UNIVERSITAS GADJAH MADA

SIMPOSIUM NASIONAL TEKNOLOGI INFRASTRUKTUR

SERTIFIKAT

diberikan kepada

Ngudiyono
Bambang Suhendro
Ali Awaludin
Andreas Triwiyono

Compressive and Tensile Creep of Glued-Laminated Bamboo

sebagai

PEMAKALAH

SIMPOSIUM NASIONAL TEKNOLOGI INFRASTRUKTUR ABAD KE-21

25 - 26 Januari 2021

Dekan Fakultas Teknik
Universitas Gadjah Mada

Ir. Muhammad Waziz Wildan, M.Sc., Ph.D., IPU.
NIP. 196805121994031003

Lampiran: Histori alur persetujuan

No	Jabatan	Nama	Jenis	Tanggal Disetujui
1	Sekretaris Departemen Teknik Sipil dan Lingkungan	Ir. Ali Awaludin, S.T., M.Eng., Ph.D., IPM.	Paraf	Jumat, 19 Februari 2021 11:19
2	Dekan	Ir. Muhammad Waziz Wildan, M.Sc., Ph.D., IPU.	Tanda Tangan	Jumat, 19 Februari 2021 15:58

Dokumen ini telah melalui proses approval secara daring sebelum QR Code dibubuhkan.
Scan QR Code yang ada di setiap halaman dokumen ini untuk verifikasi.

Prosiding

SIMPOSIUM NASIONAL TEKNOLOGI INFRASTRUKTUR Abad ke-21

Volume 1, Januari 2021

SIMPOSIUM NASIONAL
TEKNOLOGI INFRASTRUKTUR

Inovasi Teknologi Infrastruktur Menuju Masyarakat yang Maju dan Tangguh

25–26 Januari 2021

Departemen Teknik Sipil dan Lingkungan
Fakultas Teknik
Universitas Gadjah Mada

Diselenggarakan oleh:

UNIVERSITAS GADJAH MADA

Bersama dengan:

ITS Institut Teknologi Sepuluh Nopember

Diselenggarakan Oleh
DTSL FT UGM

UNIVERSITAS GADJAH MADA

Bersama

Institut Teknologi Sepuluh Nopember

Institut Teknologi Bandung

Institut Pertanian Bogor

Universitas Diponegoro

Universitas Andalas

Universitas Trisakti

Universitas Hasanuddin

Universitas Bengkulu

Universitas Katolik Parahyangan

Universitas Udayana

Universitas Negeri Padang

Didukung Oleh

Disponsori Oleh

KATA PENGANTAR

Puji dan syukur kehadirat Tuhan Yang Maha Esa atas segala rahmat dan karunia-Nya sehingga Prosiding “Simposium Nasional Teknologi Infrastruktur (SNTI) Abad 21” ini berhasil diterbitkan. Prosiding ini merupakan kumpulan makalah pada Simposium Nasional Teknologi Infrastruktur (SNTI) yang diselenggarakan pada tanggal 25-26 Januari 2021.

Seiring berkembangnya pembangunan infrastruktur Indonesia, tujuan seminar ini adalah sebagai media diskusi juga untuk meningkatkan kontribusi para akademisi dan profesional dalam pengembangan teknologi infrastruktur yang terintegrasi, berdayaguna, dan berwawasan lingkungan. Terdapat banyak sumber bencana yang mengancam berbagai wilayah Indonesia sehingga upaya mitigasi dan pemulihan pasca bencana melalui pengembangan sistem dan infrastruktur adalah hal sensial yang perlu dilakukan dengan didukung pengetahuan teknologi yang holistik dan mudah diterapkan.

“Simposium Nasional Teknologi Infrastruktur (SNTI) Abad 21”, mengajak kalangan untuk berbagi pengetahuan tentang ide, temuan, capaian, dan inovasi teknologi infrastruktur yang bermanfaat untuk mencapai kesejahteraan dan ketahanan bencana masyarakat Indonesia. Dalam hal ini, akademisi, praktisi, dan industri dalam bidang Teknik Sipil dan Lingkungan memiliki peran untuk menyelesaikan permasalahan tersebut.

