Analytical Assessment Of Creep Behaviour Of European Species In Outdoor Conditions

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NOMENCLATURE

DF	Pseudotsuga Menziesii, Douglas Fir
WF	Abies Alba Mil, White Fir
DFi (WFi)	Beam number i of species DF (WF)
$\alpha, \Delta\alpha$	crack length and crack increment
MOE, E	Elastic modulus
E_N	MOE of Notched Beam
NB	Notched beam
L	length of beam before notched
J_N	Notched beam compliance
HNB	Half notched beam
H	Height
e	Thickness
a	Lever arm
τ	Shear stress
G	Shear modulus
U, y, y^G	Deflection, deflection, Global deflection
y^M, y^V	Deflection induced by the bending moment, deflection dues to the shear force
γ	Lateral displacement dues to the shear force
V	Shear force
F_0	Intensity of total load applied on the beam

k	Constant ratio
U_h	Hydric displacement
w	Moisture content of the specimen
RH	Relative Humidity

ABSTRACT

The investigation of wood mechanical response in outdoor conditions, subjected to environmental changes, long term loadings and time effects, show a complex behaviour of this material. This behaviour, is characterized by a dimensional change which, in most cases, causes initiations and crack propagation until the total collapse of timber structures. This work presents, on the basis of the RDM assumptions of the Timoshenko beam theory, the evolution of notched beam deflection in the time. The model built takes into account the effects of moisture content variations of beam, the crack appeared until its collapse, the intensity of the loading applied and the geometry of the beam. The work is divided in three parts: (i) an experimental study, presenting the specific setup used to recorder the data; (ii) the analytical model based on the classic assumptions of the beam theory starting from the expression of the notched beam's Young modulus of notched beam (goal of this study); (iii) the validation of the model at the end, shows that the evolution of the experimental data and the analytical data have a good fit.

Keywords: Creep test, Notched beam, Moisture content effects, Beam theory, Timber.

CONTEXT AND PROBLEMATIC

Wood is defined as a material whose the mechanical behavior in structure depending on the fluctuation of its internal moisture content [1-2]. It is also known that the internal changes of humidity, coupling with long term loading bring in many times, the initiation and the propagation of cracks, which are directly an impact on the total deflection measured on the wood until its collapse [3-4]. These cracks are amplified by the geometric singularities available on the wood and are at the origin of the total collapse of the structure. In this case, a specific experimental device has been built to assess the effects of moisture content in the mechanical behavior of wood [4]. The device takes, also into account, the effects of long term loading and the crack propagations. In the base of the results obtained, an analytical model of the evolution of the creep behavior of wood in outdoor conditions are proposed herein.

ANALYTICAL MODELING OF NOTCHED BEAM DEFLECTION IN 4-POINTS BENDING TEST

Modeling Of The Compliance Of Notched Beam

The experimental campaign of creep loading is composed of two types of European species (Pseudotsuga Menziesii and Abies Alba Mil) tested as presented by [4]. During the experimental campaign the deflection of the notched beam, measured by LVDT sensor placed under the center of the beam, is considered as the principal parameter followed (Figure 1a). In this case we can assume that the evolution of the deflection takes into account the effects of loading, crack opening and crack initiations of the notched beam. Figure 1 shows the experimental setup of the creep loading.

