EXPERIMENTAL AND NUMERICAL STUDY OF THE BRICK-MORTAR INTERFACE

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Summary The principal failure mode of the masonry walls is the shearing process in a brick-mortar bed interface. In order to understand this phenomenon, an experimental study was carried out. Loading/unloading shear tests have been performed using bricks with and without hollow. The influence of brick hole was in particularly studied. According to the obtained results, an interface model was proposed and then implemented in a finite element code.

EXPERIMENTAL STUDY

Many authors studied the shear bloc-mortar interface behaviour using several specimens (triplet or couplet) [1] and [2]. The Coulomb friction law using two material parameters (cohesion and friction angle), is generally assumed to represent the failure of masonry joints under coupled loading (shear and compression). The first objective of the experimental work presented here is the investigation of the shear mortar joint behaviour using loading/unloading shear tests. The second one is to study the influence of brick hole in the interface characteristics. A combination of both solid and hollow clay brick with one type of mortar has been used. The tensile and compressive strength of the employed mortar are respectively $4.14\,N/mm^2$ and $20\,N/mm^2$. The compressive strength of the brick was also determined in two directions: in the first one (parallel joint direction) the obtained values are $34\,N/mm^2$ and $20.31\,N/mm^2$ for solid and hollow brick. While in the perpendicular joint direction, the compressive strength values are respectively $42\,N/mm^2$ and $34\,N/mm^2$. The specimens were manufactured using only half brick glued by $10mm$ of mortar and stored for 28 days at constant temperature of $25\ C^\circ$ and relative humidity of $90\ \%$.

The shear testing apparatus employed was designed at the Centre Scientifique et Technique du Bâtiment (CSTB – France). A vertical and horizontal jacks were used to apply normal and shear loads respectively. First the compressive normal stress is applied and then the shear stress is applied by imposing displacement with a velocity of $0.01\,mm/s$. The normal and shear stresses are recorded by mean of load cells. The relative displacement between the top and the bottom half brick was measured using two displacements transducer.

EXPERIMENTAL RESULTS

In order to avoid the rotation of the specimen while applying loading/unloading processes, a low compressive pre-stress is maintained at $0.3\,N/mm^2$. The shear stress versus the relative displacement curves are presented in figure1 for both combinations.

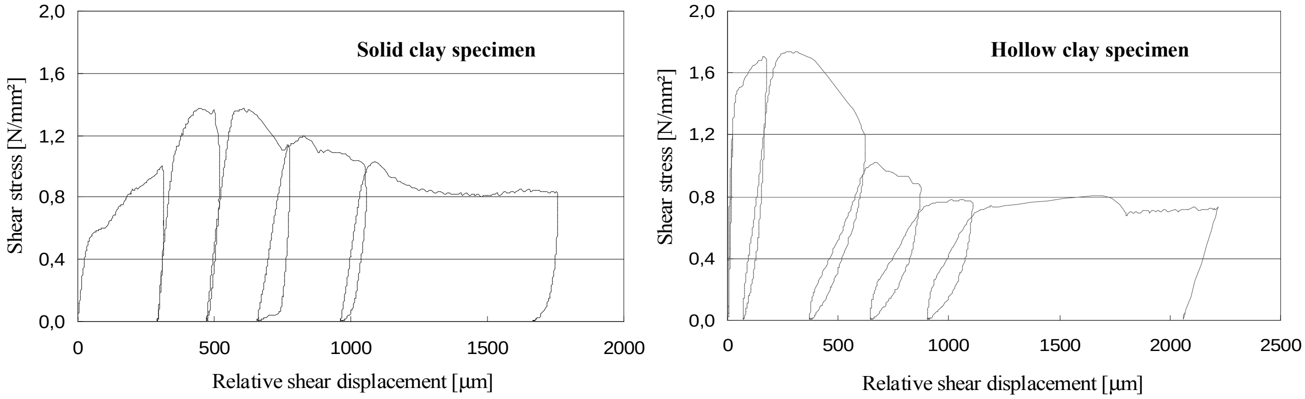


Figure1: Loading / unloading shear tests: shear stress versus relative displacement

The comparison between loading and unloading shear modulus indicates that no shear modulus degradation occurs. Furthermore, the interface shear behaviour can be considered to be elastoplastic. Irreversible displacements were registered when the stress exceeds 40% of shear strength.