Terima kasih kami sampaikan kepada semua penulis yang telah menyumbangkan makalahnya dalam prosiding ini. Terima kasih pula kami sampaikan kepada seluruh dosen dan mahasiswa Departemen Teknik Sipil dan Lingkungan, Fakultas Teknik, Universitas Gadjah Mada yang telah terlibat dalam perencanaan dan penyelengaraan seminar serta telah bekerja keras dalam pembuatan prosiding ini, baik dari segi naskah maupun tampilan yang disajikan secara apik. Kami mengucapkan mohon maaf bila terdapat kekeliruan dalam penerbitan prosiding ini. Kami berharap, seminar dan prosiding ini dapat berguna dan memberikan manfaat bagi banyak pihak, baik untuk sekarang maupun waktu yang akan datang.

Yogyakarta, Januari 2021

Ketua Panitia

Angga Fajar Setiawan, S.T., M.Eng., Ph.D.

STRUKTUR KEPANITIAAN

PENANGGUNG JAWAB **:** Prof. Dr. Ir. Joko Sujono, M.Eng.

PENGARAH **:**

1) Ir. Ali Awaludin, S.T., M.Eng., Ph.D.
2) Prof. Ir. Hrc. Priyosulistyo, M.Sc., Ph.D.
3) Prof. Ir. Sigit Priyanto, M.Sc.
4) Dr. Ir. Istiarto, M.Eng.
5) Dr. Ir. Budi Kamulyan, M.Eng.
6) Dr. Ir. Ahmad Rifa'i, M.T.

PANITIA PELAKSANA **:**

Ketua : Angga Fajar Setiawan, S.T., M.Eng., Ph.D.

Sekretaris : Endita Prima Ari Pertiwi, S.T., M.Eng., Ph.D.

Komite Paper :

1) Ashar Saputra, S.T., M.T., Ph.D.
2) Arief Setiawan Budi Nugroho, S.T., M.Eng., Ph.D.
3) Imam Muthohar, S.T., M.Eng., Ph.D.
4) Dr. Inggar Septia Irawati, S.T., M.Eng.
5) Intan Supraba, S.T., M.Sc., Ph.D.
6) Dr. Eng. Muhammad Zudhy Irawan, S.T., M.T.
7) Fikri Faris, S.T., M.Eng., Ph.D.
8) Johan Syafri Mahathir Ahmad, S.T., M.Eng., Ph.D.
9) Dr.Eng. Sito Ismanti, S.T., M.Eng.
10) Karlina, S.T., M.Eng., Ph.D.

Acara :

1) Ni Nepi Nyoman Marleni, S.T., M.Sc., Ph.D.
2) Tantri Nastiti Handayani, S.T., M.Eng., Ph.D.
3) M. Rizka Fahmi Amrozi, S.T., M.Sc., Ph.D.
4) Kartika Nur Rahma Putri, S.T., M.T.
5) Nurul Alvia Istiqomah, S.T., M.Sc.

32) Rina Yuliet, S.T., M.T.
33) Budijanto Widjaja, Ph.D.
34) Dr. Eng. Mia Wimala
35) Helmy Hermawan Tjahjanto, Ph.D.
36) Dr.-Ing. Bobby Minola Ginting
37) Tri Basuki Joewono, Ph.D.
38) Ir. Hera Widyastuti, M.T., Ph.D.
39) Dr. Eng. Januarti Jaya Ekaputri, S.T., M.T.
40) Bambang Piscesa, S.T., M.T., Ph.D.
41) Dr. Yudhi Lastiasih, S.T., M.T.
42) Dr. Techn. Umboro Lasminto, S.T., M.T
43) I Putu Gustave Suryantara Pariartha, S.T., M. Eng., Ph.D.
44) Ir. Teddy Theryo, MSCE, PE
45) Hartanto Wibowo, S.T., M.A.Sc., Ph.D, PE
46) Rijalul Fikri, S.T., M.Sc., Ph.D.
47) Chandra Setyawan, STP., M.Eng., Ph.D.
48) Dr. Faizal Wira Rohmat
49) Neil Andika, S.T., M.Sc.
50) Prayogo Afang Prayitno, S.T., M.Sc.
51) Raihan Pasha Isheka, S.T., M.Sc.

