木材の膨潤応力の測定方法についての一考察

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A Consideration on the Measuring Method of Swelling Stress of Wood

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1. Introduction

When measuring the swelling force restraining the free swelling of wood, the force-transducer (load cell) causes deflection under load and this deflection of the force-transducer (load cell) allows the specimen to swell, leading to an error in the measured force. The swelling force which is measured using this method is considerably influenced by relaxation. Suchsland[1] presented the equation (1) for the true swelling force in complete restraint, and the equation (2) for the apparent swelling force in deflecting the load cell when the load cell deflects under load,

$$P=\frac{L\alpha AE}{(1+\alpha)L}=\frac{\alpha AE}{(1+\alpha)} \quad \text{(lb.)} \tag{1}$$

$$P'=\frac{L\alpha AE}{(1+\alpha)L+AEk} \quad \text{(lb.)} \tag{2}$$

where, P : true swelling force (lb.)
P': apparent swelling force (lb.)
E : MOE of specimen (psi)
A : cross sectional area of specimen (in^2.)
L : length of specimen (in.)
k : spring constant of load cell (in./lb.)
α : free swelling (in./in.)

But in these equations, the effect of relaxation on the swelling force is not being considered. As the swelling force is significantly affected by relaxation, the term of relaxation was introduced into Suchsland's equations, and the calculated and measured values of swelling force were compared.

2. Experimental Material and Method

Specimens were the heartwood of Hinoki (*Chamaecyparis obtusa* ENDL.). The specific gravity in air dry was 0.40 and the dimensions were as shown in Fig. 1. Specimens were dried with P_2O_5 under diminished pressure and had a moisture content of between 0.5 and 1.5%. The swelling force was measured using the apparatus shown in Fig. 2, with an initial stress of load 1 kg/cm^2. The free swelling and instantaneous recovery were measured using a displacement meter and digital memory (transient time converter, Riken Denshi K. K. TCD-1000). The measurement was done in a tangential direction.

3. Results and Discussion

Fig. 3 shows a diagram of swelling force and free swelling curves against time. Curve (c) shows the swelling force, which increases gradually with time and after reaching equilibrium at t_1, the swelling force decreases gradually because of relaxation. Curve (a) shows the free swelling, which increases with time and after reaching equilibrium at t_2, the

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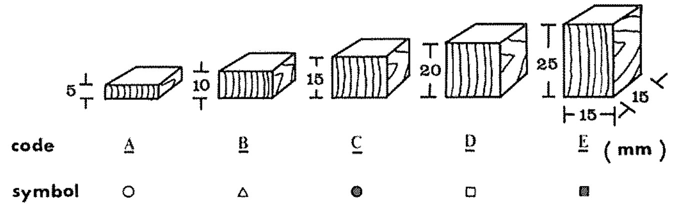

Fig. 1. Dimensions of the specimens.

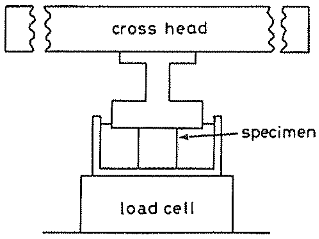

Fig. 2. Schematic diagram of apparatus for measuring the swelling force.

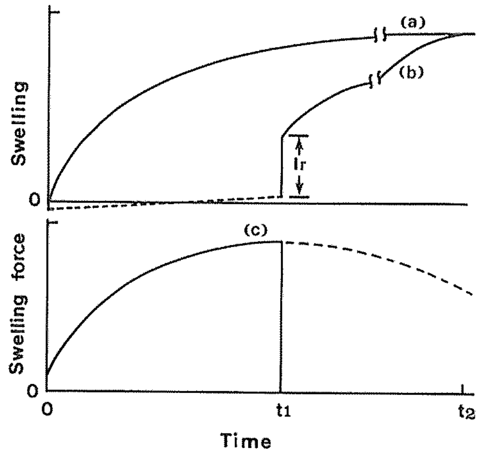

Fig. 3. Schematic diagram of the swelling force and swelling curves. (a): free swelling curve. (b): curve showing the dimensional change of the specimen while measuring the swelling force and after unloading. (c): swelling force curve. *Ir*: instantaneous recovery.

