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Original Research Article

RELAXATION OF CHIPBOARD BEAMS – ANALYSIS OF RESULTS OF EXPLORATORY RESEARCH

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Abstract

The paper presents results of experimental tests and a theoretical analysis of the phenomenon of relaxation of chipboard beams. Three linearly viscoelastic rheological models were used for mathematical modeling of the rheology of the studied material. The constants of models were determined using experimental tests and the method of least squares. Through analyses of the obtained results it was found that the rheological behavior of the beam in the specified time is best described by a five-parameter model, consisting of standard and Kelvin-Voigt models connected in series. The final verification of the model can only be ensured by conducting long-term experimental studies using a multistage load program.

Keywords: linear viscoelasticity, wood-based materials, relaxation, rheology

1. INTRODUCTION

Failure to take into account relevant rheological characteristics of wood and wood-based materials (such as chipboard) in the design process can lead to e.g. a significant underestimation of possible deflections [3, 7, 8]. Construction elements made of these materials can be reinforced or prestressed with steel

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or modern composite materials [2]. Prestressing and reinforcement of structural elements is justified when the given states may be permanent. Meanwhile, in the case of constructions made of wood and wood-based materials and plastics (composites, adhesives), one should take into account losses of the prestressing force and redistribution of stress in time, which are the result of rheological properties of materials [2, 5].

Experimental creep test is easy to perform and thus commonly used for testing and defining the values of parameters of rheological models. Relaxation test causes more technical difficulties but it can also be used for the said purposes [6]. This article presents the results of the first preliminary relaxation studies of chipboard beams carried out in the laboratory of the Institute of Structural Engineering of the University of Zielona Góra.

2. OBJECT AND METHODOLOGY

Experimental studies were conducted using a life-size three beams made of PowerBoard chipboard manufactured by SWISS KRONO. Total length was 540.00 cm and cross-section dimensions were 3.7 cm × 30.00 cm. The beam on a test bench is shown in Fig. 1 and Fig. 2. In the middle of the beam span, elements of a measuring system of deflections are visible.

Fig. 1. The beam on a test bench

A four-point bending diagram was adopted with the span of the axes of supports equal to 528.00 cm and spacing of the loading forces equal to 176.0 cm (Fig. 2).

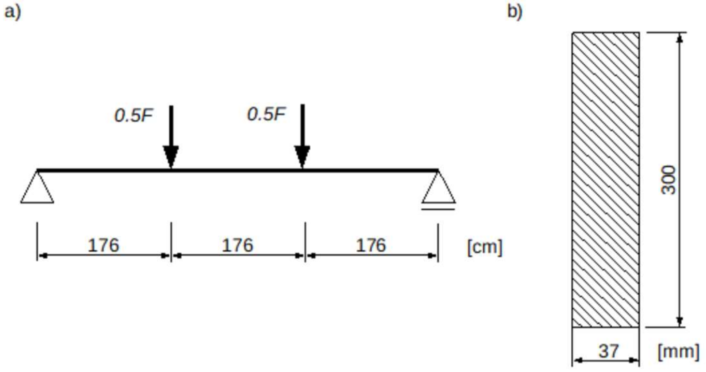

Fig. 2. Static diagram and cross section of the beam

The load was achieved using an Instron 8804 testing machine. In loading points, a deflection of 30.0 mm was applied, which had been selected based on a previous destructive test of another beam of this type. The initial loading force applied during the relaxation test was equal to approx. 40% of the breaking load. Changes of the force driving constant deflection were measured using appropriate settings of the testing machine. Three test were carried out, each test lasted 30 minutes. Average values of forces were analyzed. The tests had an exploratory character and were used to prepare an extensive programme of rheological research of elements of this type.

3. TEST RESULTS AND ANALYSIS

Results in the form of an experimental relaxation function are shown in Fig. 4 - 6. During the test, the value of the driving force decreased by 6%.

Three-, four- and five-parameter rheological models shown in Fig. 3 were used to describe the theoretical progress of the relaxation function. A compatibility coefficient R^2 was adopted as a measure of compatibility of the experimental results with theoretical functions. The Solver optimization package as part of the Microsoft Excel spreadsheet was used to determine the values of parameters of individual models.