DAFTAR ISI

Compressive and Tensile Creep of Glued-Laminated Bamboo

Ngudiyono[1]*, B. Suhendro[2], A. Awaludin[2], A. Triwiyono[2]
[1]Jurusan Teknik Sipil, Fakultas Teknik, Universitas Mataram, Mataram, INDONESIA
[2]Departemen Teknik Sipil dan Lingkungan, Universitas Gadjah Mada, Yogyakarta, INDONESIA
**Corresponding author*: ngudiyono@unram.ac.id

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.

Keywods: 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 Rangsri, 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).

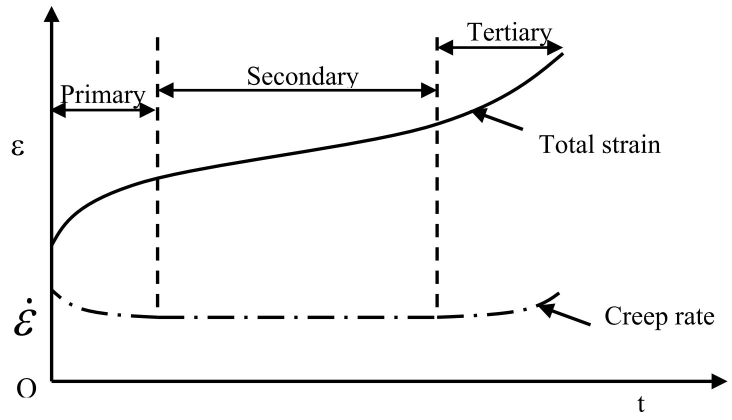


Figure 1. Three creep stage (Findley et al., 1976)

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:

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

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).

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

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).

$$\varepsilon(t) = \varepsilon_0 + at^m \tag{3}$$

where ε(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

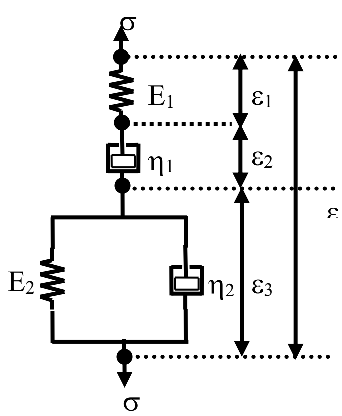


Figure 2. Mechanical element of Burger model (Findley et al., 1976)

2 RESEARCH METHODOLOGY

2.1 Materials

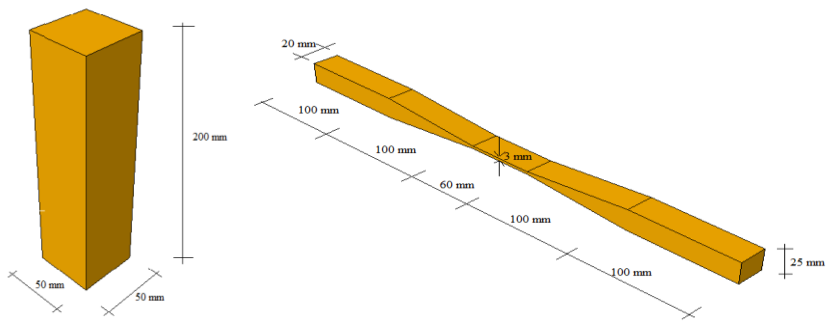
Three to four-year-old Dendrocalamus asper bamboo species used in this research for fabrication of glued-laminated bamboo specimens. The bamboo culm was preserved with a 5% borax liquid and then naturally dried until the moisture content (MC) was approximately 12% using conventional drying. Then, the 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.



