Predicting bending creep of laminated veneer lumber (LVL) sengon (*Paraserianthes falcataria*) beams from initial creep test data

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Abstract. This paper presents the results of creep tests of Laminated Veneer Lumber Sengon (LVL Sengon) beams, aiming to determine the creep factor and to establish the prediction beam deflection based on the initial creep test data. The LVL Sengon beams have a cross section of 40 mm by 80 mm and a clear span length of 2,000 mm, they were loaded at midspan for three different stress levels: 30%, 40%, and 50% of the ultimate load within 30, 60, and 90 days. Each loading level consists of four repetitive beams where one beam was wrapped with a plastic sheet. The test results showed that for 90 days the bending creep test can not determine the secondary creep yet. Curve fitting of bending creep test data indicated that the parameters of the Modified Burger creep model of the first 30 days can be accurately used to predict the beam deflection curve up to 60 and 90 days of loading.

1 Introduction

Creep is one factor that must be considered in the design of a building structure. Creep is a deflection or deformation of structures due to permanent loading over time. Creep can cause serviceability problems due to excessive deformation or to a reduction in strength [1]. The total deformation during the service life of a building must be limited. Therefore, understanding creep behaviour of material and structure will allow one to predict the behaviour of a building during its service life [2, 3], including buildings using wood and wood based (wood engineered) materials [4].

Sengon (*Paraserianthes falcataria*) laminated veneer lumber (LVL Sengon) is an engineered wood material that is recently developed as a structural component in Indonesia and is manufactured by laminating veneers obtained from Sengon timber [5]. Sengon is a fast- growing timber that can replace solid wood. Each veneer has a thickness from 2.5 to

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3.2 mm and plies parallel to length using melamine urea formaldehyde (UF) adhesive under 0.6-0.7 MPa pressure.

Similar with other wood structural materials, the utilization of LVL Sengon needs engineering properties and mechanical tests in the short-term or long-term. Compared to solid Sengon, LVL Sengon has some improvements on engineering properties, as shown in Table 1.

Table 1. Engineering properties of solid sengon and LVL sengon [6].

Engineering properties	Solid Sengon	LVL Sengon
Density	0.26	0.41
MOE (MPa)	1250-3300	5700-9000
MOR (MPa)	26.61	38.78
Tension // (MPa)	20.00	46.69
Compression // (MPa)	13.29	22.82
Compression ⊥ (MPa)	3.52	5.40
Shear (MPa)	0.60	-

This study aims to examine the bending creep of LVL Sengon through rheological (mechanical) and phenomenological models. The rheological model is based on a mathematical function to best fit experimental bending creep data, and the phenomenological model is based on constants obtained from experimental bending creep data that represents spring and dashpot model. Prediction of long term creep of LVL Sengon is calculated based on short term experiment bending creep data.

Hunt stated that the result of creep experiments is generally divided into two parts: a primary or short-term part and a secondary or long-term part. A plot of creep result against the logarithmic of time showed that after primary creep occurred in one or two days, it follows a straight line represented as secondary creep [6]. However, there is a lack of information about the long-term behaviour of material or structure components under a constant loading.

2 Bending creep experiment

Creep experiments has been done on LVL Sengon beams for 3 (three) months in a temperature- and humidity- controlled room. The dimensions of LVL Sengon beam is 40 mm in thickness, 80 mm in width, and 2000 mm in (clear) length. Beam edges are simply supported and loaded at mid-span by loading levels of 30%, 40%, and 50% of the ultimate load, which correspond to 215 N, 285 N and 355 N, respectively.

Fig. 1. (a) Bending edgewise test, (b) Setting of bending creep test of LVL Sengon.

The ultimate load was taken from the bending test of LVL Sengon based on the Japan Agriculture Standard for Laminated Veneer Lumber (LVL) Notification No.2773, 2013, see Fig. 1.

The room for bending creep test was controlled at a constant temperature of 27°C by means of an Air Conditioner (AC) and at a minimal 65% in relative humidity (RH) by means of a humidifier. However, actual measurement inside the room showed a temperature range of 24.9°C-26.3°C and RH of 65%-99%, as shown in Fig. 2. There are three unwrapped beams and one wrapped (with plastic sheet) beam for each loading level.

Fig. 2. Temperature and relative humidity data over bending creep test.

2.1 Creep model of LVL sengon

LVL Sengon is assumed to be a viscoelastic material. A viscoelastic material exhibits elasticity under rapid loading, then its strain increases slowly and continuously. Viscoelasticity combines elasticity and viscosity (viscous flow) [7]. Elastic materials can be represented by a Hookean spring and the force-deformation response is independent of time, while the dashpot represents viscous materials and can describe time-dependent behaviour. The creep model of viscoelastic materials can be arranged in spring and dashpot in various combinations [8].

