

Compressive and Tensile Creep of Glued-Laminated Bamboo

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Compressive and Tensile Creep of Glued-Laminated Bamboo

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ABSTRACT

Glued-laminated bamboo has been widely used for various structural elements of buildings. Under long term compressive and tensile constant loading the glued-laminated bamboo will causing creep deformation. The creep effect has the potential to affect service life on building structures. Limited study was carried out compressive and tension creep of glued-laminated bamboo, therefore, it is necessary to conduct a more comprehensive study of the compressive and tensile creep parallel to the grain of glued-laminated bamboo. The research aims are knowing the effect of the load level 30% on creep behavior of glued-laminated bamboo parallel to the grain subjected to compressive and tensile constant loading. The result showed that Burger model was used to fit the creep data and then can be used for predicting primary and secondary creep stage. The primary stage of the compressive creep for 2 days, while the primary of the tensile creep for 29 days, followed by the secondary stage until the 90th day, this indicates that glued-laminated bamboo is more vulnerable to compressive creep than tensile creep. The Burger and Power model were successfully for predicting viscoelastic compressive and tensile creep parameters.

Keywords: Creep, Compressive, Tensile, Burger Model, Power Law.

1 INTRODUCTION

1.1 Background

Recent years, glued-laminated bamboo has been widely used for various structural elements of buildings because the bamboo typically be harvested in less than 3 - 4 years, renewable and sustainable material, mechanical properties similiar with timber (Janssen, 2000; Sharma et al., 2015; Ni et al., 2016). Its have been applicated to many elements of building structures such as beam, column and truss. The construction of elements carrying compressive, tensile or combination force.

Glued-laminated bamboo is classified as a viscoelastic material because it possesses properties that are common to both perfect solid and liquid. Under long term constant loading the glued-laminated bamboo will causing creep deformation. Creep behaviour is well known as one of the primary structural behaviours to be understood for the development analysis and design of glued-laminated bamboo structures (Holzer et al., 1989; Gottron et al., 2014).

The creep is critical to structural design of glued-laminated bamboo structures. The creep effect has the potential to affect service life on building structures. Another problem due to creep is the ability to alter the material characteristics and mechanical properties of the structural elements, which leads to causing building structure failure (Gottron et al., 2014, Ngudiyono et al., 2019).

Research on creep bamboo, bamboo composite, glued-laminated bamboo has been carried out by previous researchers (Ma et al., 2014; Gottron et al., 2014 and Xiao et al., 2014; Ma et al., 2015; Ma et al., 2016; Ounjaijom and Rangri, 2016). However, the researchers focused more on flexural creep. Li and Xiao (2015) were carried out compressive and tension creep of glued-laminated bamboo, but limited discussion about primary and secondary creep behavior. Therefore, it is necessary to conduct a more comprehensive study of the compressive and tensile creep parallel to the grain of glued-laminated bamboo.

1.2 Creep

Creep is a slow deformation of a material under constant loading. Creep in general may be described in terms of three different stages illustrated in Figure 1. The first stage in which creep occurs at a decreasing rate is called primary creep; the second, called the secondary stage, proceeds at a nearly constant rate; and the third or tertiary stage occurs at an increasing rate and terminates in fracture (Findley et al., 1976).

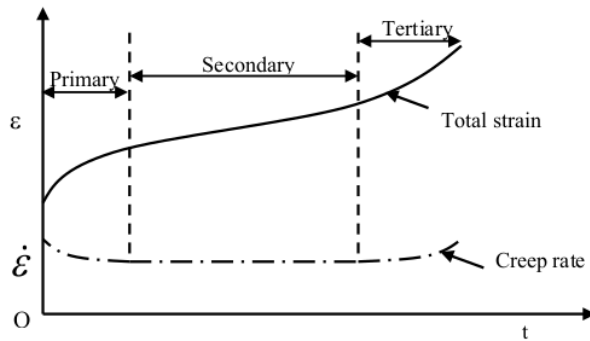


Figure 1. Three creep stage (Findley et al., 1976)

1.3 Burger Model

The arrangement of elements of the Burger model is shown in Figure 2, where the Maxwell and Kelvin models are connected in series. Constitutive equation of Burger model can be expressed as:

$$\sigma + \left(\frac{\eta_1}{E_1} + \frac{\eta_1}{E_2} + \frac{\eta_2}{E_2} \right) \dot{\sigma} + \frac{\eta_1 \eta_2}{E_1 E_2} \ddot{\sigma} = \eta_1 \dot{\epsilon} + \frac{\eta_1 \eta_2}{E_2} \ddot{\epsilon} \tag{1}$$

