MECHANO-SORPTIVE CREEP RUPTURE

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SUMMARY

Previously the research on load-duration behaviour of wood has been primarily concentrated on defining the time-to-failure of wood when different stress levels, loading modes or constant environments are applied. Yet, it has been experimentally verified that in a variable environment humidity, the time-to-failure of wood is considerably decreased and failures have been observed at lower stress levels than in constant conditions. A phenomenological modelling approach is introduced to quantify the creep of wood in variable humidity extending to the tertiary creep phase and final rupture.

DAMAGE ACCUMULATION IN CHANGING MOISTURE CONTENT

Several damage accumulation models have been proposed in earlier literature to describe the load duration behaviour of wood. In this study the damage accumulation model proposed by Foschi and Yao (1986) is used as a basis. This model does not take into account the effects due to variable moisture content, so a mechano-sorptive term has been added to it, eq.(1). This term has been chosen on the assumption that damage is proportional to the absolute value of the change of moisture content, as mechano-sorptive creep is. There is no theoretical justification for this term nor insight into the microstructural processes involved. The damage parameter, α_D, is assumed to have an initial value as zero and a final value of unity in rupture.

A threshold stress level of 50 %, stress level that must be exceeded for damage to accumulate, has been widely accepted for constant environment conditions. This threshold value is also adopted here for the first two terms of eq.(1). Threshold stress levels for load duration in variable humidity conditions have not been investigated before, but since tertiary creep and failures have been noticed at much lower stress levels then the value above (Mohager 1987; Fridley & Tang & Soltis 1991), it is assumed here that no threshold exists for the mechano-sorptive term.

The material parameters for the first two 'constant environment terms' have been taken as the mean values from Foschi & Yao (1986) corrected to SI-units. The two mechano-sorptive parameters have been adjusted here according to test results presented by Mohager (1987). Because of the small test specimen sample size in these experiments and because the values of the two parameters (u,v) have been adjusted by iterative trial, it was not appropriate to find these values to a high precision.

$$\partial \alpha_D / \partial t = a\,(\sigma/\sigma_f - 0.5)^b + c\,(\sigma/\sigma_f - 0.5)^n\,\alpha_D + u\,(\sigma/\sigma_f)^v\,|\partial u/\partial t| \qquad (1)$$

Where the parameters: $a = 1.9670 \times 10^{13}$ $\sigma_f = 60$ MPa
$b = 35.204$
$c = 0.0665$
$n = 1.429$
$u = 3.0$
$v = 2.5$ {t:[h]}

APPLICATION OF DAMAGE ACCUMULATION TO THE ANALYSIS

It is the purpose in this paper to give an attempt to model creep rupture of wood in variable humidity conditions. The above damage model has been included in the creep analysis previously described (Toratti 1991). In the analysis, the geometry of the member cross section is represented by a number of nodes in the height and in the width direction of the cross section and the constitutive equations are computed at each node. The inclusion of the damage model leads to that each node has also a damage variable representing the damage accumulated in the control area of the respective node. The accumulated damage is computed from the integration of eq.(1). Previously, the damage accumulation parameter has been assigned only one value representing the whole wood member.

The elastic modulus and the residual strength of wood are assumed to be directly proportional to the accumulated damage, eq.(2). This can be viewed as damage causing a decrease in the effective area of wood which is able to carry loads, leading to a lower stiffness and a strength degradation of the wood member.

$$E(u,t) = E(u)\,\{1-\alpha_D(t)\} \qquad (2)$$
$$\sigma_{res}(t) = \sigma_{res}\,\{1-\alpha_D(t)\}$$

NON-LINEARITY OF THE CONSTITUTIVE EQUATIONS

The introduction of the damage parameter into the constitutive equations through the relation of the elastic modulus, eq.(2) is a way to express non-linearity of wood with respect to stress. The level of non-linearity is then assumed to be directly proportional to the accumulated damage. In constant moisture content, this will lead to that the onset of linearity is equal to the threshold of damage accumulation. The onset of non-linearity in constant humidity has been given a stress level value of about 40 % in many references and the threshold stress level is widely agreed to a stress level value of 50 %. Since the threshold stress level is experimentally very hard to verify, it may well be somewhat lower and close to the observed non-linearity stress level. For variable moisture content, if the mechano-sorptive term has no threshold as in eq.(1), non-linearity would prevail at all stress levels. However, with the parameter values of eq.(1), the non-linearity is weak at service stress levels and for practical applications it can be neglected.

CREEP TEST RESULTS AT HIGH LOAD LEVELS

The above equations were used in the creep analysis described in Toratti (1991). The test results referred here were carried out and published by Mohager (1987).

