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# Characterization of timber fracture using the Digital Image Correlation technique and Finite Element Method

F. Dubois *, M. Méité, O. Pop, J. Absi

*University of Limoges, Heterogeneous Materials Research Group, Department of Civil Engineering and Durability, Boulevard Jacques Derche, 19300 Egletons, France*

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ABSTRACT

This paper focuses on a hybrid experimental and numerical approach to characterize both the energy and mechanical state in the vicinity of the crack tip within an orthotropic wood material. Optimization of the displacement field obtained by Digital Image Correlation techniques, enables determining the kinematic state of crack lips through the crack relative displacement factor. In parallel, a Finite Element discretization is performed to allow calculating stress intensity factors. A coupling between these two approaches is presented for the purpose of defining the energy release rate. The algorithm derived is then illustrated through an experimental test based on an opening mode configuration for a Douglas specimen.



## 1. Introduction

In assessing the durability of timber structures, a study of crack process provides critical information on the design optimization for beams or joints. At the material scale, scientific approaches are based on experimental tests in order to measure the tenacity, through critical energy release rate values. In conjunction with this step, Finite Element (FE) models have been developed for the purpose of calculating stress intensity factors, or energy release rate, by assuming knowledge of both the material properties and mechanical behavior definition in the vicinity of the crack tip. Local techniques (i.e. the Crack Opening Displacement method) and energy-based subroutines (independent path integrals) have been developed [1]. These approaches have then been generalized for viscoelastic behavior and mixed-mode configurations [2]. A coupling between experimental reality and model output however requires imposing hypotheses. Image analysis techniques currently allow exploring other scientific fields in the area of fracture mechanics. Considerable research has been based on marker tracking methods or Digital Image Correlation (DIC) techniques in either two or three dimensions. An initial approach relies on the notion of introducing experimental displacement fields into the independent path technique ($J$-integral or $M$-integral) [3,4], in which strain and stress tensors are computed by assuming knowledge of the elastic property [5–13]. The finite element calculation may be improved by enriching the shape functions (through applying the Extended Finite Element Method) or by taking into account singular fields in the vicinity of the crack tip [14]. These methods however proceed by integrating the experimental noise first induced by the crack lip opening and then accentuated by the strain field generated from experimental displacements. A second approach consists of optimizing experimental displacements by their theoretical asymptotic

* Corresponding author.
*E-mail address:* frederic.dubois@unilim.fr (F. Dubois).

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**Nomenclature**

*Latin symbols*

| | |
|---|---|
| $a$ | matrix of polar functions integrating the rigid body motion |
| $a^T$ | transpose of a matrix |
| $\Delta a$ | crack extension |
| $A_\alpha\chi$ | weighting coefficients of the power series |
| $\Delta A_\alpha\chi$ | increment of power series coefficients $A_\alpha\chi$ corresponding to iterative step |
| $b$ | matrix of derivative residues |
| $b^T$ | transpose of $b$ matrix |
| $B$ | an arbitrary point |
| $C_\alpha$ | reduced elastic compliance ($\alpha = 1;2$) |
| $C_1$ | reduced elastic compliance in $x_1$-direction (or longitudinal direction of wood material) |
| $C_2$ | reduced elastic compliance in $x_2$-direction (or radial direction of wood material) |
| $\widetilde{C}_1$ | arbitrary reduced elastic compliance, corresponding to $x_1$-direction |
| dV | elementary volume |
| $E_L$ | elastic longitudinal modulus |
| $E_R$ | elastic radial modulus |
| $G$ | energy release rate |
| $G\theta$ | energy release rate calculate with $\theta$-method |
| $G_{LR}$ | elastic shear modulus in wood longitudinal–radial system |
| $J$ | $J$-integral |
| $h$ | matrix of residues |
| $h^T$ | transpose of $h$ matrix |
| $h_1^p$ | residue of displacement in $x_1$-direction, corresponding to $p$th point |
| $h_2^p$ | residue of displacement in $x_1$-direction, corresponding to $p$th point |
| $f_\chi, g_\chi, l_\chi, z_\chi$ | polar functions |
| $K_\alpha^{(\sigma)}$ | stress intensity factor ($\alpha = 1;2$) |
| $K_1^{(\sigma)}$ | stress intensity factor corresponding to opening mode |
| $K_2^{(\sigma)}$ | stress intensity factor corresponding to shear mode |
| $K_\alpha^{(\epsilon)}$ | crack relative displacement factor ($\alpha = 1;2$) |
| $K_1^{(\epsilon)}$ | crack relative displacement factor corresponding to opening mode |
| $K_2^{(\epsilon)}$ | crack relative displacement factor corresponding to shear mode |
| $n$ | iteration step number |
| $N$ | power series number |
| $m$ | subsets number |
| $r$ | distance in polar coordinate system |
| $r_p$ | distance of $p$th point in polar coordinate system |
| $p$ | index number, corresponding to the subset center number or the mesh node $p = 1,\ldots,$m |
| $R$ | rigid body rotation |
| $\Delta R$ | increment of rigid body rotation corresponding to iterative step |
| $T_1$ | rigid body translation in $x_1$-direction |
| $T_2$ | rigid body translation in $x_2$-direction |
| $\Delta T_1$ | increment of rigid body translation in $x_1$-direction corresponding to iterative step |
| $\Delta T_2$ | increment of rigid body translation in $x_2$-direction corresponding to iterative step |
| $s_\alpha$ | characteristic equation roots |
| $S_{ij}$ | compliance tensor components |
| $[\vec{u}]$ | relative displacement vector of the crack lips |
| $[u]_1$ | relative displacement vector of the crack lips in $x_1$-direction |
| $[u]_2$ | relative displacement vector of the crack lips in $x_2$-direction |
| $u_1$ | displacement in $x_1$-direction of a point located on the crack lips |
| $u_2$ | displacement in $x_2$-direction of a point located on the crack lips |
| $u$ | vector of displacement fields |
| $u^T$ | transpose of $u$ vector |
| $u_1^p$ | displacement of $p$th point in $x_1$-direction |
| $u_2^p$ | displacement of $p$th point in $x_2$-direction |
| $\tilde{u}_i$ | virtual displacement vector |
| $\tilde{u}_{i,k}$ | gradient of virtual displacement vector |
| $V$ | integration domain |
| $\Delta W$ | Gibbs energy |
| $\widetilde{W}$ | virtual energy |