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Determination of timber material fracture parameters using mark tracking method

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HIGHLIGHTS

- Tests are carried out using a real post timber element under natural outdoor climatic conditions.
- Evaluation of mixed mode fracture parameters using a new formalism based on the CRDFr and SIF.
- The CRDF is evaluated from the experimental displacement measured by Mark Tracking Method.
- In parallel, the Stress Intensity Factor is calculated from a finite element analysis.
- The part of the energy release rate corresponding to the opening and shear modes is calculated.

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ABSTRACT

This paper deals with the characterization of mixed mode fracture parameters using a new formalism based on the Crack Relative Displacement Factor and Stress Intensity Factor, respectively. The Crack Relative Displacement Factor evaluation is based a kinematic approach integrating the experimental displacement measured by Mark Tracking Method. In parallel, the Stress Intensity Factor is calculated from a finite element analysis. The coupling between these two approaches allows identifying the fracture parameters in term of energy release rate without the knowledge of material elastic proprieties. According to mixed mode configuration, the part of the energy release rate corresponding to the opening and shear modes is calculated. Tests are carried out using a real post timber element under natural outdoor climatic conditions.

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1. Introduction

As is illustrated in Fig. 1, the structural integrity and the mechanical behavior of timber material may be modified by the presence of cracks. The crack evolution during the timber service life is most often conditioned by the climatic changes in term of temperature and relative humidity. In timber material the variation of moisture content is considerable and could induce the critical crack propagation. In these conditions the structural health assessment of timber structures should integrate the monitoring of cracks. So, to keep the structure integrity is necessary to evaluate the damage level in order to estimate the collapse risks. In fracture mechanics the damage level can be usually evaluated from two approaches called the local and the global approach [1–4]. In the local approach the fracture process evaluation is based on the mechanical fields assigned by the crack tip singularity. While, in the global approach this evaluation is based on the global behavior of the structure using the mechanical fields far to the crack tip singularity. Today several fracture parameters such as the Stress Intensity Factor [5–7], the Crack Relative Displacement Factor [8–12] or the energy release rate [13–15] allow to estimate the fracture process.

As mentioned above, in the case of timber elements, the fracture process is directly influenced by the moisture content of timber element. At the same time the fracture process evaluation encounters another problem related to the variability of the material properties with the climatic conditions and the material aging. Moreover, taking into account the wood material anatomy, the fracture process is most often subject of mixed mode crack kinematics. An understanding of the crack growth under mixed-mode conditions is also an important topic when analyzing timber structural integrity.

Starting from these observations, in the present study, a new formalism in fracture mechanics is proposed. The formalism is based on the of energy release rate calculation without the knowing of elastic material properties. Based on the Stress Intensity

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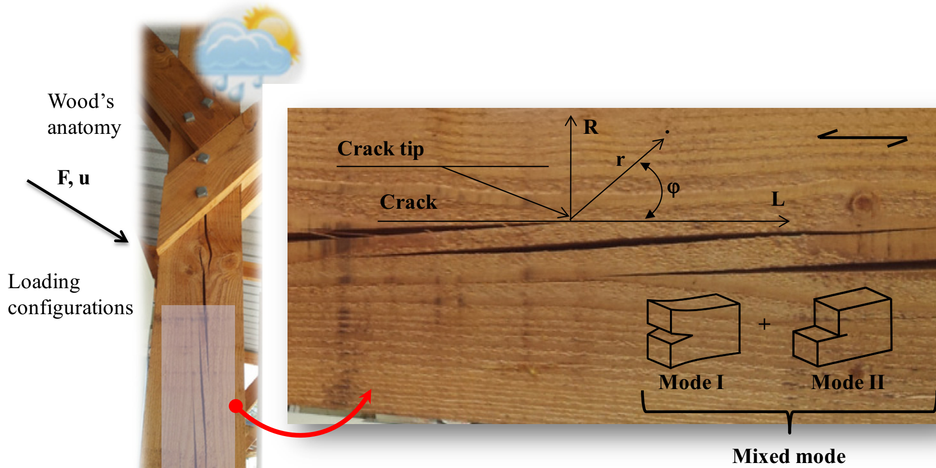

Fig. 1. Timber element under loading conditions.

Factor and the Crack Relative Displacement Factor the new formalism allows to calculate the energy release rate from the experimental measurements combined with the numerical approach by finite element method.