Three-parameter standard model was used first. In the conditions of permanent strain, the stress relaxes asymptotically according to the equation [1, 4, 7]:

$$\sigma(t) = E_0 \cdot \varepsilon_0 \cdot \left(\frac{E_1}{E_0 + E_1} + \frac{E_0}{E_0 + E_1} \cdot e^{-\frac{(E_0+E_1)t}{\eta_1}} \right) \tag{3.1}$$

where:

$\sigma(t)$ – stress, MPa,

ε_0 – strain,

E_0, E_1 – Younga’s modulusof Hooke’s factors, MPa,

η_1 – viscosity module of Newton's, MPa·s.

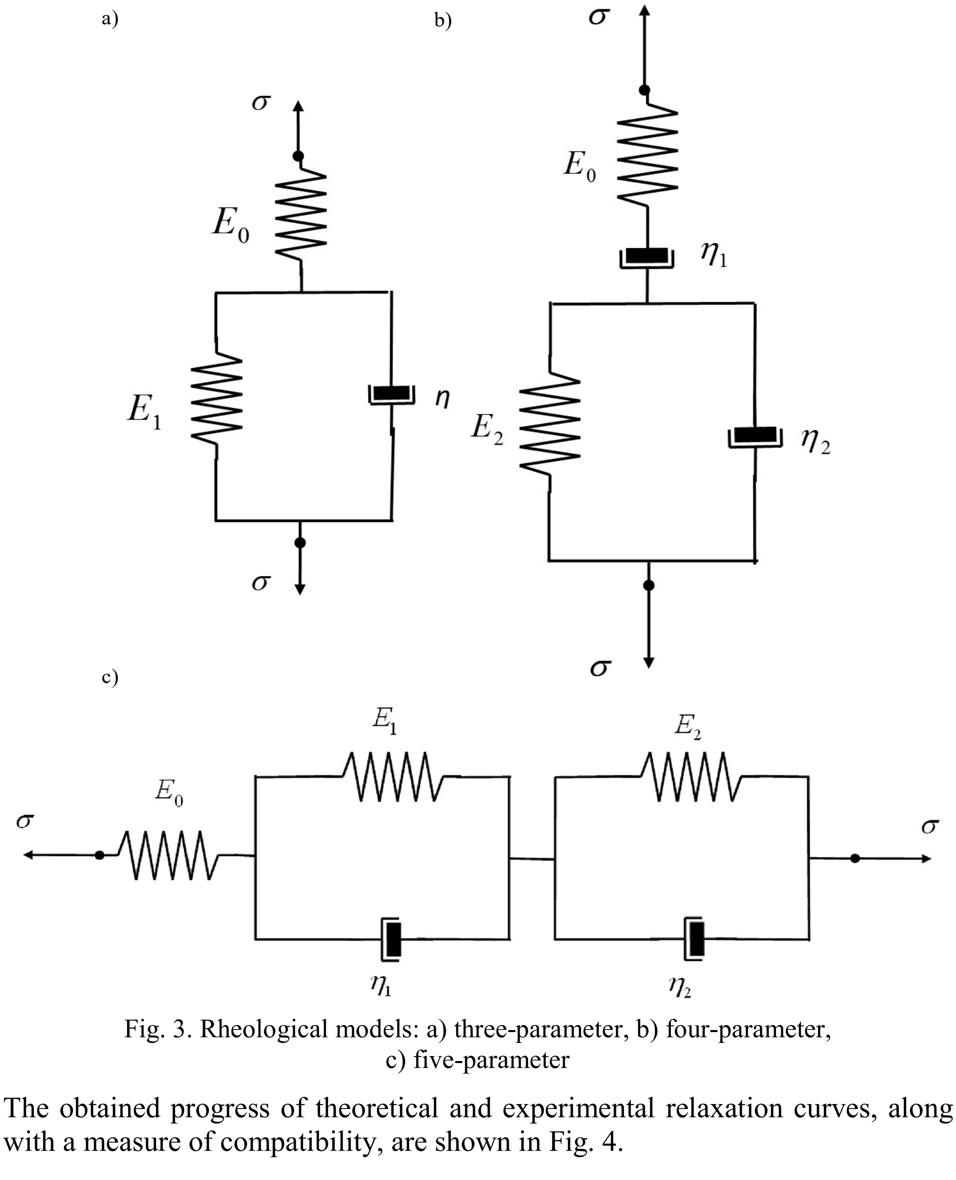

Fig. 3. Rheological models: a) three-parameter, b) four-parameter, c) five-parameter

