Tribometer friction tests on cracked brick-mortar interfaces

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Abstract. Friction significantly affects masonry, especially in determining lateral resistance. This study evaluates the contribution of friction in cracked masonry by performing reciprocating sliding tests on cracked brick-mortar interfaces, by means of a tribometer, whose application to masonry materials remains unexplored. Enabling the evaluation of the sole contribution of the friction mechanism at the cracked brick-mortar interface is rather novel for the field of mortared masonry, in which friction properties are typically calculated through an inverse analysis of experiments involving both de-cohesion and friction mechanism. A solid clay brick masonry with cement-lime mortar is considered as case study. The influence of various parameters is studied, such as the normal force and the sliding frequency. The preliminary study shows a large variability in terms of the kinetic coefficient of friction and tangential stiffness. This may suggest that the roughness and waviness of the cracked interface – and consequently, wear and debris formation – highly influence the overall friction response.

Keywords: unreinforced masonry, tribometer test, friction coefficient, tangential stiffness.

1 Introduction

Friction plays a significant role in masonry, especially in the determination of lateral resistance of structural elements (e.g. [1]). This aspect is often studied in the case of mortarless masonry (e.g. [2]), but dedicated experimental investigation are limited for mortared masonry. For this, it is relevant to evaluate what is the contribution of the friction resistance on the response of cracked mortared masonry.

In this study, reciprocating sliding tests were performed to determine the frictional behaviour of cracked brick-mortar interfaces. Tribometers formed by a reciprocating sliding drive are often used for material pairs prone to fretting fatigue, while their application to material pairs obtained from mortared masonry was not yet explored. This study examines the frictional behaviour under different normal forces and sliding frequencies. The frictional behaviour was characterised in terms of coefficient of sliding friction and tangential stiffness.

The study provides a preliminary procedure to assess the frictional resistance in cracked brick-mortar interfaces. A further development of the procedure can serve in the future to better estimate the contribution of the friction force and de-cohesion mechanism during cracking in masonry.

2 Tribometer tests on cracked masonry

This study used the tribometer RTEC MFT-5000 (1a). The test set-up is constituted by two parts: a bottom moving plate that allows a reciprocating motion, and a horizontally upper lever arm which holds a cylinder. The normal force is imposed through the upper arm, and an automated control mechanism is in place to keep the normal force as steady as possible during the different runs. Normal and tangential forces are measured through piezo-force transducers. The bottom plate hosts a linear variable differential transformer sensor for tracking the sliding.

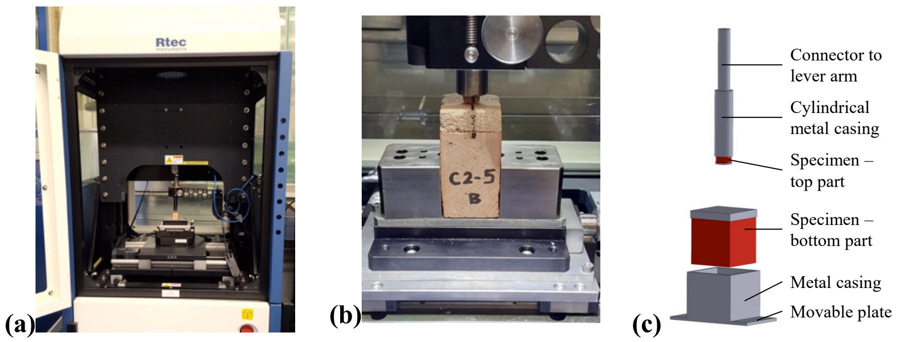

Fig. 1 – Tribometer test: (a) RTEC MFT-5000 setup; (b) cracked masonry specimen; (c) simplified sketch with annotations.

To evaluate the frictional resistance in cracked masonry, specimens presenting a pre-existing crack at brick-mortar interface were fabricated (1b). The top part of the specimen was hold in a metal casing, attached to a cylinder connected to the horizontal arm, for a depth of 45 mm, preventing eventual bending. The bottom part of the specimen, being a parallelepiped having a cross-section of 30x30 mm, was composed of the brick's portion and the largest portion of mortar. The brick's portion was constrained in a metal casing connected to the bottom plate. Specimens were extracted from couplets that had previously undergone a bond-wrench test. In this manner, the cohesive bond at brick-mortar interface was broken obtaining the typical roughness and waviness of cracks in masonry. Solid clay brick masonry with cement-lime mortar, extensively characterised in previous studies [3-4], was used.

The tribometer enables reciprocating sliding while keeping a constant normal force level and sliding distance. During reciprocating sliding, the level of the normal load was automatically adjusted by the tribometer. Tests were performed for different frequencies, 0.2 and 3 Hz, and for different normal forces ranging between 5 to 38 N. For each combination, at least 3 test repetitions were considered. In each test, the maximum imposed sliding distance was limited to +/-0.4 mm, and a total number of cycles ranging between 60 and 180, depending on the sliding frequency.

3 Preliminary observations

Fig. 2a shows the hysteresis curves in terms of estimated coefficient of friction versus sliding displacement. Note that the negative sign is not inherent to the coefficient of friction, but to the measured friction force. The curves are used to evaluate the kinetic friction coefficient and the tangential stiffness for every cycle (see Fig. 2b). It is possible to notice, that the curves show an asymmetric behaviour for positive and negative sliding. This may indicate the presence of surface wear and debris formation, which are altering the frictional response of the contact surface in every cycle [5-7]. To minimize such effect, each property is calculated independently for each sliding direction and for each cycle. The kinetic coefficient of friction, μ_{mean}, is determined as the average of the ratio between the tangential and the normal force measured for a sliding distance between -0.1 and +0.1 mm (Fig. 2b). The tangential stiffness k_t, for each cycle and each direction, is calculated as the ratio between the tangential force and the sliding distance between zero and 1/3 of the maximum tangential force for each direction (Fig. 2b). In essence, for each cycle, two μ_{mean} and two k_t are estimated.