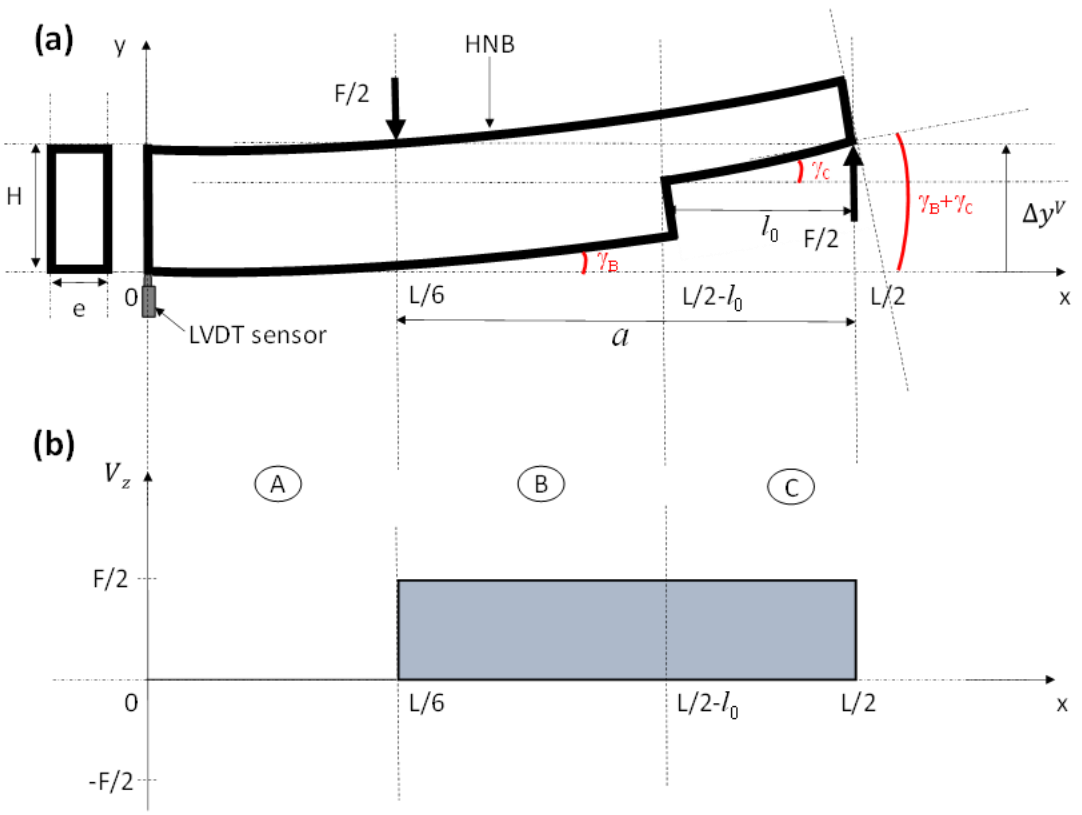

Figure 1. (a) Half Notched Beam (HNB) in 4-points bending test. (b) Diagram of shear force $\boldsymbol{V}$.

From this experimental setup (Figure 1), an analytical model of the evolution of the beam deflection is proposed. we can assume, by taking into account the general assumptions of the beam theory especially the symmetry of the system, that the study can be restricted only on the half notched beam (HNB). Then, by considered the flexural moment M_Z, the moment of inertia I_Z, the modulus of elasticity of the notched beam E_N, the crack propagation (appeared at the corner of the beam) and based on the strength of materials calculus the deflection of measured by the LVDT sensor can takes the following expression:

$$y^G = \left(\frac{23}{36}\right) \times \left(\frac{aL^2}{eH^3}\right) \times (1 + \frac{189}{23}\alpha^3) \times \; [1 + \frac{108}{115}.\left(\frac{H}{L}\right)^2.(k).\frac{1+(\frac{3}{2})\alpha}{1+(\frac{189}{23})\alpha^3}] \times (\frac{F_0}{E_N}) \qquad (1)$$

Where $y_G = y_M + y_V$ represents the general deflection measured by the LVDT sensor for a loading F_0 applied on the notched beam during the creep test (y_M deflection brought by the flexural moment, y_G deflection briought by the shear force V). k represents the constant ratio of shear with k=(E/G)=17 (E and G, respectively, the module of elasticity and the shear modulus of the notched beam gives by the predictive law of [5]. α represents the crack level propagation appeared at the corner of notched beam. By taking into account the expression shows by (1) the compliance in the time of the notched beam can take the simplified following expression:

$$J_N(\alpha,t) = \frac{y^G(t)}{A \times F_0 \times f(\alpha,k)} \qquad (2)$$

Where J_N representing the compliance of NB at the time t for a crack appeared at the corner of the beam. This expression of the compliance J_N take into account, only, the effects of mechanical behavior of beam.