(a) (b)

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

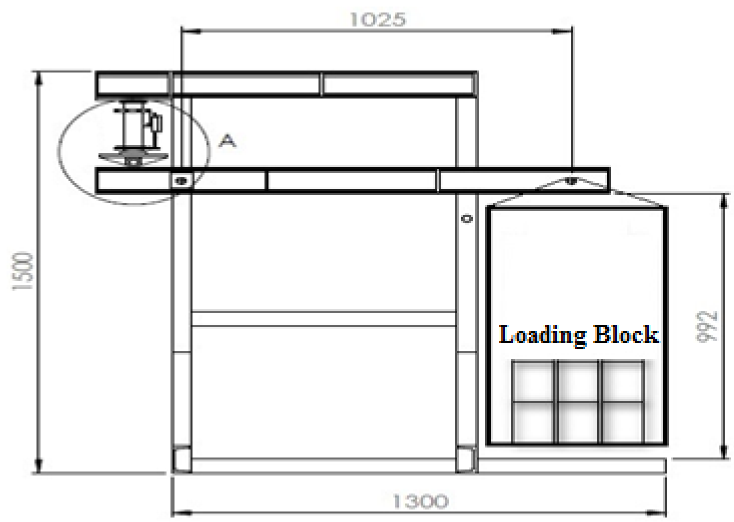


Figure 4. Setting-up of compressive creep test (unit in mm)

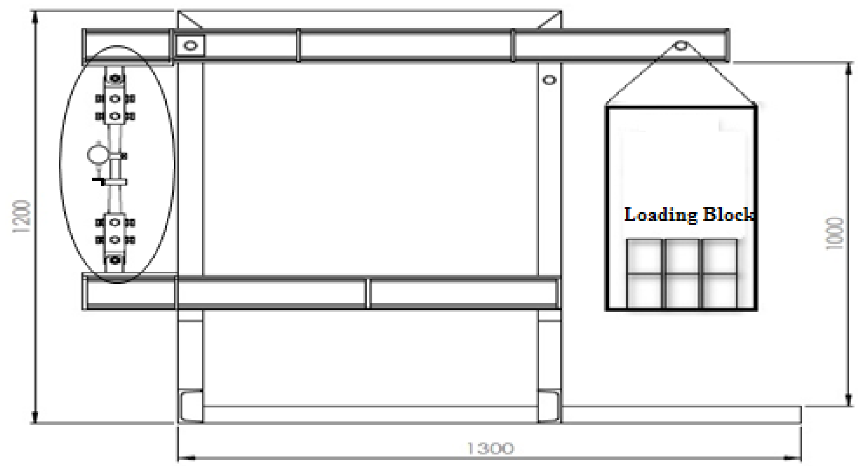


Figure 5. Setting-up of tensile creep test (unit in mm)

