



Effects of Compression Creep Deformation on the Microstructure of *Terminalia Ivorensis* (Black Afara) Timber

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ABSTRACT

The effects of compression creep on *Terminalia ivorensis* timber was presented in this paper. One-year creep test was performed in the laboratory on *Terminalia ivorensis* timber samples. The creep data were fitted to linear, exponential and logarithmic regression models. The coefficients of determination for each of the model was determined. The coefficients of determination of the linear, exponential and logarithmic models were determined as 0.689, 0.650 and 0.941 respectively. Since the logarithmic model has the highest correlation with coefficient of determination of 0.941, it gave the best compression creep prediction model for the *Terminalia ivorensis* timber. Microstructure analysis was conducted on the *Terminalia ivorensis* timber specie using scanning electron microscope on the specimen. The analysis was conducted before and after creep deformation. The microstructure analysis revealed that, the cellular structure which contained empty vessels was found to have closed after creep deformation. This implied that, the application of the long-term loading lead to the closure of the empty vessels within the cell's microstructure, leading to the densification of the timber.

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INTRODUCTION

The term timber is frequently used to refer to wood that is suitable for building or structural usage. It is one of the most frequently used building materials in both ancient and modern engineering constructions. Recently, the use of timber structures has increased in the construction industry due to attributed advantages such as environmentally friendly nature of timber, fully renewable potential and low handling costs (Hassani *et al.*, 2014). Timber is widely available natural resources throughout the world, which with properly managed wood plantation, there is potential for continuous and sustainable supply of raw timber materials.

In addition, timber exhibits unique material properties; it is a light weight material and, compared to its weight, the strength is high; the strength/weight ratio is even higher than for steel that is why it is used widely as a structural material for roofing system and pedestrian or bicycle bridges. Also, it has low modulus of elasticity compared to concrete and steel (Shuaibu, 2010), this implies low stiffness capacity and consequent poor resistance to deflection in service.

The above-mentioned attributes among others, gave rise to the acceptance of timber worldwide as building material that can compete stiffly with the conventional/popular concrete and steel in



the arena of the building industry with considerable advantages of low embodied energy, low carbon impact, and sustainability.

Unfortunately, time-dependent deformation affects the strength and stiffness of timber in service. The time-dependent behaviours of wood has been widely investigated, and the following measures of time-dependent response are commonly used in experimental investigation: creep, the increase of the deformation with time, under a sustained applied load; relaxation, the stress decay under constant deformation; stiffness variation in dynamic mechanical analysis (Ferry, 1980); and rate of loading (or straining) effects (Boyd and Jayne, 1982).

The creep process lead to a time-dependent increase of deformation of structural elements that can cause inadmissible deformation and even lead to collapse of an entire construction. Lots of rheological models have been designed by various researchers (Bodig, 1993; Toratti, 1992; Hanhijarvi, 2000; Martensson, 1992; Dubois *et al.*, 2005; Chassagne *et al.*, 2006; Dinwoodie *et al.*, 1990; Pierce *et al.*, 1985) during the last decades with the aim of describing and simulating the time dependent behaviour of a natural viscoelastic material-wood. However, the mathematical models derived contain a great variety of constants to be determined by large sample tests. In this paper, simple compression creep prediction model for timber was developed considering Nigerian grown *Terminalia ivorensis* timber specie. The creep model was determined from one-year compression creep test data for *Terminalia ivorensis* timber using linear, exponential and logarithmic regression analyses in order to find out the effect of creep on microstructure.

LITERATURE REVIEW

Mathematical Models for Creep in Wood

Several investigators have been concerned with the development of models to simulate creep behaviour in wood: Leicester (1971) devised rheological models that include "mechano-sorptive elements" to fit experimental data. Schaffer (1972) introduced a model to explain the change of creep response with changing moisture content by considering the effect of diffusion of moisture within the loaded specimen. Ranta- Maunus (1975) expressed the creep strain arising from variations in moisture content in integral (hereditary) form on the basis of hydro-viscoelasticity theory. The model was applied to published experimental results. Bazant (1985) proposed a speculative model of the effects of variations in moisture content and temperature on creep based on thermodynamics of the process of diffusion of water in wood. Mukudai and Yata (1986) proposed a model for viscoelastic behavior of wood under moisture change. Good agreement was observed between the model responses and published experimental results. Schaffer (1982) was also concerned with the design of structural timber members to sustain loading during fire exposure. He developed a nonlinear (in stress) viscoelastic-plastic model based on thermodynamic constitutive theory (Schapery 1966). The model was correlated with experimental creep data, and Schaffer concluded that the resultant qualitative model sufficiently characterizes the viscoelastic- plastic response of dry wood parallel to the grain. Viscoelastic behavior of wood in changing environments was considered by Tang (1980).