Taking into account of the moisture content (*w*) effect

In outdoor conditions wood is submitting to the effects of moisture content, in this case and by taking into account this hypothesis, it seems necessary to bring a correction on the compliance given by equation (2). By starting from the Fick law, for an unidirectional diffusion, a correction is done on the expression of moisture content w of the NB tested. Then, the hydric displacement (U_h) brings by the hydric phenomenon takes the following expression:

$$U_h = \beta \cdot \left(\frac{H}{2}\right) \cdot [w(\%) - w_i(\%)] \quad (3)$$

Where, β is the shrinkage-swelling coefficient along the considered axis.

Figure 2 presents a comparison done between the evolutions of the hydric displacement measured and the hydric displacement calculated. The results show that there is a good fit between the data taken from the experimental campaign and those taken from the predictive model proposed.

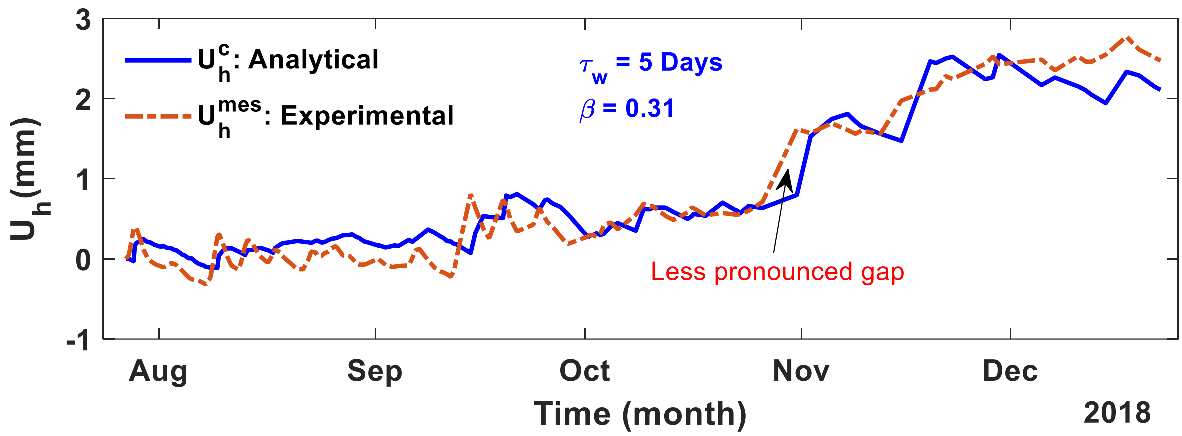

Figure 2. Relationship between the experimental and analytical evolutions of the hydric displacement of the height of the notched beam tested.

On the base of this result and by taking into account the superposition theorem, the compliance of the NB can take definitively the following expression:

$$J_N(\alpha, t) = \frac{y^G(t) - U_h(t)}{A \cdot F_0 \cdot f(\alpha, k)} \quad (4)$$

RESULTS AND DISCUSSIONS

Figure 3 shows the relationship between the compliance of the NB of the specimens DF9 and WF9, loaded in 4-point bending test in an uncontrolled environment with the variation of the internal moisture content (w) measured on the matched beams. The literature [6-8] shows that there are three distinct observable behaviors: (i) the first relates to increasing compliance for any reduction of the moisture content of the tested wood. In present study for example and despite the fact the studies are done in the uncontrolled environment, the same conclusions can be highlighted. Indeed, on the paths J_N (DF9) (Figure 3) the drying phases (-, drying) are followed by an increase in compliance (section bc for example in path J_N (DF9)). (ii) the second behavior shows that during a humidification (++) greater than the first (see path J_N (DF9)), there is a consequent increase in compliance. (iii) the last behavior (the most complex to observe) is that for humidification below a level already reached, compliance decreases (see section cd Figure 3).

