Identify the factors of creep behavior on small clear wood

HSIEH Tai-Yun[1], MONTERO Cédric[1], ALMERAS Tancrède[1], BARDET Sandrine[1]

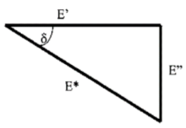
[1] Laboratoire de Mécanique et Génie Civil (LMGC), Université de Montpellier, CNRS, Montpellier, France
tai-yun.hsieh@umontpellier.fr

Keywords: Wood creep; vibration test; density; specific modulus

Context and objectives

Wood is a biomaterial which has been used from ancient time from the design of tools to the construction of buildings. To use wood in the architecture, its long-term behavior needs to be considered and controlled. Creep behavior acts as the deformation increase with time, even if the loading on the structure does not change. When the deformation increases to the limitation of the material, it will lead to damage or serviceability issues. So, it is important to pay attention to time-dependent behavior. To consider it, thicker beams would be used in structure, and an accurate model is necessary to fulfil economic competitively. Unlike inorganic materials like concrete or steel, wood is a natural composite, which has included numerous compositions and microstructural organizations. Not only the biopolymers like cellulose, hemicellulose, lignin, but also the extractive and the ash. The percentage of the polymers, the cellular anatomy, and the interaction with the environment condition, e.g., moisture content, affect the mechanic behavior of the wood and consequently the rheological behavior among time scales.

Rheology is the study of the deformation and flow of materials (Menard, 1999). According to Morlier (1994), Schaffer said that the wood creep behavior is non-linear at all the stress level. Only the short-term behavior at the stress level, which is lower than 40% of failure, could be approximated as linear behavior and Boltzmann's superposition principle is well-fitted (Holzer et al., 1989). In Morlier (1994), Whale also point out the characteristics of wood materials under long-term loading. When the stress, moisture content and temperature are low, the long-term behavior of wood will close to linear elastic manner; when all the conditions raise, the linear viscoelastic in nature behavior will be presented. Under high stress level or in fluctuating environment conditions, wood becomes a kind of non-linear viscoelastic material. So, in controlled conditions, wood is a liner viscoelastic material which shows a delay deformation during loading and dynamic mechanical analysis (DMA), and the complex modulus E* can represent the material behavior. E* can be marked on the polar coordinate system by storage modulus E', loss modulus E" and the angle δ. The damping coefficient, tanδ, is defined by E"/E' (Fig. 1).



$$E^* = E' + i\,E"$$

$$tan\delta = \frac{E"}{E'}$$

Fig. 1: DMA relationship (Menard, 1999)

As previous, another way to understand the material's behavior of rheology is dynamic test like vibration test. According to Kataoka and Ono (1975), the vibration test has been used to study on the dynamic behavior for a long time. From the vibration test, we can have the Young's modulus (E) by the Equation 1.

$$E = 48\pi^2 \rho l^4 f^2 / m^4 h^2 \tag{1}$$

ρ is the density, l is the length and h is the thickness of the specimen, f is resonance frequency, m is a constant. At normal testing condition, m = 4.73 (Kataoka and Ono, 1975). The tanδ can be measured by the decrement of amplitude (Equation 2).

$$\lambda = \frac{1}{n}\ln\frac{A_0}{A_n} \approx \pi \times \tan\delta \quad (2)$$

A_0 are the initial amplitude, A_n the amplitudes at the cycle n. The logarithmic decrement λ came from the regression result of the peak amplitudes by time. After the vibration test, we can have the frequency which had the maximum amplitude call f_R and the bandwidth at half-power of the peak call Δf. The quality factor (Q^{-1}) was defined as the Equation 3. According to Brémaud et al. (2012), the relationship between Q^{-1} and tanδ was almost y=x and with the R^2 = 0.989. It means that in the normal cases, we can take Q^{-1} as tanδ. At the same time, it is a factor stands for the rheological behavior of materials.

$$Q^{-1} = \Delta f / f_R \quad (3)$$

In this study, the vibrational characteristics of the specimens have been collected in addition to usual wood information, and the 10-day creep test has been done to understand the relationship between the factors and the creep behavior.

