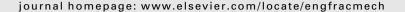
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Engineering Fracture Mechanics





Mixed mode fracture properties characterization for wood by Digital Images Correlation and Finite Element Method coupling

M. Méité, F. Dubois*, 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 seeks to characterize the mixed-mode energy release rate for orthotropic media subjected to a mixed-mode complex loading under service conditions. Experimental full-field information on Digital Image Correlation along with numerical modeling by the Finite Element Method have been considered as complementary approaches to determining fracture behavior in wood. An optimization technique allows calculating the kinematic state from Crack Relative Displacement Factor. A finite element analysis is performed in the local stress field characterization based on Stress Intensity Factor. This hybrid method has proven that the mixed-mode energy release rate uncoupling for fracture mode separation is achieved without taking into account local elastic mechanical properties; these properties can then be deduced by computing reduced elastic compliances from the additional information provided by Digital Image Correlation and Finite Element Method coupling. Such a hybrid method has been employed for cracked Douglas fir specimens undergoing complex loading in tension for various mixed-mode ratio values.

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1. Introduction

Wood used as a lightweight building material has many advantages over other materials also possessing good environmental and thermal properties. Progress in the field of timber structures is currently being impeded by durability issues. More precisely, natural or accidental cracks induce, during a timber structure's life cycle, a decrease in lumber strength by means of concentrating mechanical stresses in the crack tip vicinity. An understanding of the crack growth process under mixed-mode conditions is therefore an important aspect when analyzing timber structural integrity. In accordance with orthotropic specifications, the energy balance for crack growth initiation refers to a fracture multi-criterion that seeks the separation of each fracture mode part [1,2]. Within this field of study, several numerical investigations have been carried out in the literature for the purpose of characterizing crack tip parameters through use of the energy method for mixed-mode configurations [3–9], for isotropic and orthotropic media. At present, these efficient techniques require an explicit knowledge of material properties; for orthotropic cases in particular, the complete compliance tensor is needed. In recognition of the fact that wood is a rather heterogeneous material, these methods are not yet applicable.

To circumvent these difficulties, the promising set of tools developed are proposed herein in order to predict crack tip parameters for a fracture mode separation analysis conducted on a wood specimen without any *a priori* knowledge of its orthotropic mechanical properties. This novel method utilizes the combined Digital Image Correlation (DIC) plus Finite Element Method (FEM) and moreover integrates DIC and FEM as complements rather than alternatives, as is the case with most characterization studies. DIC and FEM have already been considered as complementary tools for predicting fracture

^{*} Corresponding author.

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

Nomenclature

 $\{X\}^T$

transpose of X matrix

```
Latin symbols
           crack length
[a]
           matrix of polar functions integrating the rigid body motion
[a]^T
           transpose of a matrix
A_{I}^{i}, A_{II}^{i}, A_{\alpha}^{i} weighting coefficients of the power series for opening and shear modes
           reduced elastic compliance (\alpha = 1; 2)
C_{\alpha}
           reduced elastic compliance in x_1 – direction (or Longitudinal direction of wood material)
C_1
           reduced elastic compliance in x_2 – direction (or Radial direction of wood material)
C_2
\tilde{C}_1
           arbitrary reduced elastic compliance, corresponding to open mode
\tilde{C}_2
           arbitrary reduced elastic compliance, corresponding to shear mode
dΫ
           elementary volume
           arbitrary longitudinal modulus
\tilde{E}_L
           arbitrary radial modulus
E_R
F
           external force
G
           energy release rate
G_1
           part of energy release rate for open mode
G_2
           part of energy release rate for shear mode
           arbitrary shear modulus in wood Longitudinal-Radial system
G_{LR}
           integer representing the singularity level
f_{i},g_{i},l_{i},Z_{i}
K_{\alpha}^{\sigma}
K_{1}^{\sigma}
K_{2}^{\sigma}
uK_{\alpha}^{\sigma}
           polar functions
           Stress Intensity Factor (\alpha = 1; 2)
           Stress Intensity Factor corresponding to opening mode
           Stress Intensity Factor corresponding to shear mode
           real stress intensity factors
\nu K_{\alpha}^{\alpha}
           virtual stress intensity factors
K_{\alpha}^{\varepsilon}
K_{1}^{\varepsilon}
K_{2}^{\varepsilon}
           Crack Relative Displacement Factor (\alpha = 1; 2)
           Crack Relative Displacement Factor corresponding to opening mode
           Crack Relative Displacement Factor corresponding to shear mode
N
           power series number
Μ
           subsets number
M\theta
           integral M\theta
r
           radial distance in polar coordinate system
           distance of r^{th} point in polar coordinate system
r_k
\tilde{p}_{\alpha}, \tilde{q}_{\alpha}
           arbitrary elastic properties
R
           rigid body rotation
\overrightarrow{T}
           rigid body translation vector
           rigid body translation in x_1 – direction
T_1
T_2
           rigid body translation in x_2 – direction
           characteristic equation roots
S_{ii}
           arbitrary compliance tensor components
[u]_1
           relative displacement vector of the crack lips in x_1 - direction
           relative displacement vector of the crack lips in x_2 - direction
[u]_2
           displacement vector
īi
           displacement in x_1 – direction of a point located on the crack lips
u1
           displacement in x_2 – direction of a point located on the crack lips
и2
           vector of displacement fields
{u}
\{u\}^T
           transpose of u vector
u_1^k
u_2^k
           displacement of kth point in x_1 – direction
           displacement of kth point in x_2 – direction
\vec{v}
           virtual displacement vector
           gradient of virtual displacement vector
v_{i,k}
           integration domain
           cartesian coordinate
x_1, x_2
           cartesian coordinate of kth point
           correction of the crack tip position in x_1 – direction
           correction of the crack tip position in x_2 – direction
           matrix of unknowns parameters
```

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