FRACTURE AND DELAYED FRACTURE OF NOTCHED BEAMS

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Duration of load tests were made on wood notched beams under varying climate (outdoor) and constant climate.

Experimental results show that air humidity variations greatly influence the lifetime as shown by differences obtained between sealed and unsealed beams.

A theoretical model derived from Schapery analysis was developed to take into account variations of moisture content at crack tip. Simulations confirm that moisture content variations seem to reduce the duration of load.

INTRODUCTION

Long term strength of wooden structures is an important problem in construction, especially at mechanical connections. A fairly new approach of wooden beams duration of load is fracture mechanics approach, which involves the study of a stable crack propagation. Duration of load is therefore the time for the crack to get a critical length. This crack can be, for instance initiated by a stress concentration around a notch or a hole.

This paper concerns the duration of load of half-height notch beams (Figure 1). Moreover, it is well known that wood mechanical behaviour is strongly linked to its moisture content. This paper attends to answer the following question:" How wooden notched beams strength is dependent on moisture content during long term tests?".

In part one, comments on experiments results are made. A modelling proposal is given in part two.

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EXPERIMENTS AND RESULTS

Notched beams are tested in 3 points bending (Figure 1). One set is tested indoor, a second one outdoor. For indoor tests, loads remain constant, for outdoor tests loads are increased by 10% every two weeks from 50% to 100% stress level. Outdoor, half specimens gets a sealing mastic on notch faces to prevent any water transfer at notch tip.

After one year, three main observations can be made and they concern only outdoor experiments:

① Duration of load of sealed and unsealed beams are nearly the same, 55 and 51 days respectively.

② The time to initiate a crack is around 15 days longer for sealed specimens than for unsealed ones. This duration is close to 30 days for unsealed beams.

③ For each batch, at least 75% of beams broke during daytime (Figure 2).

Some comments can be qualitatively deduced from these experiments.
Sealing makes the time to initiate longer. It is concluded that water movements at notch tip accelerate damage mechanisms which bring to crack initiation.

Thanks to remarks ① and ②, it is concluded that once cracked, sealed beams break rapidly. The propagation time is therefore shorter on sealed specimen than on unsealed one. It can be assumed that it is due to the important water transfer at crack tip. Indeed, the wood behind the sealing is dry. Once cracked, this wood is in contact with the external humidity and draws rapidly important water masses. Water kinetic at notch tip makes initiation time shorter but at crack tip also increases crack propagation speed.

This is confirmed by remark ③. Indeed, most of fracture happen during daytime when the most important air humidity variations occur as well (Figure 2. and Figure 2 bis.). This shows also that the effects of air humidity changes are quasi instantaneous. This lead to think that the volume of material affected by humidity changes is very small, i.e. with a small hydric inertia. In the same time this small volume gets a great influence on crack propagation. This volume must be the process zone (so called the damaged zone at crack tip) whose mechanical properties are very sensitive to water movements.

Barenblatt's model and Schapery's analysis (1) of crack propagation in a viscoelastic media are modified to make the process zone size dependent on air humidity variations .

DURATION OF LOAD MODELS

In previous paper (2)(3), it was shown that delayed fracture could be predicted assuming a crack propagation in a viscoelastic media. Based on Schapery analysis, assuming that process zone length , α, remains constant and that reduced viscoelastic compliances follow a 2-parameters power law ($C_v(t)=C_1.t^n$), a fundamental relation yields

$$\frac{da}{dt} = AK_I^{2/n} \qquad (1)$$

After integration and simplifications, one gets model I:

$$t_f = t_{ref}\left(\frac{\sigma_{ref}}{\sigma}\right)^{2/n-2} \qquad (2)$$

where t_f is the duration of load under applied load σ.

t_{ref} is a reference time corresponding to the reference stress σ_{ref}

Relation (2) can be directly applied to notched beams by taking σ_{ref}, the instantaneous fracture stress from short term tests on notched beams.