Materials and Methods

Four kinds of wood have been used, including Douglas fir (*Pseudotsuga menziesii*), European Beech (*Fagus sylvatica*), European Oak (*Quercus petraea*), and Poplar (*Populus spp.*). All kinds of wood were cut into the size 150 mm (L) * 12 mm (b) * 2 mm (h). The specimens were put in the climatic chamber Memmert HPP750 at 20 °C and relative humidity (RH) 30% for 3 weeks. After stabilization, the size and the weight of the specimens were measured, and the vibration test has been done. These measurements have been tested on the environment 20 °C and RH = 85% again.

The setup of the vibration testing system (Vybris) was designed by LMGC. A piece of metal was pasted at the end of the specimens, and they were hanged by 2 cotton threads at the distance of 0.224mm of the specimens' length from the end. An electromagnet to give a vibration including a series of frequency at the end side of the specimen. The vibration signal was sensed by a laser sensor at the center of the specimen. By the program developed by LabVIEW, the results of the fast Fourier transform f_R, Δf and A_0 were collected. The specific modulus and Q^{-1} were calculated by the testing result.

The vibration test results were the reference of sampling. In this study, 10 specimens were selected to have the most wiled density diversity and the closest specific modulus for the creep test. There were 3 Douglas fir, 2 Poplar, 3 European Beech, and 1 European Oak (Fig. 2).

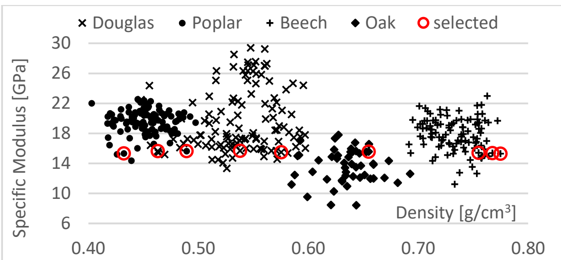


Fig. 2: Preliminary measurements of vibrational specific modulus and density on all specimens and sampling results for a fixed domain of specific modulus

A 4-point bending creep test was settled inside the climate chamber with the environment 20 °C and RH = 85% with a constant load about 650 g for 10 days. The length between the 2 supports was 110 mm and the length between 2 loading points was 60 mm (Fig. 3).

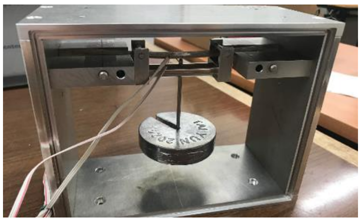
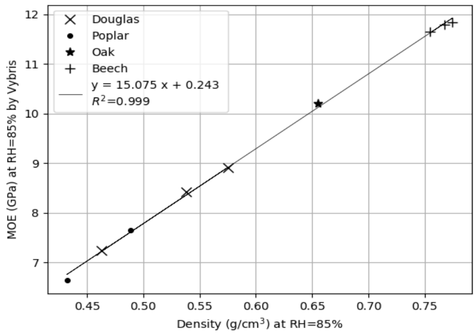


Fig. 3: The 4-point bending setup

Results and Discussion

In the vibration test result, under stable environment and all the specimens have similar specific modulus, there was a well-fitted relationship between density and the modulus of elasticity (MOE) (Fig. 4). When the specific modulus of the specimens was the same, the specimens were similar in the scale of cell wall level, including similar microfibril angle and grain angle (Brémaud et al., 2012). The density would be only related to the porosity, so it presented a high correlation result. In Fig. 6 are presented results of 10-day creep test including strain, swelling and compliance. We defined the first point of compliance as J0 and the last point as J10. The static MOE can be calculated by the reciprocal of J0. Comparing the dynamic MOE value from vibration test and the static MOE, it had also a good correlation with a 10% increment. It presented the relation of the dynamic and static MOE value (Fig. 5).



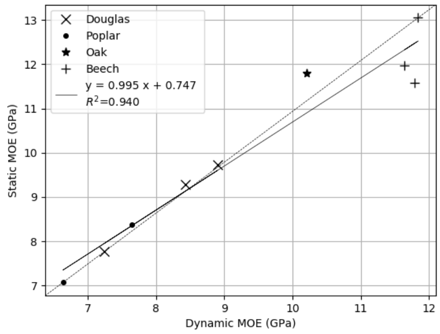


Fig. 4: Relationship between density and MOE   Fig. 5: Relation of static and dynamic MOE