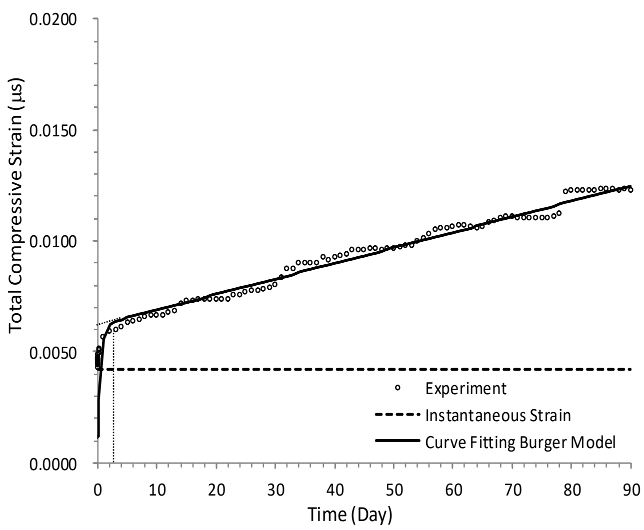
3 RESULTS AND DISCUSSION

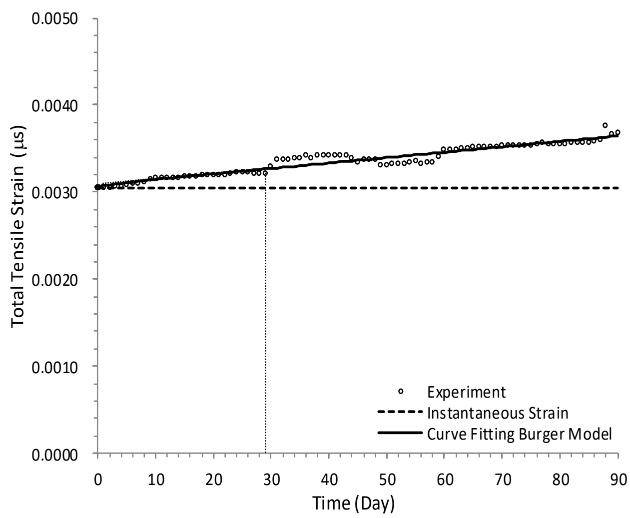
3.1 Primary and Secondary Compressive and Tensile Creep

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 μs, while the initial/instantaneous/elastic tensile strain 0.00305 μs. 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

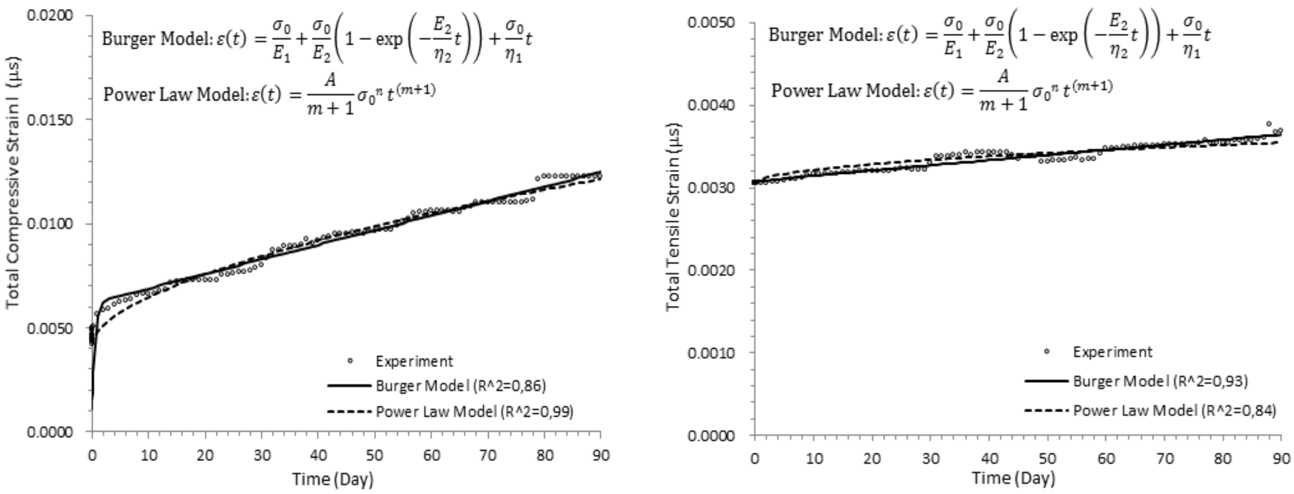
The compressive and tensile creep parameters were obtained from the Burger and Power Law model fitting curves of the total strain testing data vs time as shown in Figure 12 for compressive creep and Figure 12 for tensile creep until 90 days. The result of the curve fitting was presented in Table 1 and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





(a) (b)

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



(a) (b)

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 E_1 is Maxwell's modulus of elasticity, which can show elastic deformation behavior and can be used to predict MOE of glued-laminated bamboo. Meanwhile, E_2 is the Kelvin modulus of elasticity (delayed elastic modulus), the parameter E_2 also related to the retardation time creep and shows the slope level of the secondary creep curve. η_1 is Maxwell's dashpot viscosity constant and η_2 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 E_1 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 E_2 from compressive creep is 2871,510 MPa which is smaller than E_1. Meanwhile, the value of parameter E_2 from tensile creep is 2430042,743 MPa which is smaller than E_1.