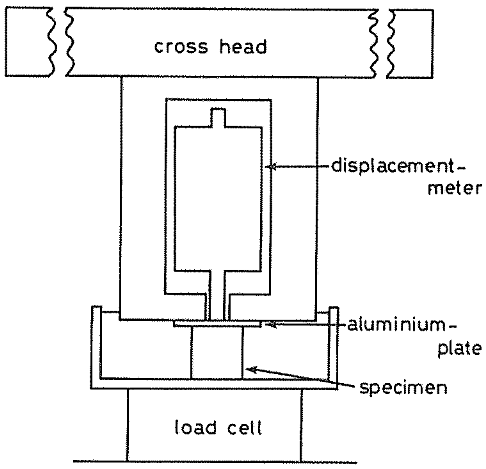

Fig. 4. Schematic diagram of apparatus for measuring instantaneous recovery and swelling.

free swelling remains constant. Curve (b) shows the dimensional change of the specimen during measurement of the swelling force and after unloading. The dimension of the specimen at first decreases in relation to the initial load and it then swells corresponding to the increase of the deflection of the load cell with the increase of the swelling force. When the swelling force reaches the maximum at t_1, the load is unloaded. At this point, the swelling force becomes zero and the dimension of the specimen increases instantly at t_1 (this is instantaneous recovery), it then begins to swell until it becomes equivalent to the final stage of curve (a).

In equations (1) and (2) α is the free swelling, and P and P' are the force for compressing α. In these equations, the influence of relaxations on P and P' has not been taken into account. When measuring the swelling force restraining the free swelling of wood, the result is significantly influenced by relaxation, so the effect of relaxation on swelling force was considered. When the swelling force reached the maximum level, the load was unloaded, and instantaneous recovery (*Ir*) was measured. The value of α *Ir* is smaller than the value of taken at the same moment in time. This difference is considered to be the amount of relaxation by the swelling force.

The equation (3) for true swelling force including relaxation and the equation (4) for

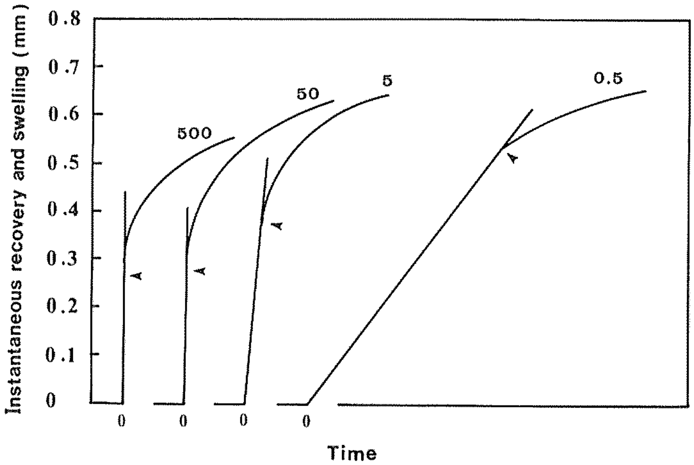

Fig. 5. Effect of unloading speed on instantaneous recovery. The numerical values in the figure give the unloading speed and the arrows show the value of instantaneous recovery.