The creep behavior of the Burgers model under constant load can be obtained with solving the equation (1), that second order differential equation with Laplace transformation method in two initial conditions, shown in Equation (2).

$$\epsilon(t) = \frac{\sigma_0}{E_1} + \frac{\sigma_0}{\eta_1} t + \frac{\sigma_0}{E_2} (1 - e^{-(E_2/\eta_2)t}) \tag{2}$$

1.4 Power Law Model

Empirical mathematical equations the most successfully descriptions for creep in the viscoelastic material under constant relative humidity and temperature is the power law model, of the general form (Dinwoodie, 2000).

$$\epsilon(t) = \epsilon_0 + at^m \tag{3}$$

where $\epsilon(t)$: time-dependent strain, ϵ_0 : instantaneous strain, a and m are material constants can be determined with curve fitting experiment data, and t : elapsed time. The empirical equation above can adequate to describe a secondary stage, nonlinear creep behavior of the viscoelastic material, and easier than using other mode

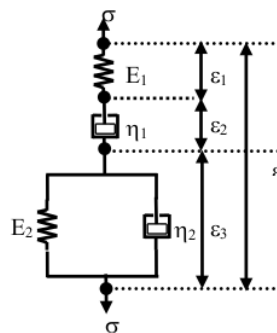


Figure 2. Mechanical element of Burger model (Findley et al., 1976)

2 RESEARCH METHODOLOGY

2.1 Materials

Three to four-year-old *Dendrocalamus asper* bamboo species used in this research for fabrication of glued-laminated bamboo specimens. The bamboo culm was preserved with a 5% borax liquid and then naturally dried until the moisture content (MC) was approximately 12% using conventional drying. Then, the bamboo culm was cut 1.5 m and splitting producing strips with cross section of 20 mm widths and about 10-15 mm thick (according to the thickness of the bamboo culm) and then planned until the final dimension of strips bamboo was 15 mm of width and 5 mm of thickness. The strips of bamboo were laminated together by using Polyvinyl Acetate (PVA) into beams with rectangular cross-section and then a hydraulic jack pressure of 2 MPa was applied for minimum 6 hours.

2.2 Specimens

The specimen of glued-laminated bamboo parallel to the grain of compressive and tensile creep test according to the ASTM D143 as shown in Figure 4.

2.3 Compressive and Tensile Creep Test

Compressive and tensile creep test according to the ASTM D6815. From the short term test average ultimate compressive and tensile strength of glued-laminated bamboo parallel to the grain were 48.67 MPa and 160.68 MPa. Constant load level was applied 30% to ultimate compressive and tensile strength (14.60 MPa and 50.60 MPa). Setting-up can be seen in Figure 5 and 6, deformation of specimen was measured by using dial gauge with an accuracy of 0.001. The instantaneous or elastic deformation was recorded after 1 minute a constant load was applied, then the load was maintained for 90 days. An intensive recording was done every 5 minutes for 60 minutes (1 hour), every 60 minutes (1 hour) until 300 minutes (5 hour), then every day until 90 days.

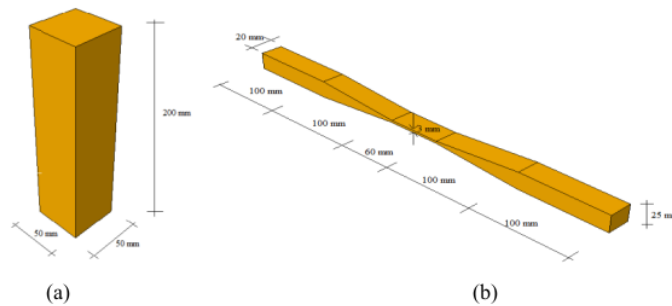


Figure 3. (a) Specimen of compressive creep test (b) Specimen of tensile creep test (ASTM D143, 2002)

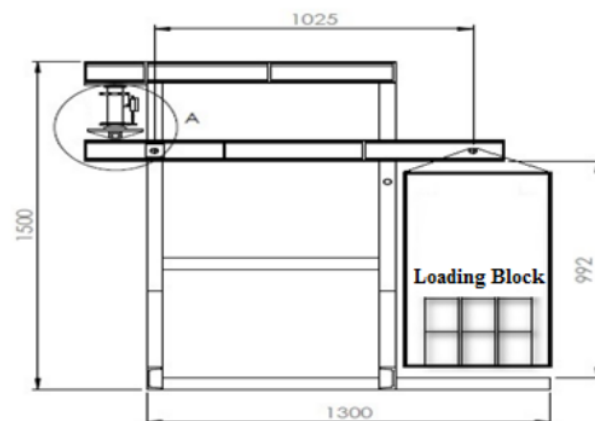


Figure 4. Setting-up of compressive creep test (unit in mm)

