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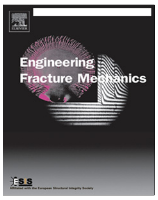

Influence of hygrothermal effects in the fracture process in wood under creep loading

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ABSTRACT

The knowledge of crack driving forces such as energy release rate is very important in the assessment of the reliability of timber structures. This work deals with both static and creep fracture tests in opening mode crack growth under hygro-thermal and mechanical loadings. The experimental tests combining creep and hygro-thermal loadings are performed in a climatic chamber. The Double Cantilever Beam specimen with variable inertia machined in Douglas Fir and White Fir species is used to investigate the effects of these loadings on fracture processes. Two experimental protocols are presented. First, instantaneous tests are carried out in order to identify the moisture content effects on fracture properties. R-curves are studied using a finite element approach. Secondly, creep tests are performed by imposing high speed humidity variations in a climatic chamber. During these tests, the evolutions of the crack length are recorded.

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1. Introduction

Aided by environment aspects and climate changes, timber structures know today a good industrial development in the civil engineering community. Moreover, due to the advantages provided by its mechanical behavior (particularly under extreme loading conditions such as fire and seismic events), as well as its aesthetic and environmental effects, timber is employed in building and civil engineering structures [20,21]. However, the development of timber bridges or buildings [8] meets today some brakes induced by the problematic of durability [13]. For example, timber bridges are often placed in extreme climates due to the presence of river. During the in-service life of the structure, and according to the external loadings (such as permanent loads, service charges, snow, wing or traffic) associated with climatic conditions, several pathologies can appear such as the acceleration of creep, the development of hydric stresses induced by the shrinkage-swelling process around the join influence zones [22,16]. In addition, cracks can also appear in the surface, due to gradients of moisture content and the material orthotropy. The aim is to know if these cracks can propagate through the cross section. This problematic also exists in buildings in which heat systems induce dry and hot atmospheres. For example, infra-red systems can generate high temperatures exceeding 45 null. The blocking of deformations around steel joints causes a

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concentration of tension stresses that can cause cracks [6]. Coupled with external loadings such as permanent and climatic loads, designers must find solution in order to limit, to stop the crack propagations, and to reinforce the joint stiffness [23]. To sum up, timber elements can exhibit micro-cracks, which eventually propagate under fatigue [11], overload or creep loading, which could cause failure of the structure. In addition, timber is a hygroscopic material whose mechanical behavior is very sensitive to climatic changes such as temperature and moisture variations. For example, drying process accelerate the crack growth, while wetting process induce the delay of the crack propagation [10]. This fact is accelerated with the time-dependent behavior of wood during long-term loading and creep tests [2,3]. The coupling between viscoelastic behavior and moisture content changes is characterized by a coupling that is called today mechano-sorption, and which seems to induce a more complex interaction between mechanical loading and moisture content variations [19].

A durable timber structure design needs the understanding of the fracture risks. Today, the scientific locks can be classified in three families. (i) The understanding of the crack growth process combining, at the same time, a complex mechanical behavior that includes both shrinkage and swelling effects [9], mechano-sorptive [12,7] behavior and viscoelastic properties. (ii) The fracture analysis that includes the mechanical fields around the crack tip as well as their evolutions during climatic changes, energetic balance in the crack tip vicinity including the separation energy in terms of viscoelastic and mechano-sorptive dissipations. (iii) The experimental demonstration of the crack growth process caused by humidity variations under creep loadings. This paper deals with this third point. Because it was observed that crack initiations are observed during climate reheating or drying, this work focuses on desorption phases. The paper's target is the highlight of moisture content variations under creep loadings configurations on the crack growth process by taking into account mechanical behavior and fracture characteristic evolutions versus moisture content. Thus, the paper is divided into three sections.

The present work is devoted to the fracture tests performed in a climatic chamber. It deals with the crack growth process in timber elements subjected to both mechanical loadings and climatic variations. Through an experimental approach, it focuses on the crack growth advance induced by high speed climatic variations applied on a hygroscopic and viscoelastic material characterizing wood. The first part of the paper presents the experimental set-ups with samples preparation for two species used in Europe (Douglas Fir [1] and White Fir). The wood sample geometry is a Double Cantilever Beam (DCB) [5] in order to provide the stability of energy release rate during the crack growth process in opening mode. The fracture properties through characterization static tests are studied by considering two distinct moisture levels, a low one and a high one, respectively: the results are presented in terms of stiffness, R curve and critical energy release rate value. In the last section, we present and discuss results in terms of crack propagation driven by humidity cycles through creep tests.

2. Double cantilever beam geometry

2.1. Linear fracture mechanic

In the past, Chazal and Dubois [4] and Dubois et al. [5] studied the effects of viscoelasticity on the crack growth process. In order to separate loadings effect and long term evolutions induced by creep properties, a double cantilever beam had been proposed. Because the crack stability was the main design criterion, the specific geometry includes a variable inertia. This stability is driven by the instantaneous evolution of the energy release rate versus the crack length. Let us consider a cracked body in which W_{ext}, W_{ε} are the external loading work and the strain energy density, respectively. By neglecting the dynamic effects during the crack tip advance ∂a, the energy balance can be written through the following energy release rate definition:

$$G = \frac{\partial}{\partial a}(W_{ext} - W_{\varepsilon}) \tag{1}$$

During the crack process, according to an instantaneous fracture test, let us neglect the displacement variations versus the crack tip advance. In this case, the expression (1) can be simplified by:

$$G = -\frac{\partial W_{\varepsilon}}{\partial a} \tag{2}$$

The crack growth initiation is driven by the critical value of the energy release rate called G_c according to the following fracture criterion:

$$G < G_c: \text{ crack stationary}, \quad G = G_c: \text{ crack growth initiation} \tag{3}$$

We can add to the last criterion a crack stability concept based on the rate evolution G versus the crack length a:

$$\frac{\partial G}{\partial a} < 0 \text{ and } G < G_c: \text{ crack stability}, \quad \frac{\partial G}{\partial a} \geqslant 0 \text{ and } G \geqslant Gc: \text{ crack instability} \tag{4}$$

The criteria stated in expressions (3) and (4) will be used for the determination of the specimen geometry in an open mode configuration.

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