Because of remark ③, it's necessary to incorporate air humidity variations in duration of load model. A proposed modelling of the moisture content variations is to make α dependent on air humidity changes. According to Schapery,

$$\alpha = \frac{\pi}{2}\left(\frac{K_I}{\sigma_m I_1}\right)^2 \qquad (3)$$

where K_I is the stress intensity factor in mode I

σ_m is the maximum stress in the process zone.

I_1 represents the integral of the stress distribution in the process zone. I_1 is mathematically upper bounded by 2, which represents a constant cohesive stress distribution along α. A proposed variation is:

$$I_1 = 2 - k|\Delta H| \qquad (4)$$

where ΔH represents air humidity variations.

Using this equation, it makes α equally sensitive to a drying or a moistening which was already proposed for wood (4).

A generalised power law approximation of reduced viscoelastic compliances is used, $C_v(t)=C_0+C_2t^n$, which gives the following crack tip velocity equation,

$$\frac{da}{dt} = \frac{\pi}{2}\left[\frac{C_2}{8\Gamma\left(1 - \frac{K_I^2}{K_{Ig}^2}\right)}\right]^{1/n} \lambda_n^{1/n} \frac{K_I^{2(1+1/n)}}{\sigma_m^2 I_1^2} \qquad (5)$$

where Γ is the fracture energy

λ_n is a dimensionless function of n

K_{Ig} is the K_I value at which crack becomes unstable.

Analytical integration is not easy in this case, but assuming that during the time needed by the crack to extend to α , all parameters remain constant (From Schapery (3)), a numerical integration is used to get model II.

Figure 3 presents a comparison of both models described above with no air humidity variation. Figure 4 presents the model II presented with several sensitivities of I_1 to ΔH. Air humidity is function of time and in this simulation it is to be a sinusoidal function with a 24 h period and it's between 100 and 20%.

CONCLUSIONS

This first year, long term tests on notched beams in outdoor conditions showed the great and 'instantaneous' influence of air humidity changes on crack speed. This influence was, in a first attempt, modelled by making the length of the process zone depend on air humidity changes. Simulation displays a fast decreasing of duration of load at low stress level (Figure 4), which is qualitatively in agreement with observations. This simulation will be confirmed or not during the second year of tests. These tests will be made outdoor but with constant loads.

Simulations can be completed by taking into account a damage mechanism which brings to crack initiation and is also accelerated by water transfers at notch tip.

REFERENCES

(1) Schapery R.A , Int. J. Fracture, Vol. 11, Parts I,II and III,
pp. 141-159, pp. 369-388, pp. 549-562 (1975).

(2) D'Almeida A.G, Bordeaux I University Thesis N°355 (1984).

(3) Jourdain C, Racois Ph, Valentin G,
'Delayed fracture of spruce notched beams', COST 508, Finland (1994).

(4) Ranta-Maunus A, Wood Sci. Technol. 9:189-205 (1975)