The obtained progress of theoretical and experimental relaxation curves, along with a measure of compatibility, are shown in Fig. 4.

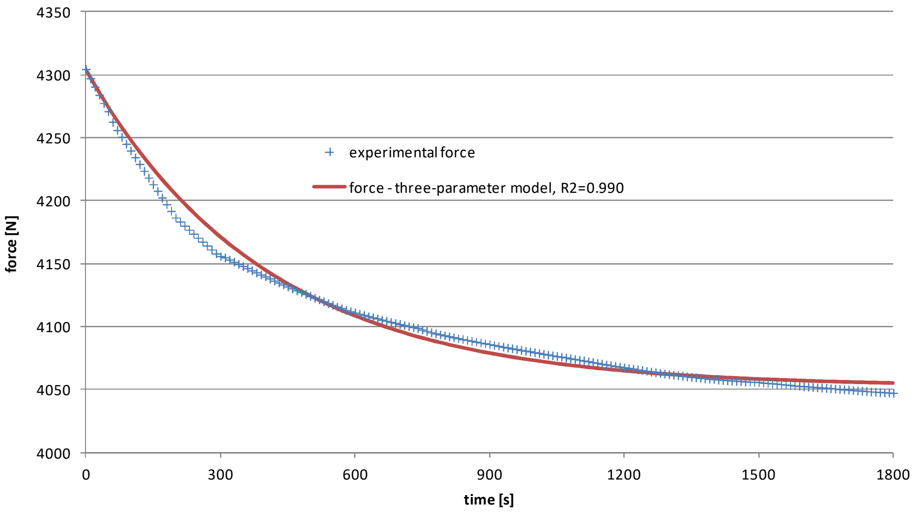

Fig. 4. Relaxation test – three-parameter model

In the case of the four-parameter model in the conditions of permanent strain, the stress relaxes according to the formula [1, 4, 7]:

$$\sigma(t)=\frac{\varepsilon_0}{A}\cdot\left[\left(q_1-q_2\cdot r_1\right)\cdot e^{-r_1\cdot t}-\left(q_1-q_2\cdot r_2\right)\cdot e^{-r_2\cdot t}\right], \tag{3.2}$$

where:

$$r_1=\frac{p_1-A}{2\cdot p_2},\quad r_2=\frac{p_1+A}{2\cdot p_2},\quad A=\sqrt{p_1^2-4\cdot p_2}\ , \tag{3.3}$$

p_1 and q_1 are linear combinations of Young's modulus E_i and viscosity modules η_i :

$$p_1=\frac{\eta_1}{E_0}+\frac{\eta_1}{E_2}+\frac{\eta_2}{E_2},\quad p_2=\frac{\eta_1\cdot\eta_2}{E_0\cdot E_2},\quad q_1=\eta_1,\quad q_2=\frac{\eta_1\cdot\eta_2}{E_2}\,. \tag{3.4}$$

The obtained progress of theoretical and experimental relaxation curves, along with a measure of compatibility, are shown in Fig. 5.