Microstructure of Wood

Wood cell contains three polymers: cellulose, hemicellulose, and lignin. Cellulose, the primary constituent, is arranged in microfibrils. Lignin and



hemicellulose serve as the matrix to bind the fibrils together. Although the polymer composite is complex, it obeys general polymer physics principles. Thus, it is anticipated that to a certain extent, concepts such as time-temperature superposition will be applicable, if only in a thermo-rheologically complex sense. Although one can conduct phenomenological rheology studies to curve fit rather arbitrary mathematical models to experimental data, the insights gained into long-term prediction capabilities and justification cannot be as great as could be derived from a molecular rheology approach (Pentoney and Davidson 1962). The unique cellular microstructure of wood suggests reasons for observed behavior. For example, the creep of wood in shear is less than the creep perpendicular to the grain (Schniewind and Barrett 1972). This is exactly opposite the measured behavior in man-made fiber reinforced plastics, but it can be explained by the cellular honeycomb-like microstructure of wood. An understanding of the microstructure and its variability can provide valuable insight into wood behavior. Microstructural analysis of sample is usually obtained using scanning electron microscope. A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the sample's surface topography and composition.

MATERIALS AND METHODS

Materials

The material used in this study is *Terminalia ivorensis* (Black afara) timber, obtained from the Sabon Gari Zaria timber market (Zaria timber sheds). This specie was chosen to reflect the current trends in wood usage of timber in Nigeria. *Terminalia ivorensis* is used extensively as timber for many structural applications especially for roof truss fabrication. The *Terminalia ivorensis* timber specimen were prepared for the creep tests after conditioning to $(20 \pm 2) ^\circ\text{C}$ and $(65 \pm 5) \%$ relative humidity, prior to testing.

Methods

Creep Test

All materials undergo deformation when subjected to loading. The deformation is a gradual process under constant load and accumulates with time into a large deformation (creep). In this study, the DIN 50119 (1978), a German code of practice that deals with creep is used to measure the time-dependent deformation of *Terminalia ivorensis* timber in compression. A machine called the TONI.MFL PRUFSYSTEME creep testing machine in the heavy duty laboratory of the Department of Civil Engineering, Ahmadu Bello University, Zaria, was used for the experimental work. It keeps the sample under constant stress by a nitrogen tank of 96 bars (960kN) maximum test force. The samples are placed in between top plate and base plate mounted on spring with oil pot as seen in the plate. The magnitude of the load applied on the sample is one-third the specimen compressive strength as specified by the code. The setup of the creep test machine is shown in Plate 1.0.



Plate 1.0: Set-up of Creep Testing Machine

Microstructure Analysis

In the microstructure of the *Terminalia ivorensis*, four specimens were prepared. Two specimens were tested before creep and two after creep. The size of each specimens is 2mm x 2mm. Scanning Electron Microscope with model number MVE 016477830 was used to carry out the Scanning Electron Microscopy (SEM) in Department of Chemical Engineering, Ahmadu Bello University, Zaria. For each test, a piece of the timber specimen is placed on a sample stub. A carbon double adhesive was placed on the sample stub and then charged into the sputter coater. A five nanometer of gold was deposited on the sample to make it conductive. A sample holder was used to hold the sample and introduced into the column of SEM machine,

where it was viewed with a navigation camera for proper focusing, brightness and contrasting. This was then transferred into SEM mode where different magnifications saved via a USB stick.

RESULTS AND DISCUSSIONS

Compression Creep Prediction Models

Regression analysis was performed on the one-year creep deformation data, using Microsoft Excel. Linear regression, exponential regression model as well as logarithmic regression analysis were performed on the creep data for the *Terminalia ivorensis* timber, with the compression creep as the dependent variable and the loading time as the independent variable. The creep deformation plot is presented in Figure 1.0.