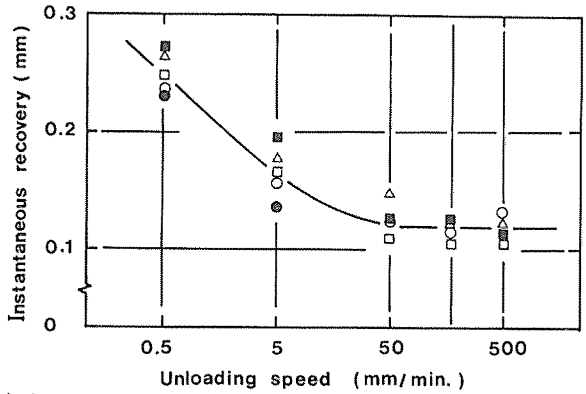

Fig. 6. Relationship between the instantaneous recovery and unloading speed. The symbols are shown in Fig. 1.

apparent swelling force including relaxation are proposed,

$$P=\frac{L\alpha' AE}{(1+\alpha')L}=\frac{\alpha' AE}{1+\alpha}\quad \text{(kg)} \tag{3}$$

$$P'=\frac{L\alpha' AE}{(1+\alpha')L+AEk}\quad \text{(kg)} \tag{4}$$

where, P : true swelling force including relavation (kg)

P': apparent swelling force including relaxation (kg)

E : MOE of specimens (kgf/cm^2)

A : cross sectional area of specimen (cm^2)

L : length of specimen (cm)

k : spring constant of load cell (cm/kg)

α' : instantaneous recovery (cm/cm)

$$\alpha'=\frac{Ir-\delta}{L+\delta}$$

where, Ir: instantaneous recovery (cm)

δ : deflection of the force-transducer caused by swelling force (cm)

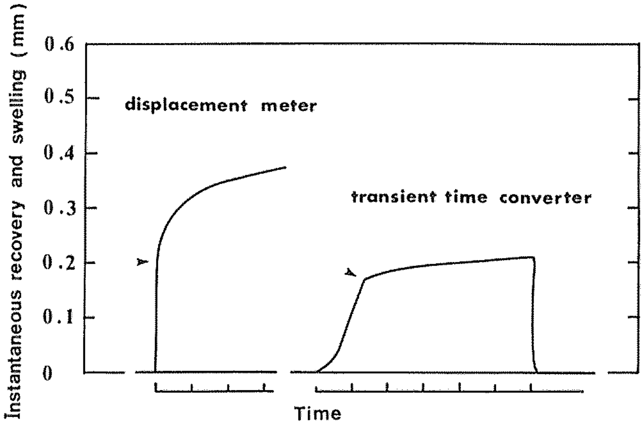

Fig. 7. Instantaneous recovery and swelling vs. time curves. The arrows show the value of instantaneous recovery.

Table 1. Comparison of calculated values from equations (1), (2), (3) and (4) and measured values

code	eq. (1)	eq. (2)	eq. (3)	eq. (4)	Measured
A	217.3	76.9	60.0	20.4	19.9
B	264.0	137.9	54.9	27.6	25.4
C	233.8	144.4	46.7	28.2	30.6
D	211.5	108.1	43.1	29.0	31.3
E	203.5	148.3	37.2	26.6	31.9

Notes: $Et = 1800$ kg/cm^2 unit: kgf
$k = 0.00024$ cm/kg
See Fig. 1 for explanation of code

Fig. 4 shows the apparatus used to measure the instantaneous recovery. The displacement meter separates from the crosshead and the rod of the displacement meter is on the specimen through the aluminium plate. The instantaneous recovery can be measured at the same time as the swelling force is unloaded.

Fig. 5 shows an example of the instantaneous recovery and swelling chart. The relationship between the instantaneous recovery and unloading speed is shown in Fig. 6. The faster the unloading speed, the smaller the instantaneous recovery, but as is evident in Fig. 6, the value of instantaneous recovery is hardly affected by the unloading speed in the range of 50 to 500 mm/min. However in that range of unloading speed, the distinction between the instantaneous recovery and subsequent swelling, is not clear. In order to draw a clear distinction between instantaneous recovery and swelling, a transient time converter was used. Fig. 7 shows an example of the instantaneous recovery chart obtained by the displacement meter and transient time converter. As is obvious from the Fig. 7, by using the transient time converter, the instantaneous recovery is easily distinguished from the subsequent swelling.