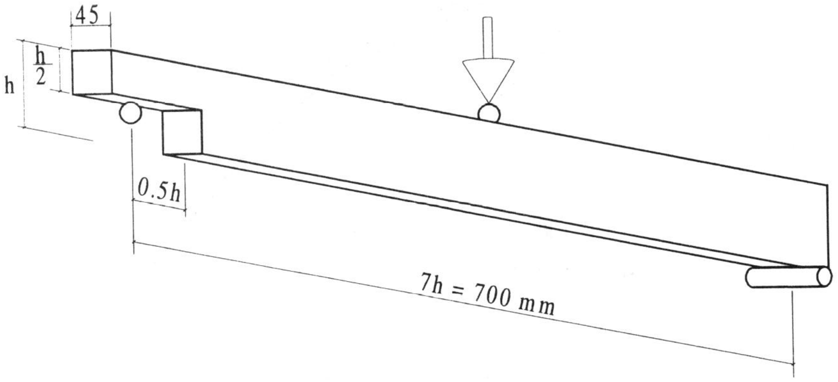

Figure 1. Notched beam geometry and loading supports

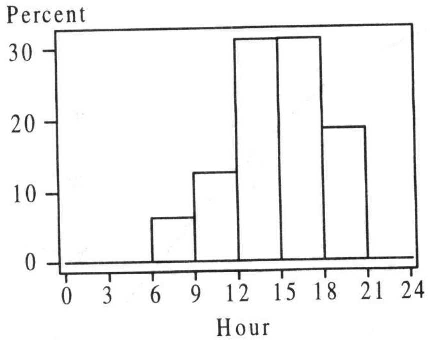

Figure 2.
Time Fracture distribution

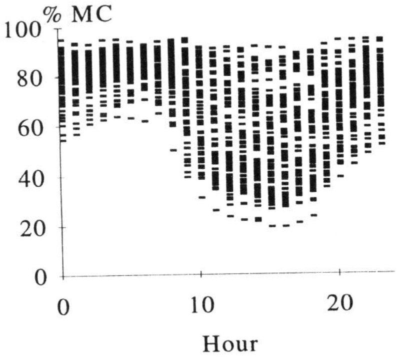

Figure 2 bis.
Air humidity day by day

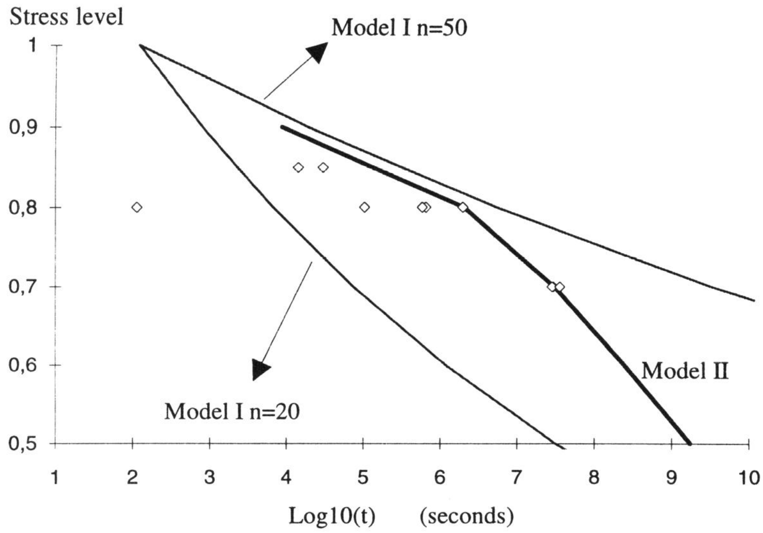

Figure 3. Indoor tests (◊) and models

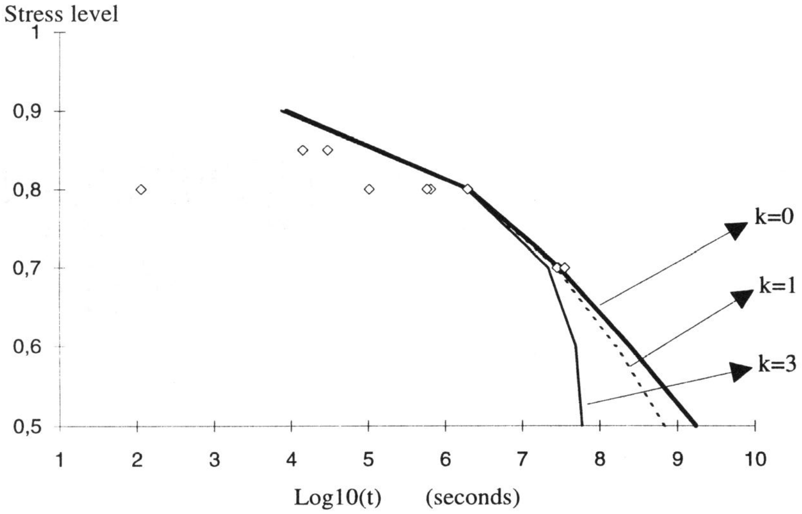

Figure 4. Model II with several sensibilities and indoor tests (◊).
of I_1 to air humidity variations.