The Maxwell creep model combines a spring and a dashpot joined in series and the Kelvin creep model consists of a spring and a dashpot in parallel arrangement. The Burger or four-element creep model [7] is represented by inserting the Kelvin creep model between a spring and a dashpot of the Maxwell creep model, as shown in Fig. 3. The mathematical form of the Burger model is given in Eq. (1).

Fig. 3. Burger creep model.

$$u(t) = \beta_1 + \beta_2(1 - e^{-(\beta_3)t}) + \beta_4 t \tag{1}$$

where $\beta_1 = P_0 / k_e$, $\beta_2 = P_0 / k_k$, $\beta_3 = k_k / \eta_k$, and $\beta_4 = P_0 / \eta_v$.

Initial elastic deformation is denoted by β_1 that is associated with the spring constant k_e . β_2 and β_3 correspond to the delayed elastic or recoverable creep components and are associated with the combined effect of the spring constant k_k and the dashpot constant η_k , and finally β_4 represents the irrecoverable creep component contributed by the dashpot constant η_v .

In other words, Eq. (1) shows that the first term of the right-hand side represents the instantaneous deformation, the second term describes the delayed elasticity, and the third term describes the plastic flow component. [9]

2.2 Modification of burger creep model

Dinwoodie [8, 10] states that any further models of creep tests are demanded to be able to predict long-term performance from short-term data. For timber and the various board materials, the third term in the right-hand side of the Burger creep model needs to be modified to a non-linear form by powering the variable t with the viscous modification factor β_5 . So, Eq. (1) yields to become Eq. (2).

$$u(t) = \beta_1 + \beta_2(1 - e^{-(\beta_3)t}) + \beta_4 t^{\beta_5} \tag{2}$$

Value of β_5 is $0 < \beta_5 < 1$.

3 Result and discussion

Bending creep test of LVL Sengon beams have been conducted for three months at each stress level. The temperature and relative humidity (RH) of the room test were continuously monitored, and deflection of the beams at mid span was recorded. The wrapped LVL Sengon beam in each load level of bending creep test was expected to exhibit the influence of change in water content in rate of creep.

The creep deflection data of LVL Sengon beams for each load level are plotted and can be seen in Fig. 4.

Fig. 4. Plotting of bending creep LVL sengon test

Fig. 3 showed that the primary creep occurred in the first 30.5-56 days of the bending creep test. At each stress level, the bending creep of LVL Sengon has the same pattern, which in secondary creep, the creep data tends to be linear or has a constant creep rate.

By using the Toolbox Solver program available in Microsoft Excel, the parameters in Eq. (1) and (2) that represent the Burger and Modified Burger creep model are determined, and plotted to bending creep data, as be shown in Fig. 5, 6 and 7, and the correlation coefficient (r square, r^2) can be calculated. Table 2, Table 3, and Table 4 show the parameters and the correlation coefficient of the curve fitting the Burger and Modified Burger models for load levels of 30%, 40%, and 50%, respectively. The modified Burger model has a correlation coefficient value above 0.9. However, the primary or secondary creep cannot be determined yet because for 90 days the bending creep test deflection of beam still tend to rise and asymptote was not yet reached.

Table 2. Parameters and correlation coefficient of bending creep test - load level 30%.

Load Level 30%	Beam 1		Beam 2		Beam 3		Wrapped Beam	
	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger
β1	11.014462	10.743241	10.630519	10.045564	10.755228	9.8913208	11.275741	11.112222
β2	0.4596346	0.1059182	0.5918641	7.1551585	0.6417043	0.1212905	0.557184	0.1632276
β3	1.5091411	326.13852	3.9302119	0.0012219	2.1939024	0.1449747	2.9283197	6.87342
β4	0.0152939	0.5014498	0.0157328	1.0624344	0.0060496	1.3068948	0.0105215	0.4635783
β5		0.217885		0.1097768		0.0798948		0.2106864
r^2	0.7613996	0.9918171	0.9595336	0.9913091	0.9602579	0.9879488	0.9666538	0.9851335

Table 3. Parameters and correlation coefficient of bending creep test - 40% load level

