a weak embodied energy, the ability to regulate the relative humidity of a building, their abundance in most areas and ease of recycling [5,7]. Earth materials can be used to build load bearing and non-load bearing walls. To improve their mechanical resistance and water resistance, additives such as lime and cement

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can be used; however, in this case, the use of these additives leads to greater environmental impact.

Many earth construction techniques exist for building construction, some of which are traditional, such as rammed earth, cob and adobe [5,7], and some are more modern, such as extruded and pressed bricks. Modern manufacturing processes such as extrusion are promising for the development of earth materials in our industrial society [8]. The extrusion and compression processes used in the fired brick industry can be directly applied to the manufacture of earth brick. Unfired extruded clay bricks are obviously less resistant than high-energy materials (concrete blocks, fired bricks); however, in the case of non load-bearing walls, improved resistance is not necessary. Indeed, a timber frame with a mortared earth material as a filling is an example of an alternative construction that provides suitable resistance for housing [9–11]. In earth construction, the mortar is very important for the mechanical resistance of the wall. Typically, mortars are a mixture of sand and clay that is used to manufacture the block. Cement, lime, starches and sugars are also used as additives in some cases [5]. Traditional mortar provides weak bonds with earth of approximately 25×10^{-4} MPa, particularly with other materials such as wood. However, the use of additives can improved the resistance of mortar, providing a bond strength of 25×10^{-2} MPa [7].

Earth materials and wood are fundamentally different materials. One is mineral, and the other is vegetal; however, both are sensitive to water and have the ability to absorb moisture easily. This ability is advantageous to the interior environmental conditions for occupants because it can regulate humidity. Nevertheless, problems arise from dimensional changes with varying humidity and temperature, which are characterized by swelling and shrinkage phenomena. Occupants of buildings with this type of construction have detected some cracks over the course of a year at the interface between the wood and earth blocks [11]. To minimize or inhibit this problem, a binder that provides proper adhesion between earth and wood is necessary. The required properties for this binder must be focused on the chemistry close to the clay due to the earth brick and to the possibility to assume a transfert inside the wood. In terms of structural aspect, improve bond between wood and earth could improve the stiffness of the interface and thus the stiffness of the entire wall which can be interesting in terms of flexural strength. However as the interface is rigidified, this interface becomes more brittle and this leads to a loss of ductility which can be a drawback for the wall behavior in duration. Among the potential compounds currently available, the geopolymer family is a good candidate because they are synthesised from raw materials [3]. Geopolymers are amorphous three-dimensional alumino-silicate binder materials that are synthesised by the alkaline activation of alumino-silicate sources, such as calcined clays, industrial waste, natural minerals and more [12,13]. Lawrence and Walker [14] have shown the suitability of a binder made of a mix of sodium silicate and earth for use with unfired extruded brick. Moreover, a recent study showed that the addition of silica fume to a geopolymer mixture led to the formation of a foam that provided two advantages: the ability to adhere to wood and a low conductivity value between 0.22 and 0.24 $W\,m^{-1}\,K^{-1}$ [15,16]. In addition, previous works on construction designs made from wood, earth and geomaterial have indicated the viability of these structures by demonstrating the ability of the geopolymer binder to produce strong bonds between the wood and earth [17]. In the earth construction field, data have mainly been collected on the mechanical properties of the material, such as their compressive strength [18,19], which is the principal characteristic measured. The hygrothermic behavior of earth materials has also been investigated [20]. Few data are available on the mechanical behavior of masonry, especially for construction designs composed of wood and extruded earth brick with a geopolymer binder. To validate the performance of a geopolymer binder as an interface material, the adhesion mechanism of the assembly must be understood. Consequently, the development of a feasible test that adequately describes the real phenomenon is of primary importance. For non-load-bearing walls, two type of stress are relevant: shear and pull-out can be observed at their interfaces as a result of the swelling and shrinkage phenomena of wood and earth. The shear test is primarily used to study joints because it reproduces their typical load conditions. Although less used, the pull-out test is interesting because it is highly discriminatory. The shear and pull-out tests are thus suitable to understanding and describing the behavior of these assemblies [21].

This work concerns load-bearing timber frames with industrially extruded bricks as fill. The focus of the study is an investigation of the shear and pull-out resistance of an assembly of three materials (wood, geopolymer binder and earth) to validate the performance of the geopolymer binder as a joint material. Moreover, the shear behavior has been investigated by Digital Image Correlation (DIC) to describe the mechanical behavior of the assembly. The experimental results and full-field displacement maps of the tests are presented and discussed.

2. Experimental

2.1. Raw materials used

Two types of extrusion-manufactured industrial earth bricks were used in this study. They differ in mineral composition (denoted B1 and B2), and they have densities of 1700 kg/m^3 and 2000 kg/m^3 for B1 and B2, respectively. Compressive stress is around 1 MPa for B1 and around 3.5 MPa for B2. A local company of Limoges supplied Douglas fir wood that was dried and planed. Its strength class was C24, its density (12% RH) was approximately 540 kg/m^3 and its shrinkage was approximately 13.2%. Concerning the timber mechanical properties, the compression parallel to the grain at failure was approximately 55 MPa, $\boldsymbol{f}t, 0, k$ characteristic value of tensile strength parallel to grain was 14 MPa, $\boldsymbol{f}c, 0, k$ characteristic value of compressive strength parallel to grain was 21 MPa and $\boldsymbol{E}$ and mean characteristic value of modulus of elasticity parallel to grain was 11,000 MPA [22,23]. Potassium hydroxide pellets (85.7% purity), potassium silicate (H_2O = 76.07%, SiO_2 = 16.37% and K_2O = 7.56%) solution, silica fume supplied by FERROPEM (Chambery, France) and metakaolin M1000 from AGS (Clerac, France) were used to synthesize the geopolymer foam binder [16].

2.2. Manufacturing of samples

2.2.1. Synthesis of the geomaterial foam

The synthesis protocol and raw materials used were based on the work of Prud'Homme et al. [16] and a previous study presenting the feasibility of assembly [17]. Fig. 1 summarizes the synthesis protocol for the geomaterial foam binder. A notable feature of the binder is its porosity, which is a result of the oxidation by water of the free silicon that is present in small amounts in the silica fume, leading to the formation of hydrogen gas (Eq. (1)).

$$4H_2O + Si^0 \rightarrow 2H_2 + Si(OH)_4. \quad (1)$$

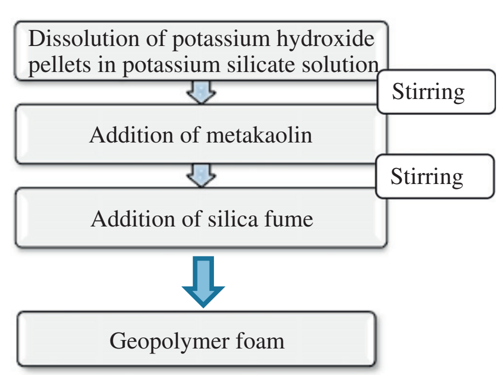

Fig. 1. Synthesis protocol of geo-material foams.

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