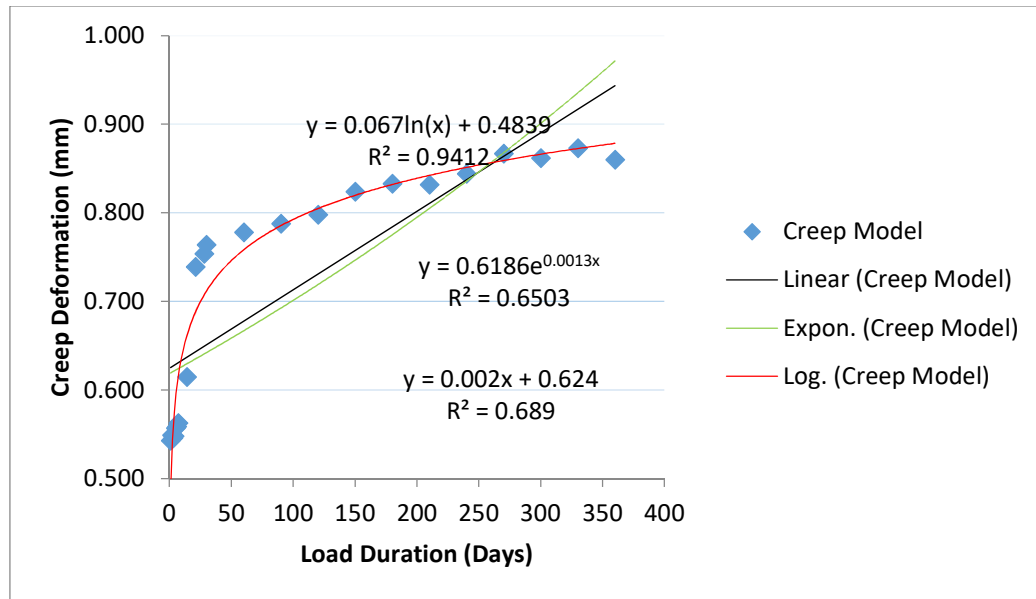


Figure 1.0: Regression analysis for the compression creep of *Terminalia ivorensis*

As observed from the plot, the coefficients of determination are 0.689, 0.650 and 0.941 respectively for the linear, exponential and logarithmic models. The

$$u_{creep} = 0.002(t) + 1.031 \quad R^2 = 0.689 \quad (1.0)$$

$$u_{creep} = 1.006 e^{0.001t} \quad R^2 = 0.650 \quad (2.0)$$

$$u_{creep} = 0.170 \ln(t) + 0.670 \quad R^2 = 0.941 \quad (3.0)$$

Where u_{creep} is the creep deformation in mm and t is the sustained loading time in days.

The logarithmic prediction model has coefficient of determination of 0.941, followed by that of the linear model with coefficient of determination of 0.689. The exponential prediction model has the least coefficient of determination of 0.650. This indicates that the logarithmic model has the highest level of acceptability with strong correlation between the creep deformation and the time of sustained loading.

developed linear, exponential and logarithmic creep deformation prediction models are given by equation 1.0, 2.0 and 3.0 respectively.

Microstructure of *Terminalia ivorensis* Timber

Plates 3 to 5 show the longitudinal sections of *Terminalia ivorensis* cell before and after compression creep at 1000 x and 1500 x magnifications, obtained from scanning electron microscopy (SEM). Plates 2 and 4, show the Microstructure of the test specimens at 1000 x and 1500 x magnification, before creep deformation. The green arrows indicate open vessel cells and the red arrow points to parenchyma cells (darker areas that surround vessels). Blue arrow points to fiber cells (lighter areas).

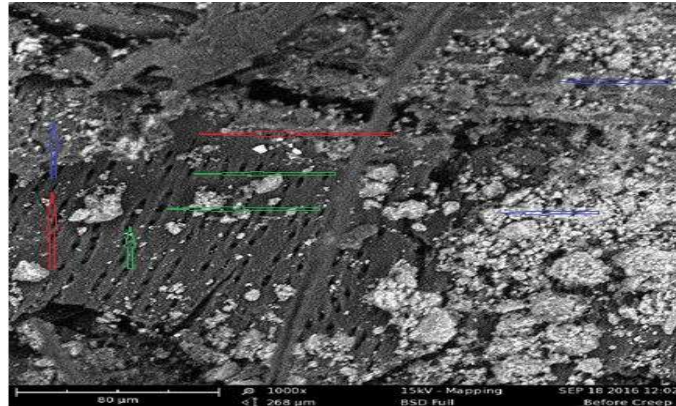


Plate 2: Microstructure of the longitudinal section of *Terminalia ivorensis* timber before creep (1000x magnification)

