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Relationship between fracture toughness and porosity of clay brick panels used in ventilated façades: Initial investigation

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ABSTRACT

Fired clay elements are commonly used for external cladding, but the fragility of this material causes crack formation that, in conjunction with environmental actions, can even break clay brick elements. In order to optimize this technology, a relationship between fracture toughness and porosity can be helpful.

In this paper, linear elastic fracture mechanics (LEFM) was applied to study the fragility of clay bricks used in ventilated façades. Stress intensity factor K_{IC} was calculated under Mode I (opening mode) loading condition. Pore structure was evaluated by digital image analysis (DIA). We found that an increase of about 200 μm^2 in pore dimension corresponds to a decrease in fracture toughness of about 24%.

1. Introduction

Clay bricks and panels are commonly used for external cladding application because this material has shown good resistance to ageing and to external actions. Ever increasing applications of clay panels as cladding material are visible in the architectural field, mainly because of its versatility and of its many benefits, like quick and easy installation.

Some architects recently used this material in a new form. Brick panels were used in some recent buildings as cladding in order to create ventilated façades. In ventilated façades, clay brick elements are connected to a metallic fixing system with metallic clips. Examples of this technology are shown in Fig. 1.

The external layer of ventilated façades is subjected to many external factors that cause some different weakness in the system. In this field, a recent study makes a classification of anomalies in ceramic tiling applied to building facades and their most probable causes [1,2]. These studies were based on direct observations in Portugal and Southern Europe. The highest frequency of the anomalies was in the detachment and cracking of the elements of the system mainly due to environmental actions. The authors validated their classification system and have confirmed that fracture and cracking, volume change or deterioration of the stone are the most relevant anomaly groups [3]. The most influencing factor for decay is wetting time, which increases both speed and magnitude of damage with it [4].

Recent researches in Italy [5,6] have studied the durability of outer layer in ventilated façades and its resistance to impacts. In these investigations, there was a classification of the most probable anomalies in ventilated façades in which clay brick elements were used. The analysis was conducted, following the suggested methods proposed in the literature [1,2], on buildings in Italy which were built over the last fifteen years, covered with brick panels fixed to wall by mechanical system.

For each building, five different areas were visually inspected: at floor level, on continuous walls, around openings, on top of facades and in corners and edges. Collected data by direct in situ observation were then analyzed in order to identify

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Nomenclature

W	height of the specimen, see Fig. 3
B	thickness of the specimen, see Fig. 3
a	initial fracture length, see Fig. 3
S	support span in three point bending test, see Fig. 3
E	Young modulus
K_I	stress intensity factor
K_{IC}	critical K_I
F	force applied in the middle of the specimen, see Fig. 3
δ_v	displacement in the middle of the specimen

predominant defects. Fig. 2 shows that cracks and ruptures are visible in each observed zone and are 25% of the total damages. Other revealed damages are stains, movement of the panels, change in color, efflorescence and growth of vegetables.

Depending on maintenance operations, cracking and breakage of the panels are the most dangerous and onerous defects in ventilated façades. For these reasons, investigations on fracture toughness of clay brick blocks and panels used in ventilated façades are necessary. Fracture toughness depends on many factors like test procedure, environmental conditions and geometry of the samples (the "scale effect") [7,8]. The relationship between fracture toughness and other parameters was investigated in other studies. Correlations between K_{IC} and physical properties of rocks like compressional wave velocity, grain diameter, dry density, grain contact length and porosity were examined in the literature [9]. In this study, porosity affects K_{IC} values, but the scatter of data does not allow to find a clear correlation function. Relationship between fracture toughness of concrete and temperature was also investigated [10]. By increasing temperature up to 300 °C, K_{IC} decreases by about 28%. Other authors have found a correlation between K_{IC} and tensile strength of clay [11,12]. They found a linear correlation between these two parameters. The relation proposed by the authors may provide a helpful method for estimating fracture toughness from tensile strength which can be measured more easily. In a certain range, the fracture toughness of homogeneous rock has shown to exhibit a simple linear relationship with density [13], but this relationship collapse with rocks that possess significant levels of anisotropy. The authors sustain that initial rock fracture toughness test is necessary to identify conforming materials. Correlation between roughness and fracture energy was also investigated [14], and it was possible to confirm that fracture toughness is dependent on microstructural aspects, such as preferential orientation of mineral and grain size. Interaction between fixing system and flexural strength of sawed slate applied on ventilated façades was investigated by Pires et al. [15]. Rupture detachments obtained from the authors were very heterogeneous and they were not able to propose a proper rupture model. The authors emphasize the importance of performing a complete characterization and evaluation of the material before its application in building facades.

In this study, we focus on the correlation between fracture toughness and porosity of clay brick panels. In this field, there are some papers in the literature that describe the problem. The effect of pore size on fracture toughness in brittle material was studied by using simplified 2D model of porous material [16]. Despite its simplicity, the model leads to a satisfying and

Fig. 1. Bank of Lodi, Renzo Piano Building Workshop.