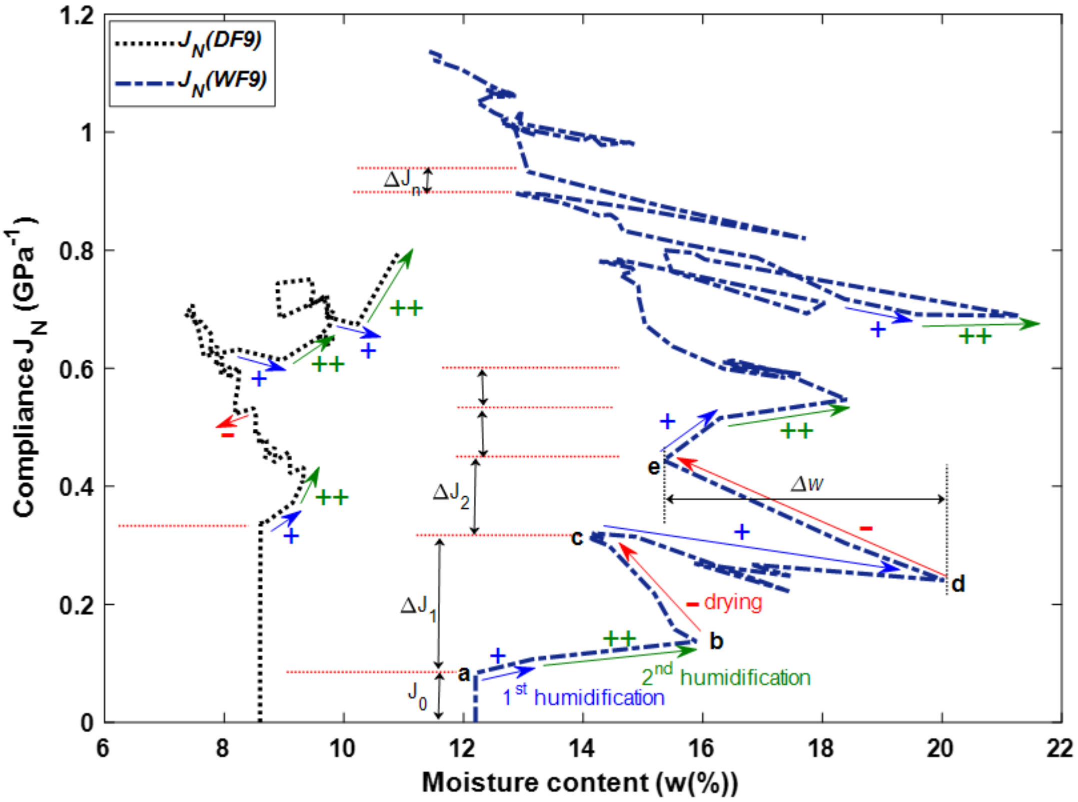

Figure 3. Typical trajectory J_N of the notched beams DF9 and WF9 in function of the evolution of corrected moisture content (*w*).

CONCLUSIONS

In this paper, by seeing the results obtained, especially with the comparison of the evolution of the experimental data and the model, we can remark that the proposed model describes satisfactorily the evolutions of the parameters arrested. The first limitation of the model is that it is based on one-dimensional approach of notched beam. This approach tends to minimize the 3D effects of the structure and to amplify, to a lesser extent, the effects of changes in internal moisture of the wood, hence the presence of abnormal peaks appearing on the path of the model during periods of high humidification. A second limit remains the consideration of the tip of the crack at the expense of the crack front, but also the heterogeneity of the material, the 3D discontinuity of moisture, etc. The modeling of the *MOE* of a notched beam allowed us to report the behavior of the compliance trajectory of a NB in 4-points bending test, in uncontrolled environment. The general tendency observed is the highlight of the "++" effect of the internal humidity causing an increase in compliance and the existence of a limit of compliance.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the valuable contributions of the National Research Agency (ANR) for their financial support of this work through the CLIMBOIS ANR-13-JS09-0003-01 project, as well as the labeling awarded by France's ViaMéca cluster and the laboratory of physical meteorology (Lamp) of University Clermont Auvergne for the regular sending of meteorological data. The authors acknowledge also the CNRS for the financial support through the project "Ingéniérie verte" RUMO.

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