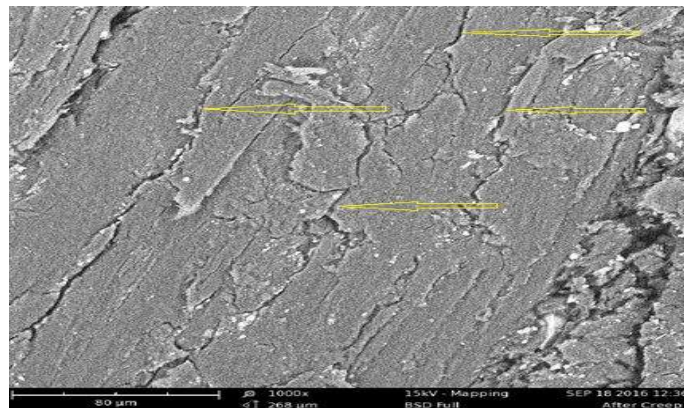


Plate 3: Microstructure of the longitudinal section of *Terminalia ivorensis* timber after creep (1000x magnification)

However, observing the Microstructure of the deformed specimens subjected to compression creep Plates 3 and 5 corresponding to 1000x and 1500x magnifications respectively, there is no visible vessel cells in the section; they are all closed. The yellow arrows in the images indicate more compact cellular structure of

the wood fiber. This could be attributed to the densification (closure) of the timber due closure of the empty cells during compressive loading. During densification, the cellular structure of wood is permanently packed together.

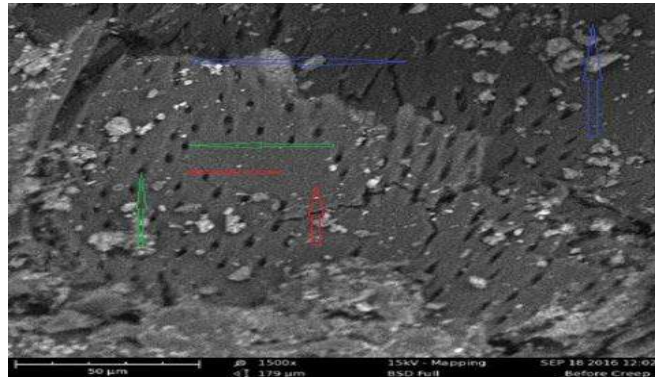


Plate 4: Microstructure of the longitudinal section of *Terminalia ivorensis* timber before creep (1500x magnification).

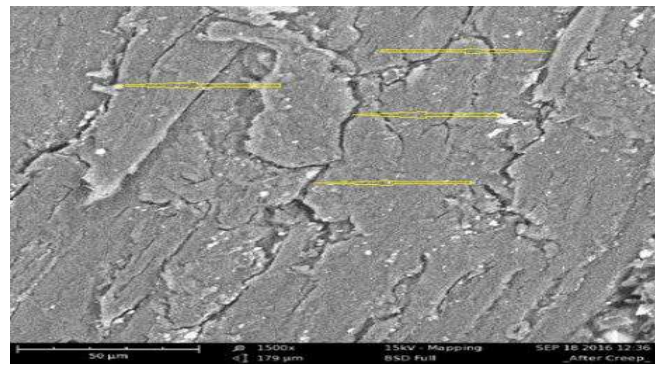


Plate 5: Microstructure of the longitudinal section of *Terminalia ivorensis* timber after creep (1500x magnification).

In addition, the densification observed from the microscopic analysis could be explained with reference to what is presented in the literature as follows: When compressed transversely, a honeycomb pattern of wood will first deform elastically. Following the elastic deformation, cell walls will begin to buckle, causing cell layers to cave in on themselves. When cells collapse, the inner walls will come in self-contact, causing an increase in stiffness. The load-displacement curve will then begin linearly, followed by a strain-hardening region where strain increases with little increase in stress (caused by cell wall buckling). After the strain-hardening, a further increase in stiffness can sometimes be noticed, which is

caused by self-contact in the cells (Kettunen, 2009).

CONCLUSION

In this study, the compression creep model and microstructures of *Terminalia ivorensis* (Black Afara) timber was presented. Based on the results obtained from the compression creep deformation tests. From fitting of the compression creep data to linear, exponential and logarithmic regression models. The coefficients of determination for each of the model was determined. The logarithmic model showed the highest correlation between the creep deformation and load duration. The coefficient of determination (R^2) was measured as 0.941 (94%). This implied that,



logarithmic regression model is the most appropriate. The time-dependent creep deformation model developed in this study is recommended for use in determining compression creep deformation at any age of timber life of timber compression members.

From microstructure analysis conducted before and after compression creep deformation, the results of the analysis revealed that, the cellular structure contains voids which were found to have closed after creep deformation. This implied that, the application of the long-term loading lead to the closure of the voids within the cells microstructure, leading to the densification of the timber.

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