Fig.1 shows the test results in bending from Mohager (1987), which were carried out in cyclic relative humidity of 15-90 %RH, with a cycle length of 20 days. The specimen size was 10x10 mm^2 and these were loaded to 20 MPa, 30 MPa and 35 MPa. The curvatures of the eight specimens at the constant moment region are given until specimen failure. The curvature was calculated from the elastic modulus, bending moment load and the relative creep

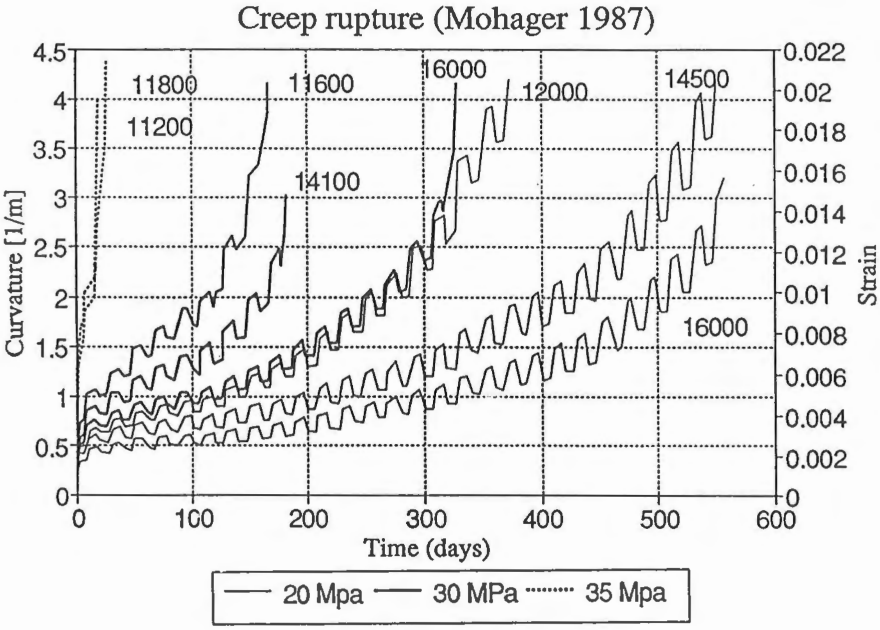

Fig.1. Bending creep test results of eight 10 x 10 mm^2 clear wood specimens at cyclic humidity conditions loaded to stresses of 20 MPa, 30 MPa and 35 MPa, from Mohager(1987). The elastic modulus of the specimens is given beside the respective curve in [MPa].

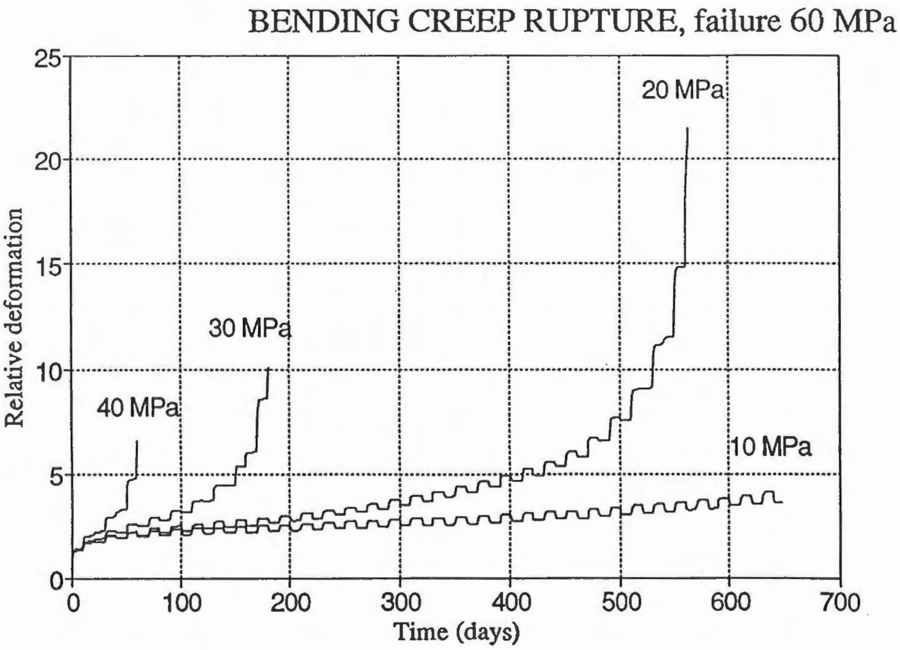

Fig.2. Computed creep and creep rupture results using the damage accumulation model.

observed from the test results. In the right-hand y-axis the equivalent bending strain is given.