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.

ACKNOWLEDGMENTS

The authors would like thank to the Mataram University which has financial supporting for this publication.

REFERENCES

ASTM. (2002). *ASTM D6815 2002 Standart Specification for Evaluation of Duration of Load and Creep Effect of Wood and Wood-Based Product*, ASTM International West Conshojocken, United States.

ASTM. (2002). *ASTM D143 2002 Standard Methods of Testing Small Clear Specimens of Timber*, ASTM International, West Conshojocken, United States.

Dinwoodie, J. M., (2000), *Timber: Its Nature and Behavior*, E & F Spon, London, England.

Findley, M. N., Lai, J. S., and Onaran, K. (1976). *Creep and Relaxation of Nonlinear Viscoelastic Material with Introduction to Linear Viscoelastic*, Dover Publication, Inc., New York, United States.

Gottron, J., Harries, K. A., and Xu, Q. (2014). “Creep Behavior of Bamboo”, *Contruction and Building Material*, 66, pp. 79-88.

Holzer, S. M., Loferski, J. R., and Dillard, D. A. (1989). “A Review of Creep in Wood : Concepts Relevent to Develop Long-Term Behavior Predictions for Wood Structures”, *Wood and Fiber Science*, 21(4), pp. 376-392.

Janssen, J. J. A. (2000). *Designing and Building with Bamboo (Technical Report:Vol 20)*, International Network for Bamboo and Rattan, Beijing, China.

Li, L., and Xiao, Y. (2015). “Creep Behavior of Glubam and CFRP-Enhanced Glubam Beams.” *Journal of Compositers for Contruction*, June 10, 1-11.

Ma, X., Wang, G., Jiang, Z., Xian, Y., and Li, H. (2014). “Comparison of Bending Creep Behavior of Bamboo-Based Composites Manufactured by Two Types of Stacking Sequences.” *BioResources*, 9 (3), 5461-5472.

Ma, X., Jiang, Z., Tong, L., Wang, G., and Jeng, H. (2015). “Development of Creep Models for Glued Laminated Bamboo Using the Time-Temperature Superposition Principle.” *Wood and Fiber Science*, Vol. 47 (2), 1-6.

Ma, X., Liu, X., Jiang, Z., Fei, B., and Wang, G. (2016). “Flexural Creep Behavior of Bamboo Culm (Phyllostachys pubescens) in Its Radial Direction.” *Journal Wood Science*, 62, 487–491.

Ni, L., Zhang, X., Liu, H., Sun, Z., Song, G., Yang, L., and Jiang, Z. (2016). “Manufacture and Mechanical Properties of Glued Bamboo Laminates, Glued Bamboo Lumber.” *BioResources,* 11(2), 4459 – 4471.

Ngudiyono, Suhendro, B., Awaludin, A., and Triwiyono, A. (2019). “Review of Creep Modelling for Predicting of Long-Term Behavior of Glued-Laminated Bamboo Structures.” *MATEC Web Conf. Volume 258, Proc. Of International Conference on Sustainable Civil Engineering Structures and Construction Materials (SCESCM)2018,* Yogyakarta.

Ounjaijom, T., and Rangsri, W., 2016, “Numerical and Experimental Study of the Transverse Creep-Recovery Behavior of Bamboo Culm (Dendracalamus hamiltonii).” *Walailak Journal Science & Technology*, 13(4), 615 – 629.

Sharma, B., Gatoo, A., Bock, M., and Ramage, M. (2015). “Engineered Bamboo for Structural Applications.” *Construction and Building Material*, 81, 66-73.

Xiao, Y., Li, L., and Yang, R. Z. (2014). “Long-Term Loading Behavior of a Full-Scale Glubam Bridge Model.” *Journal of Bridge Engineering*, 19(9).