Since some years optical methods were increasingly applied to fracture mechanics. Among the optical methods, the Mark Tracking Method [16,17] seem to be best to monitor the structural health of timber and the cracks evolution. It should be noted that the data obtained from the optical measurements can be easily coupled with the numerical approach such as the Finite Element Method (FEM) [18–21].

Based on these observations, coupling between the experimental measurements by Mark Tracking Method and FEM to evaluate fracture parameters in cracked timber elements is proposed. The proposed approach allowing to estimate the three fracture parameters, the Stress Intensity Factor, the Crack Relative Displacement Factor and the energy release rate without the knowledge of material properties of timber element.

The experimental test was carried out using a real timber element subject to natural outdoor climatic conditions. The timber element is made in Douglas fir.

2. Marks Tracking Method

The deformations of the timber element surface were measured by the Mark Tracking Method. These measurements allowed for determining displacement and strain fields, and investigate the fracture parameters.

The basic principle of Mark Tracking Method summarized in Fig. 2 is based on comparison of two images acquired during the test, one before deformation and another one after deformation [16,17]. The displacement of each mark is in fact the translation vector (u_1, u_2) in x_1 and x_2 directions of the center of gravity.

Where the center of gravity coordinates (x_{1g}, x_{2g}) are given by:

$$\left\{ \begin{array}{l} x_{1g} = \frac{\sum_i x_i \cdot (I_i - I_s)}{\sum_i (I_i - I_s)} \\ x_{2g} = \frac{\sum_i y_i \cdot (I_i - I_s)}{\sum_i (I_i - I_s)} \end{array} \right\} \tag{1}$$

where I_i is the gray level of the pixels whose coordinates are (x_1, x_2) and I is the threshold value to distinguish the mark.

In our study this optical method was used to measure the kinematic state in the vicinity of the crack tip and to calculate the Crack Relative Displacement Factor. By coupling this method with an adjustment procedure, the crack tip position and orientation may be also evaluated [8–12].

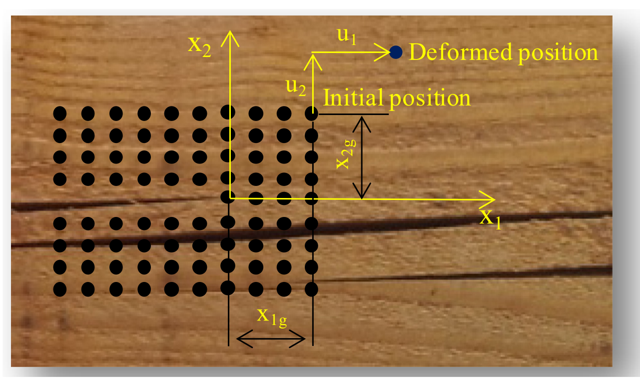

Fig. 2. Principle of Mark Tracking Method.

3. The new formalism in energy release rate evaluation

Based on Dubois' developments [8–12], the formalism express the energy release rate in term of the Crack Relative Displacement Factor (CRDF) and the Stress Intensity Factor (SIF):

$$\begin{array}{l} G_\alpha = \frac{K_\alpha^{(\varepsilon)} \cdot K_\alpha^{(\sigma)}}{8} \quad \alpha = 1;2 \\ \text{where}: \\ K_\alpha^{(\varepsilon)} = C_\alpha \cdot K_\alpha^{(\sigma)} \end{array} \tag{2}$$

where $K_\alpha^{(\varepsilon)}$ is Crack Relative Displacement Factor, $K_\alpha^{(\sigma)}$ is the Stress Intensity Factor, C_α is the reduced elastic compliance [22,23] and α is the loading mode.

Based on the kinematic state in the vicinity of the crack tip, the crack Relative Displacement Factor is calculated from the optical measurements by Mark Tracking Method. The calculation of CRDF is based on a coupling between the experimental displacement fields and the analytical displacement distribution in the crack tip vicinity expressed by the Williams' series. This approach requires an adjustment procedure allowing to adjust the Williams' series on the experimental fields [24,25]. Taking into account the measurement conditions (e.g. specimen symmetry, crack orientation, experimental noises), the adjustment procedure allows mainly to obtain a minimization of experimental uncertainty

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