From these test results, it can be observed that the bending strain at failure seems to be of about an equal value between the specimens, regardless of the elastic modulus of wood or the load level used in the test. Although it should be emphasized, that precise values for the failure strain is difficult to determine without continuous measurement techniques. From these results, the failure strains are around 2 %. This value is about twice the failure strain expected from a static ramp test.

COMPARISON OF ANALYSIS TO TEST RESULTS

Using the damage accumulation model, eq.(1), together with the relations eq.(2) and eq.(3) in the creep analysis described in Toratti (1991), the computed results presented in fig.2 were obtained for bending stresses of 10 MPa, 20 MPa, 30 MPa and 40 MPa. The analysed beams were of similar size and were subjected to the same environment as the test results in fig.1. All but the 10 MPa stressed members have failed during the duration studied. During the computation, failure is noticed when the iterations of force equilibrium is unable to converge, because the internal stresses cannot withstand the external loads.

In fig.3 the computed results are compared to the results presented in fig.1 for the specimens loaded to 20 MPa and 30 MPa. Relatively good agreement between test results and the model was found.

TIME TO FAILURE IN CYCLIC HUMIDITY CONDITIONS

It can be noticed, that when wood is subjected to variable humidity during loading, the time to failure is considerably decreased. Only few duration of load tests have been carried out to failure in variable humidity conditions. In fig.4 the time to failure test results from Schniewind (1967), cross section 10x20 mm2 RH 35-87% 24h cycle length, and from Mohager (1991), 10x10 mm2 RH 15-90% 20d cycle length, are presented. The analysis was carried out to model these two test series using the appropriate cross sections and environment humidities.