In order to calculate the interface characteristics, tests were carried out using several normal compressive stresses, varied from -0.1 to $-1.5N/mm^2$. A linear relationship between shear bond strength τ_u and the applied normal compressive stress σ_n is experimentally observed for both solid and hollow brick. Therefore, the Coulomb friction law is applicable:

$$|\tau_u| = c + \sigma_n \cdot \tan\varphi \qquad (1)$$

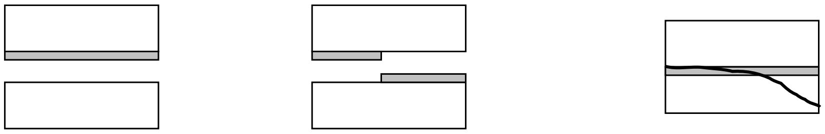
where c and φ are respectively the cohesion and friction angle defined by linear regression. Likewise, the residual shear bond and the applied normal compressive stress relation determine the residual bond characteristics.

In literature, the tangent of the friction angle depends on the used material. These values range from $\tan\varphi = 0.7$ to $\tan\varphi = 1.2$ [3]. In our case, the internal friction angle φ is found to be equal to $45°$ $(\tan\varphi = 1.01)$ which remains within the interval of observed values. Further, this angle is the same for both solid and hollow bricks. However, the mortar penetrating into the brick holes increases the bond stiffness and the residual bond cohesion.

FAILURE MODES

For the solid clay, two failure modes were experimentally recorded: A brittle failure obtained for low pre-compression stress, and a quasi-brittle failure in the case of higher pre-compression. For the hollow brick, a quasi-brittle post-peak behaviour is often obtained whatever is the pre-stress. Moreover, the residual shear stress is about 50% of the shear strength (see figure1).

Figure2 shows the different failures modes obtained during the shear tests.



Mode (a) **Mode (b)** **Mode (c)**

Figure2: Failure modes in shear tests

THEORETICAL CONSIDERATIONS

The experimental shear behaviour investigation helps us to propose an interface model accounting for tensile and shear behaviour. For the bond tensile behaviour, Pluijm R. van der is referred [2]. The yield criterion is given by a tensile yield function F_t and a shear yield function F_s:

$$\begin{cases} F_t = \sigma_n - \overline{\sigma}(\kappa_t) \\ F_s = |\tau| - \sigma_n \cdot \tan\varphi - c(\kappa_s) \end{cases} \tag{2}$$

Corresponding to the Rankine and the Mohr Coulomb failure criteria, respectively. σ_n and τ are respectively the normal and the tangential component of the stress vector. $\overline{\sigma}$ is the interface tensile strength, which is function of the tensile hardening parameter κ_t. The decrease of shear strength is represented by the cohesion variation, which is function of the shear hardening parameter κ_s. It is assumed that a configuration of joint without cohesion has a very small tensile strength, which is near 0. This model was implemented in finite element code CAST3M with which some simulations were performed.

CONCLUSIONS

The shear joint mortar behaviour was investigated using loading/unloading shear tests. According to the experimental results, the mortar joint behaviour can be considered to be elastoplastic. The brick hole influence was also studied with two combinations of bricks and mortar. This study shows that the friction angle is independent on the existing hole. The test results allow the development of an interface model. With this model, some numerical simulations were performed on, reproducing consequently non-linearity provoked by the material behaviour such as joint opening and sliding.

References

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[3] Lourenço P.B., Barros J.O., Oliveira J.T.: Shear testing of stack bonded masonry, Construction and Building Materials (Article in press)