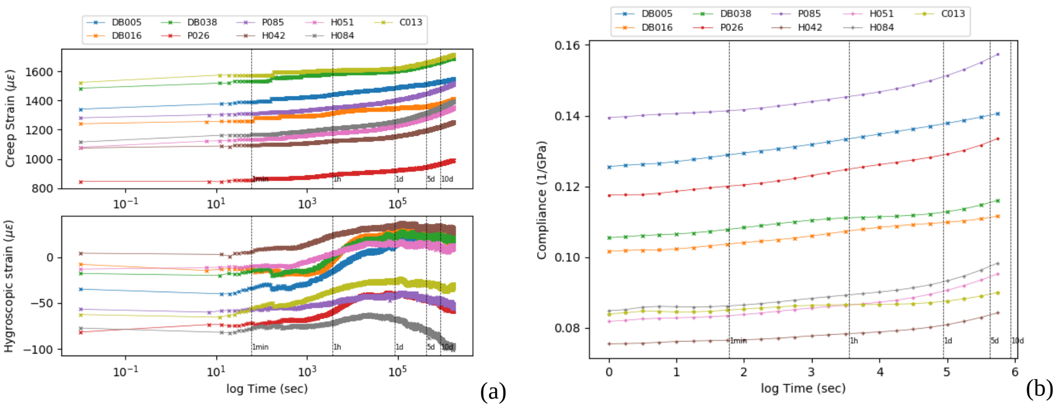


Fig. 6: the 10-day creep test results

From the fitting result of MOE of Vybris and J10, there was a good linear correlation between the 2 values (Fig. 7 (a)). It means that MOE from the short-term dynamic test can also be a predictor of long-term creep test. We can also find a linear relationship between J0 and J10 (Fig.7 (b)). It shows that the static MOE can well-predict the creep behavior.

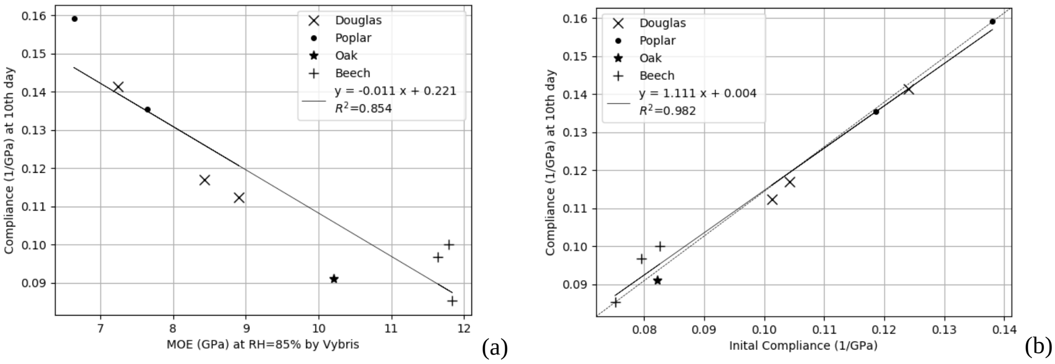


Fig. 7: The comparison of creep test results

Discussion and conclusion

In this study, we can find a linear relationship between dynamic and static MOE. It means that vibration tests can well measure the characteristics of wood, and we can also observe the rheological behavior. Under stable environment, when the specific modulus of the specimens was controlled, we can assume that all the wood specimens have similar cell wall structure. In this case, density was a strong predictor of creep behavior.

Acknowledgments

This work has been supported by French National Research Agency (ANR) during EFEUR5 project (ANR-15-CE08-0027) for the investments into experimental equipment.

References

Kataoka A., Ono T. (1975) Relation between measured values of vibration and kinetic properties of wood specimens and experimental conditions — 1 — Errors based on the measuring apparatus. Journal of the Japan Society of Wood Science, 21(10), p543-550.

Brémaud I., El Kaïm Y., Guibal D., Minato K., Thibaut B., Gril, J. (2012) Characterisation and categorisation of the diversity in viscoelastic vibrational properties between 98 wood types. Annals of Forest Science, 69(3), 373-386.

Holzer, S. M., Loferski, J. R., Dillard, D. A. (1989) A review of creep in wood: concepts relevant to develop long-term behavior predictions for wood structures. Wood and Fiber Science, 21(4), 376-392.

Menard, K. P (1999). Dynamic mechanical analysis. CRC press.

Morlier, P. (Ed.). (1994). Creep in timber structures. CRC Press.