The five-parameter model was used as the last one. Similar models were used to describe wood creep by Schänzlin [3} and Toratti [8]. The relaxation function of this model takes the form [7]:

$$E(t) = \frac{1}{p_2 \cdot \rho_1 \cdot \rho_2} \cdot \left\{ q_0 - \frac{1}{\rho_2 - \rho_1} \cdot \left[\rho_2 \cdot e^{\rho_1 \cdot t} \cdot \left(q_0 + q_1 \cdot \rho_1 + q_2 \cdot \rho_1^2 \right) - \right.\right. \\ \left.\left. + \rho_1 \cdot e^{\rho_2 \cdot t} \cdot \left(q_0 + q_1 \cdot \rho_2 + q_2 \cdot \rho_2^2 \right) \right] \right\}. \tag{3.5}$$

where:

$$\rho_1 = \frac{1}{2 \cdot p_2} \cdot \left[- p_1 + \left(p_1^2 - 4 \cdot p_2 \cdot p_0 \right)^{\frac{1}{2}} \right], \tag{3.6}$$

$$\rho_2 = \frac{1}{2 \cdot p_2} \cdot \left[- p_1 - \left(p_1^2 - 4 \cdot p_2 \cdot p_0 \right)^{\frac{1}{2}} \right]. \tag{3.7}$$

$$\begin{gathered} p_0 = E_0 \cdot E_2 + E_1 \cdot E_2 + E_0 \cdot E_1, \\ p_1 = \left(E_0 + E_1 \right) \cdot \eta_2 + \left(E_2 + E_0 \right) \cdot \eta_1, \; p_2 = \eta_1 \cdot \eta_2, q_0 = E_0 \cdot E_1 \cdot E_2, \\ q_0 = E_0 \cdot E_1 \cdot E_2, \; q_1 = E_0 \cdot \left(E_1 \cdot \eta_2 + E_2 \cdot \eta_1 \right), \; q_2 = E_0 \cdot \eta_1 \cdot \eta_2. \end{gathered} \tag{3.8}$$

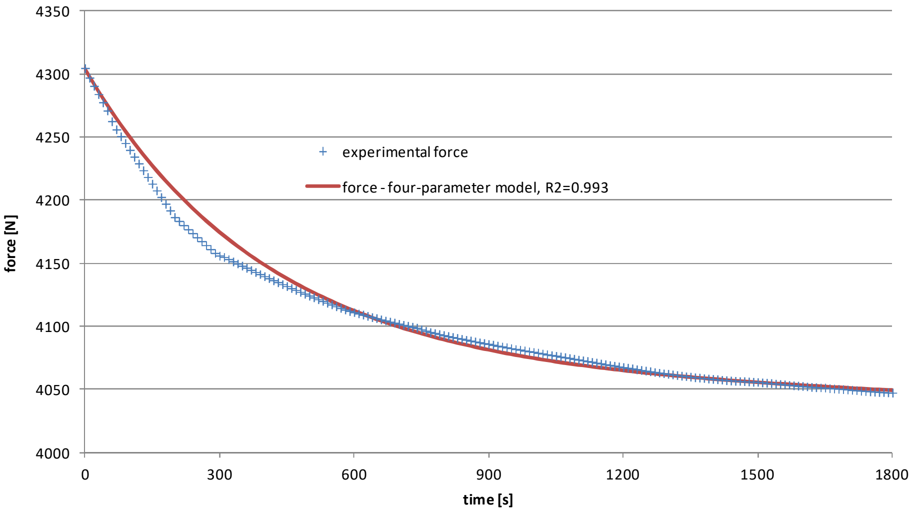

Fig. 5. Relaxation test – four-parameter model

The obtained progress of theoretical and experimental relaxation curves, along with a measure of compatibility, are shown in Fig. 6.