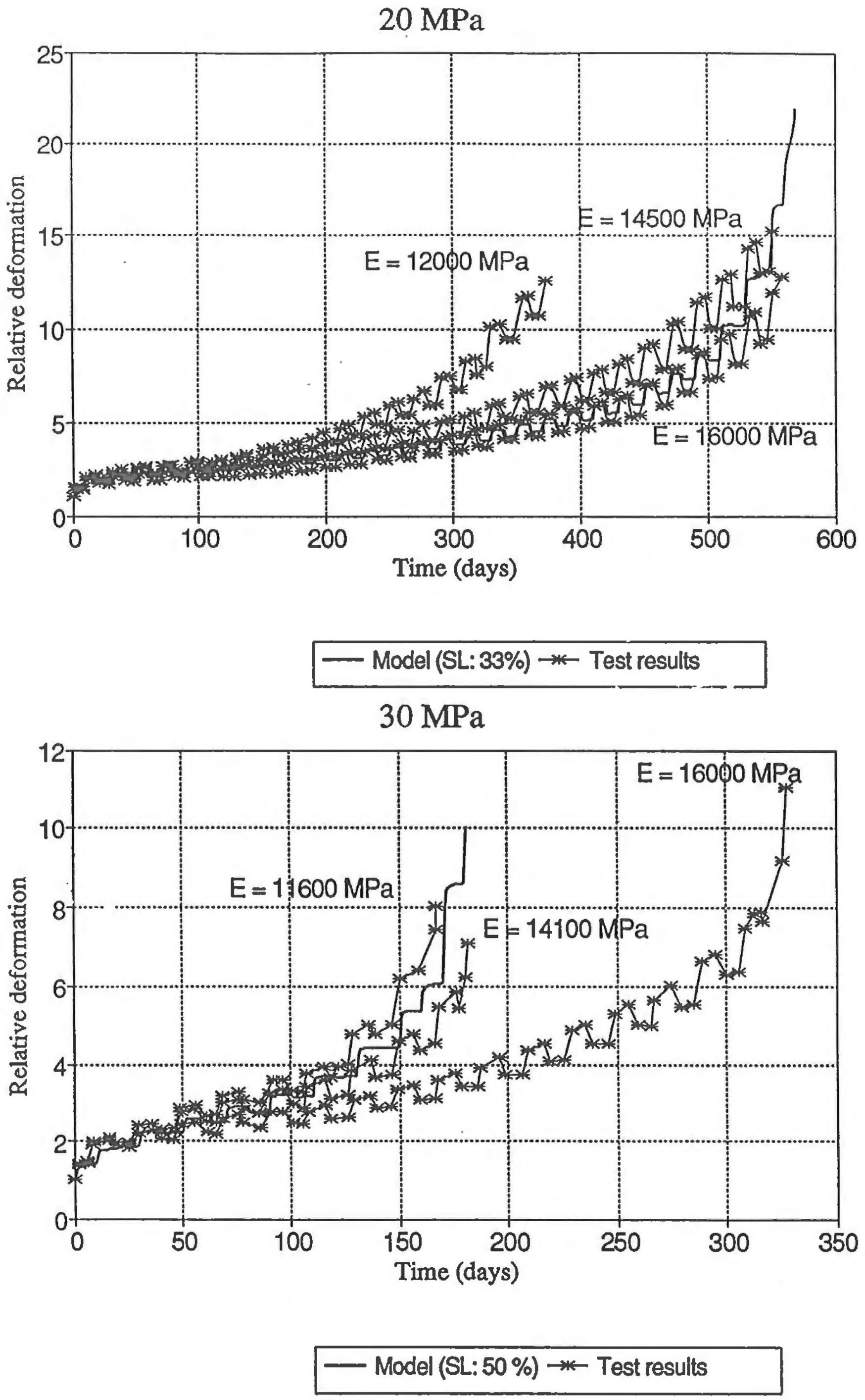

Fig.3. Comparison of computed results to test results using the damage accumulation model for bending stresses of 20 MPa (upper) and 30 MPa (lower).

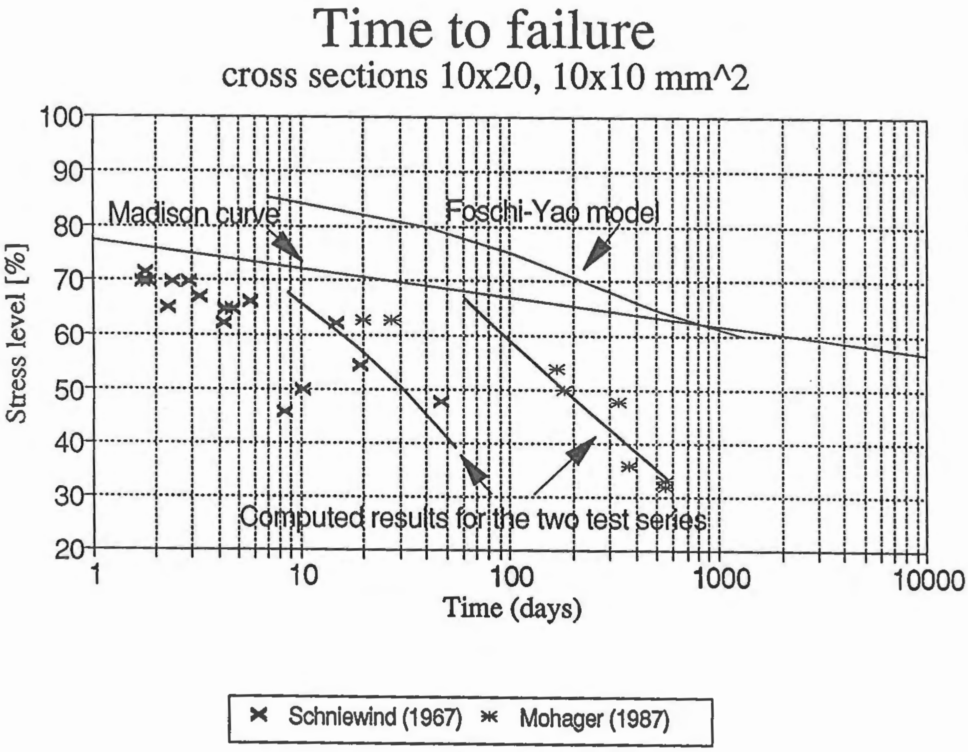

Fig.4. Time to failure test results in cyclic humidity from Mohager (1987) and Schniewind (1967). Computed results for these two test series using the damage accumulation model is given.

The computed results are represented by the line curve, the left curve for Schniewind's and the right curve for Mohager's results. The mechano-sorptive parameters of the damage model were adjusted to the test results of Mohager, but the model is also in fair agreement to Schniewind's results with these same parameters.

CONCLUSION

An approach to model the whole creep life of wood extending to the tertiary phase and rupture is introduced. The use of the mechano-sorptive damage accumulation model in the creep analysis has given promising results. It would need however more experimental evidence to verify the model presented.

It is evident that a variable moisture content during loading at intermediate and high stress levels does cause additional damage: mechano-sorptive damage. There remains still plenty of questions regarding the subject: How does mechano-sorptive damage progress?, is there a threshold on stress level also for the mechano-sorptive term? This is directly linked to the possible existence of a creep limit.

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