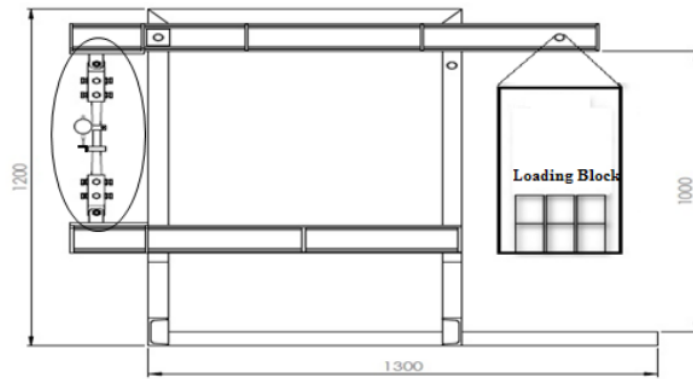


Figure 5. Setting-up of tensile creep test (unit in mm)

3 RESULTS AND DISCUSSION

3.1 Primary and Secondary Compressive and Tensile Creep

In order to explain the primary and secondary behavior of the creep, creep test data was performed in a curve fitting using the Burger mechanical model (combination of Maxwell and Kelvin's model in series). The results of the analysis are presented in Figures 7 and 8. Based on the Figures, it can be seen that the initial/instantaneous/ elastic compressive strain occurred after 1 minute the load applied to the bamboo fiber parallel to the grain $0.0042 \mu\text{s}$, while the initial/instantaneous/elastic tensile strain $0.00305 \mu\text{s}$. Furthermore, the strain continues to increase along the time. It can also be seen from the graph that the primary stage of the compressive creep for 2 days, while the primary of the tensile creep for 29 days, followed by the secondary stage until the 90th day.

3.2 The compressive and tensile creep parameters

The compressive and tensile creep parameters were obtained from the Burger and Power Law model fitting curves of the total strain testing data vs time as shown in Figure 12 for compressive creep and Figure 12 for tensile creep until 90 days. The result of the curve fitting was presented in Table 1 and 2.

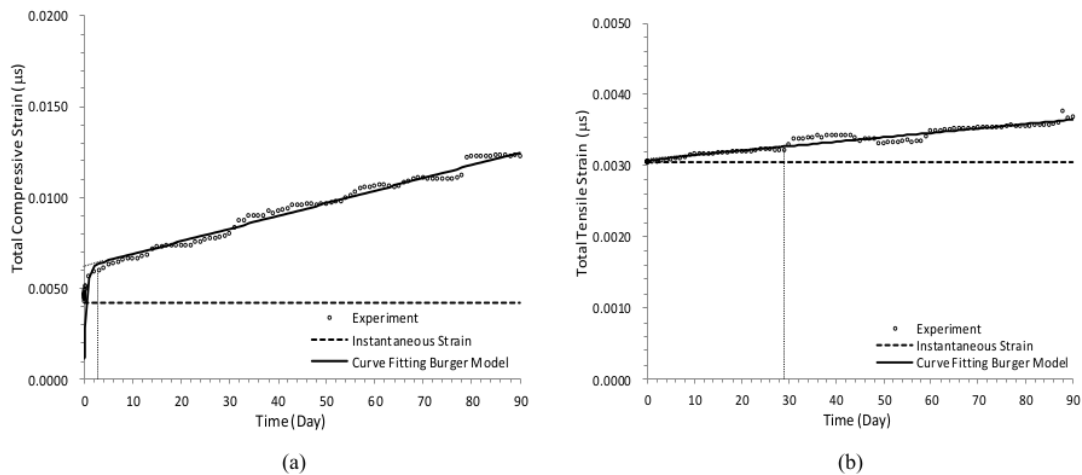


Figure 6 (a) Curve fitting total compressive strain vs time of glued-laminated bamboo ; (b). Curve fitting total tensile strain vs time of glued-laminated bamboo