Load Level 40%	Beam 1		Beam 2		Beam 3		Wrapped Beam	
	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger
β1	11.963632	11.665513	15.579611	15.083565	15.257304	15.195111	11.044243	10.417463
β2	1.5549819	0.6343554	1.1255464	1.0117962	0.709855	0.5395663	1.0175549	0.1
β3	3.0377474	4.9188426	2.9299405	0.0185637	5.9720318	19.664109	3.0567505	2.4553115
β4	0.0065362	0.7927475	0.0171349	1.1316776	0.0222004	0.0680656	0.0107038	1.2869235
β5		0.1802985		0.1469388		0.7713479		0.1336519
r^2	0.9765191	0.9898161	0.9765191	0.994404	0.9947873	0.9960177	0.9682679	0.9888365

Table 4. Parameters and correlation coefficient of bending creep test - 50% load level

Load Level 50%	Beam 1		Beam 2		Beam 3		Wrapped Beam	
	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger	Burger	Modified Burger
β1	16.929935	16.600675	16.717006	16.555549	17.979456	16.470662	16.823075	16.815437
β2	1.6432949	0.6772799	2.2854176	1.8998207	1.8091653	0.2722463	0.5707824	0.3599286
β3	4.8883584	18.898913	11.168978	23.369226	2.7157508	28.777776	0.2670009	0.4405904
β4	0.0270193	0.9640834	0.020849	0.2313281	0.0076878	2.4088906	0.0089837	0.0528588
β5		0.2500661		0.5183995		0.0986125		0.6584842
r^2	0.887781	0.9977287	0.9823285	0.9942495	0.9588157	0.9915616	0.9939356	0.9945301

Fig. 5. Curve fitting of bending creep data – load level 30%.

Fig. 6. Curve fitting of bending creep data – load level 40%.

Fig. 7. Curve fitting of bending creep data – load level 50%.

Based on the result of the bending creep test of LVL Sengon beam, bending creep modelling by the Modified Burger model fit enough to creep test data. So, its model can predict the continuous creep. Table 2 shows the correlation coefficient of fitting the curve data for each beam and load level.

Table 2. The correlation coefficient (R^2) of fitting 1-month creep data, prediction 2 and 3 months based on fitting 1-month creep data.

Specimen	Load Level	1 Month		Prediction 2 months		Prediction 3 months	
		Burger model	Modified Burger model	Burger model	Modified Burger model	Burger model	Modified Burger model
Beam 1	30%	0.9485	0.9933	0.9196	0.9932	0.6746	0.9945
	40%	0.9838	0.9678	0.8050	0.9760	0.0037	0.9446
	50%	0.9770	0.9904	0.7282	0.9738	-0.8014	0.1857
Beam 2	30%	0.9854	0.9541	0.9478	0.9584	0.7267	0.9626
	40%	0.9963	0.9967	0.9870	0.9658	0.8592	0.9572
	50%	0.9774	0.9020	0.9350	0.9463	0.5010	0.9668
Beam 3	30%	0.9878	0.9888	0.9100	0.9409	0.2439	0.5452
	40%	0.9774	0.9804	0.9495	0.9897	0.8570	0.9923
	50%	0.9645	0.9807	0.8265	0.9860	-1.1318	0.9868
Wrapped Beam	30%	0.9735	0.9169	0.9310	0.9260	0.7579	0.9497
	40%	0.8862	0.9148	0.9313	0.9582	0.8612	0.9745
	50%	0.9775	0.9647	0.9581	0.9803	0.8369	0.9912

This paper discusses the prediction of the bending creep of LVL Sengon beam from 1-month data by using the Modified Burger model. Its coefficients or parameters will be used to predict 2- and 3-month bending creep. Results will be correlated with experiment bending creep data. Plotting bending creep data of beam 1, 2, 3, and the wrapped beam, as in Fig. 8, 9,10, and 11, respectively, showed that the Modified Burger model is good enough to predict 2- and 3-months bending creep from 1-month bending creep data.

Fig. 8. Prediction 3 months of bending creep from 1-month creep data (Beam 1).

Fig. 9. Prediction 3 months of bending creep from 1-month creep data (Beam 2).

Fig. 10. Prediction 3 months of bending creep from 1-month creep data (Beam 3).

Fig. 11. Prediction 3 months of bending creep from 1-month creep data (Wrapped Beam).

4 Conclusion

This paper’s study performed the prediction of three-months creep of LVL Sengon beam based on analysis of one-month bending creep data using the Burger and Modified Burger model. Curve fitting data showed that: 1. The Modified Burger model can be used to predict bending creep of LVL Sengon beam. 2. A longer bending creep testing is required to obtain a more satisfactory result on bending creep of LVL Sengon.

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