Table 1 shows the calculated values from equations (1) to (4) and the measured swelling force. The calculated value from equation (2), in which only the deflection of the load cell is being considered, gives a value of between 4 to 5 times the measured value. The calculated value from equation (4), in which both the deflection of the load cell and relaxation are being considered, gives a relatively good agreement with the measured value. The swelling force measured restraining the free swelling of wood, can be explained by the deflection of the force-transducer (load cell), Young's modulus of wood and the amount of relaxation (instantaneous recovery).

The measured swelling force increased with the length of the specimen. This is because the force-transducer (load cell) deflects under load and the deflection depends on the length of the specimen. If the deflection of the load cell is not dependent on the length of the specimen, the measured swelling force is a constant, regardless of the length of the specimen.

The swelling force of wood is measured by (1) restraining, (2) compressing[2] and (3) repeating[3] methods. The swelling force measured by the latter two is not affected by relaxation. The first method is the most popular and practical, but it is impossible to avoid the effect of relaxation as described already. It is proposed that the swelling force is always depedent on relaxation, and equation (3) is true swelling force and the equation (4) including the deflection of the force-transducer (load cell) is the apparent swelling force.

4. Conclusion

When measuring the swelling force restraining the free swelling of wood, the effect of relaxation cannot be avoided. The term of relaxation has been introduced into Suchsland's equation of swelling force including the deflection of the force-transducer (load cell), and a comparison was made between the measured value and the calculated value. The results are summarized as follows;

(1) The measured swelling force restraining the free swelling of wood agreed relatively with the calculated value from equation (4). From this result, the measured swelling force restraining the free swelling of wood can be explained by the deflection of the force-transducer (load cell), Young's modulus of wood and stress relaxation during the swelling force measurement.

(2) Measuring the swelling force by restraining the free swelling of wood is the most popular and practical method, but as the effect of relaxation is unavoidable, the approach to define the true swelling force of wood as the swelling force involving stress relaxation was proposed.

(3) The maximum measured swelling force increased with the length of the specimen. This is because the force-transducer (load cell) deflects under load, and if the force-transducer (load cell) does not deflect under load or the deflection of it is very small, the swelling force is independent of the dimensions of the specimen.

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Summary

Suchsland proposed the equations of swelling force including the deflection of the load cell under load. When measuring the swelling force restraining the free swelling of wood, the swelling force is influenced by relaxation considerably and it is unavoidable, so the introduction of the term of relaxation into Suchsland's equations was considered. The calculated values agreed relatively well with the measured values and the measured swelling force can be explained by the deflection of the force-transducer (load cell), Young's modulus of wood and relaxation. The swelling force of wood is usually measured by restraining the free swelling of wood and this method is practical. But as in this method the effect of relaxation on the swelling force is unable to avoid, it was proposed to define the true swelling force of wood as the swelling force involving stress relaxation.

Key words: swelling stress, relaxation, measuring method

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木材の膨潤応力の測定方法についての一考察

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要　旨

木材の自由膨潤を拘束して膨潤応力を測定する方法では，応力検出部（ロード・セル）に変位が生じ，それに伴って試験体は膨潤するので，測定値にはこれが誤差となって現れる。Suchsland はこのロード・セルの変位を考慮した膨潤応力の式を提案している。しかし木材の自由膨潤を拘束して膨潤応力を測定する方法では緩和の影響が大きく，この影響は避けられないので，Suchsland の提案した式に緩和を考慮した項を導入し，測定値と比較した。その結果，計算値は測定値と比較的良く一致したことから，この方法で測定した膨潤応力の値はロード・セルの変位，試験体のヤング率及び応力の緩和から説明出来ると思われる。

木材の膨潤応力は拘束法，圧縮法，繰り返し法によって測定されるが，木材の自由膨潤を拘束して測定する方法（拘束法）が最も一般的であり，実用的でもある。しかし，この場合には応力の緩和が避けられないので，応力の緩和を含んだ膨潤応力の値を木材の真の膨潤応力と定義することを提案した。