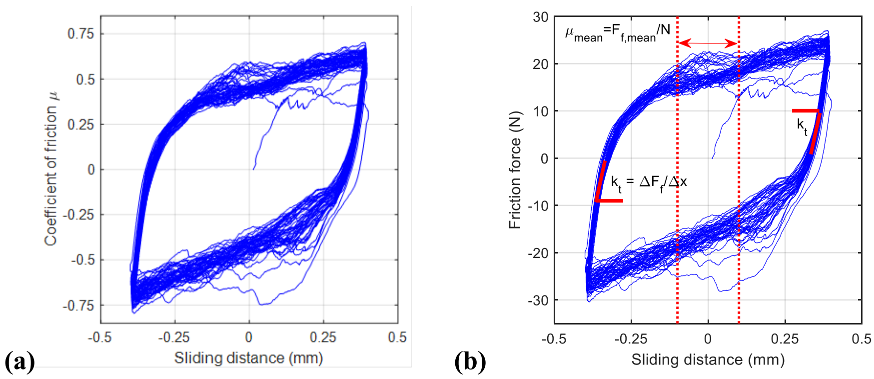

Fig. 2 –Hysteresis curves for a data set recorded with a reciprocating sliding frequency of 3 Hz and a normal force of 38 N: (a) the coefficient of friction versus sliding distance; (b) the friction force versus sliding distance. The latter indicates the segments of data in which the tangential stiffness and the coefficient of friction are estimated.

Below, a summary of all the identified values of μ_{mean} and k_t, from all the cycles, is provided in terms of distribution graphs. The coefficient of friction does not show a significant dependence on the normal force (Fig. 3a,b), while the tangential stiffness shows a relevant dependency (Fig. 3c,d). In general, the coefficient of friction has an average value ranging between 0.4-0.5. These values of the coefficient of friction are in line with other values identified from different experimental studies on clay brick masonry [8-9]. The values of the tangential stiffness ranged between nearby zero to 500 N/mm, showing a large spread. Part of this spread is most likely due to the dependency between the tangential stiffness and the normal force, and also to the dependency to the rate of the tangential pulling force (which is linked to the sliding frequency). Depending on the frequency, the largest scatter of results was either found at low normal forces (tests at 0.2 Hz), or at high normal forces (tests at 3 Hz).

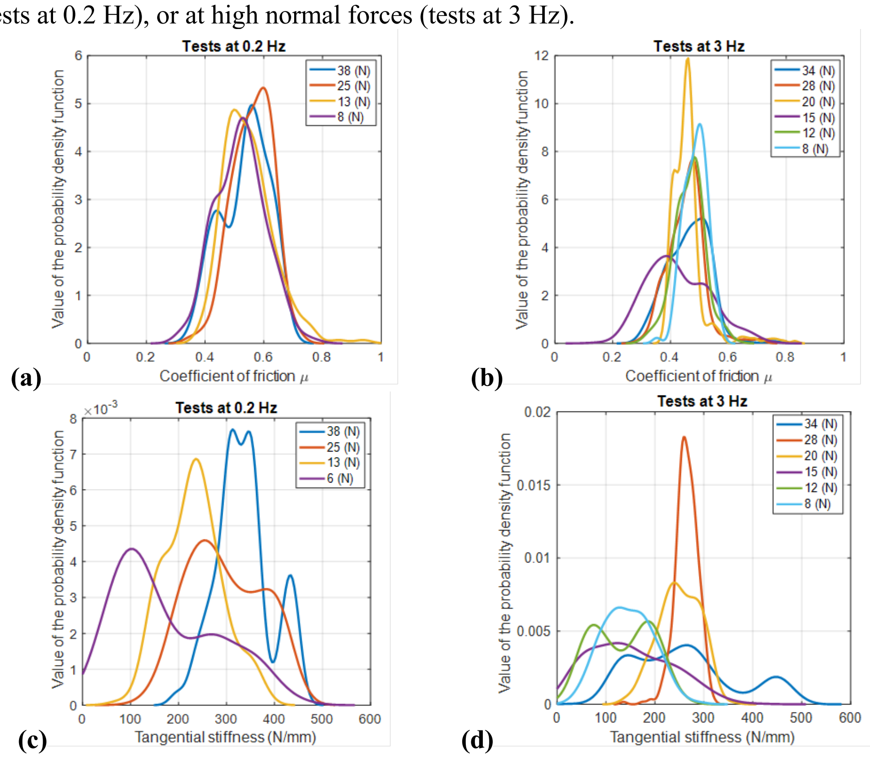

Fig. 3 – Friction properties in terms of estimated probability density functions: (a)-(b) coefficient of friction; (c)-(d) tangential stiffness**.**

4 Concluding remarks

This study presents a novel experimental procedure to evaluate the frictional behaviour of cracked brick-mortar interfaces. Preliminary investigations were performed on an unreinforced clay brick masonry. The friction hysteresis response during the tests showed an asymmetric behaviour for positive and negative sliding. This resulted in a significant scatter for the identified friction properties. The normal force resulted influential for the tangential stiffness, but not for the kinetic coefficient of friction. These results may suggest that the surface roughness and waviness, and its evolution during the sliding process, including wear and debris formation, may play a significant role in the frictional behaviour. Future studies will focus on investigating the influence of the surface roughness, and expand the dataset for other masonry types.

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