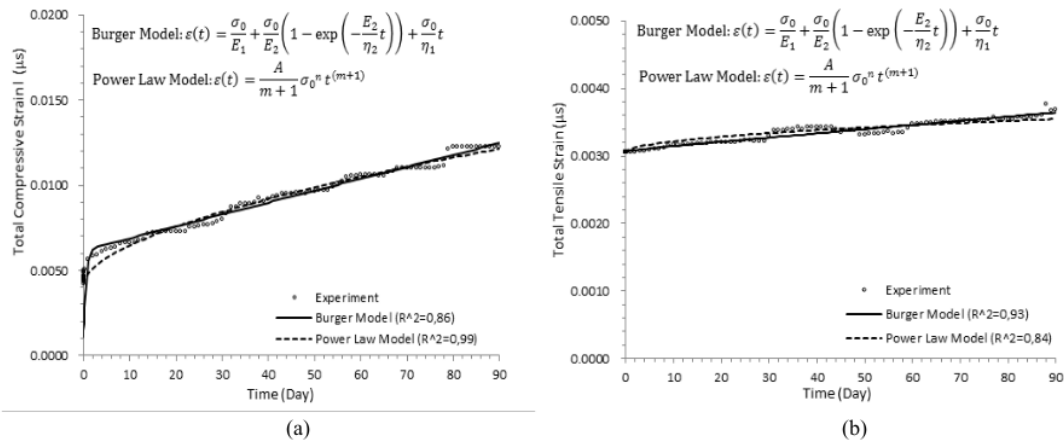


Figure 7. (a). Curve fitting total compressive strain Burger and Power Law model of glued-laminated bamboo; (b). Curve fitting total tensile strain Burger and Power Law model of glued-laminated bamboo

Table 1. Viscoelastic parameters compressive and tensile glued-laminated bamboo from the Burger model

Parameter	Unit	Compressive	Tensile
E ₁	MPa	13248.639	16645.320
E ₂	MPa	2871.510	2430042.743
η ₁	MPa/day	208910.810	8206070.603
η ₂	MPa/day	1435.755	9520005.541

Table 2. Parameters compressive and tensile glued-laminated bamboo from the Power Law model

Parameter	Compressive	Tensile
A	5.88E-05	1.01E-08
n	0.655	2.000
m	-0.423	-0.500

The Burger model has been used successfully to obtain the viscoelastic parameters of glued-laminated bamboo (Table 1). This parameter can be used to validate or predict the creep behavior of a glued-laminated bamboo structure under constant long-term tensile, compressive and flexural loading. The parameter E₁ is Maxwell's modulus of elasticity, which can show elastic deformation behavior and can be used to predict MOE of glued-laminated bamboo. Meanwhile, E₂ is the Kelvin modulus of elasticity (delayed elastic modulus), the parameter E₂ also related to the retardation time creep and shows the slope level of the secondary creep curve. η₁ is Maxwell's dashpot viscosity constant and η₂ is Kelvin's dashpot viscosity constant. These three parameters can explain the viscoelastic behavior or creep of glued-laminated bamboo. From Table 1, it can be seen that the value of E₁ compressive and tensile is 13248,639 MPa and 16645,320 MPa which are close to the MOE from short-term compressive and tensile glued-bamboo lamination test. The value of parameter E₂ from compressive creep is 2871,510 MPa which is smaller than E₁. Meanwhile, the value of parameter E₂ from tensile creep is 2430042,743 MPa which is smaller than E₁.

Likewise, with the Power Law model, it has been successfully used to obtain the glued-laminated bamboo creep parameters (Table 2). Parameter A determines the creep deformation as a whole, while parameter m is related to curve curvature and parameter n explains that the creep rate is affected by the load level. From Table 2 it can be seen that the parameter value of A compressive creep greater than tensile creep, shows that the laminated bamboo compressive creep strain greater than tensile creep. The parameters of m and n compressive creep glued-bamboo laminated is smaller than the tensile creep, this shows that the rate of compressive creep is faster compared to tensile creep.

4 CONCLUSION

Compressive and tensile creep behavior of glued-laminated bamboo was investigated in the creep test room subjected constant loading 30% ultimate strength, the following conclusions could be made from the results and discussions presented above. Burger model was used to fit the creep data and then can be used for predicting primary and secondary creep stage. The primary stage of the compressive creep for 2 days, while the primary of the tensile creep for 29 days followed by the secondary stage until the 90th day, this indicates that glued-laminated bamboo is more vulnerable to compressive creep than tensile creep. The Burger and Power model were successfully for predicting viscoelastic compressive and tensile creep parameters.

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