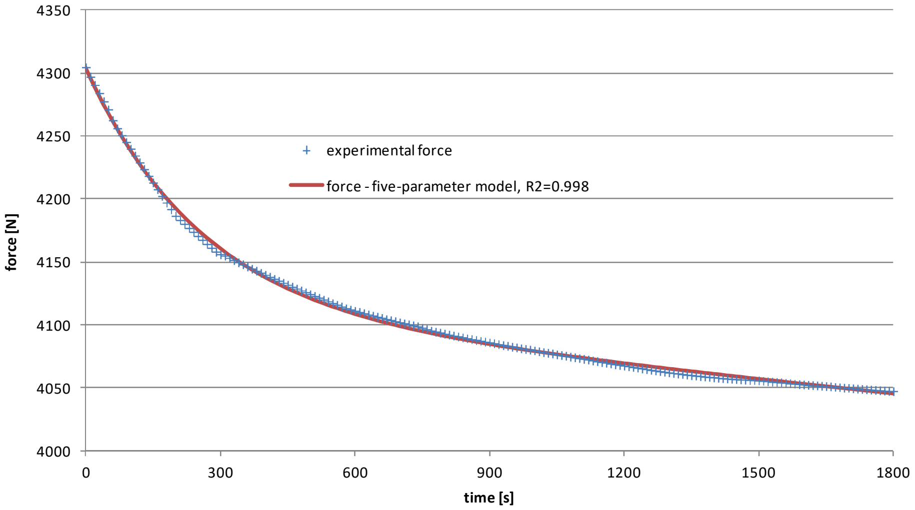

Fig. 6. Relaxation test – five-parameter model

4. CONCLUSION

The conducted experimental relaxation tests of chipboard lead to the following conclusions:

- Using all applied models, a high compatibility with the experimental data was obtained. However, the exploratory nature of the research should be emphasised. The choice of the model best describing the rheology of the tested material will definitely require longer tests.
- The final verification of the adopted rheological model can be achieved only by conducting long-term experimental studies using a multistage load program (a clear separation of the identification of model parameters and its verification).

REFERENCES

1. JAKOWLUK A., *Procesy pełzania i zmęczenia w materiałach*, WNT, Warszawa 1993.
2. KULA, K.; SOCHA, T.; 2016. *Renovation and strengthening of wooden beams with CFRP bands including the rheological effects*. Civil and Environmental Engineering Reports, 2016, No. 22(3), 93-102.
3. SCHÄNZLIN J.: *Modeling the long-term behavior of structural timber for typical serviceclass-II-conditions in South-West Germany*, Habilitation,

Institut für Konstruktion und Entwurf, Stahl- Holz- und Verbundbau, Universität Stuttgart, 2010.

4. SKRZYPEK J.: *Plastyczność i pełzanie*, PWN, Warszawa 1986.
5. SOCHA, T.; 2010. *Rheological redistribution of stresses in multi-layered beams*. Civil and Environmental Engineering Reports, 2010, No. 5, 219-233.
6. SOCHA, T.; 2011. *Wyznaczanie parametrów modeli reologicznych drewna na podstawie doświadczalnej próby relaksacji*. Drewno i materiały drewnopochodne w konstrukcjach budowlanych, red. Z. Mielczarek. Szczecin 2011, 303-314.
7. SOCHA T.: *Ocena wpływu obciążeń długotrwałych na naprężenia i odkształcenia w drewnianych belkach z wklejonym zbrojeniem kompozytowym*, Maszynopis rozprawy doktorskiej, Uniwersytet Zielonogórski 2005.
8. TORATTI T.: *Creep of timber beams in variable environment*. PhD-thesis, Helsinki University of Technology, Laboratory of Structural Enginieering and Building Physics, 1992.

RELAKSACJA BELEK Z PŁYT WIÓROWYCH – ANALIZA WYNIKÓW BADAŃ ROZPOZNAWCZYCH

Streszczenie

W referacie przedstawiono wyniki badań eksperymentalnych oraz analizę teoretyczną zjawiska relaksacji belek z płyt wiórowych. Do matematycznego modelowania reologii badanego materiału wykorzystano trzy liniowo lepkosprężyste modele reologiczne. Stałe modeli wyznaczono wykorzystując przeprowadzone badania doświadczalne oraz metodę najmniejszych kwadratów. Analizując uzyskane wyniki stwierdzono, iż reologiczne zachowanie belki w rozpatrywanym czasie najlepiej opisuje model pięcioparametrowy, złożony z szeregowo połączonych modeli standardowego i Kelvina-Voigta. Ostateczną weryfikację modelu zapewnić może jedynie przeprowadzenie długotrwałych badań eksperymentalnych z wykorzystaniem wielostopniowego programu obciążeń.

Słowa kluczowe: liniowa lepkosprężystość, materiały drewnopochodne, relaksacja, reologia

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