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COMPRESSION CREEP MODEL FOR NIGERIA GROWN *TERMINALIA IVORENSIS* (BLACK AFARA) TIMBER

A. I. Mohammed[1,*], A. Ocholi[2], S. P. Ejeh[3] and Y. D. Amartey[4]
[1,] JULIUS BERGER NIGERIA PLC, 10 SHETTINA MUNGUNO CRESCENT, UTAKO, ABUJA FCT, NIGERIA
[2, 3, 4,] DEPARTMENT OF CIVIL ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA, KADUNA STATE NIGERIA
E-mail addresses: [1] *ismaila.amodu@julius-berger.com*, [2] *amanaocholi@yahoo.com*
[3] *engrdrspejeh@yahoo.com*, [4] *dadaamartey@yahoo.co.uk*

ABSTRACT
Mathematical model of compression creep for Terminalia ivorensis (Black Afara) timber were developed and presented in this paper. One-year creep test was performed in this process 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.

Keywords: *Black Afara timber, Compression Creep, Creep prediction model, Terminalia ivorensis, Load duration*

1. INTRODUCTION

The term timber is frequently used to refer to wood that is suitable for building or structural use. 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 [1]. Timber is a widely available natural resources throughout the world, which with properly managed wood plantations, 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 in some cases that is why it is widely used as a structural material for roofing systems and pedestrian or bicycle bridges. Also, it has low modulus of elasticity compared to concrete and steel [2]; 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 [3]; and rate of loading (or straining) effects [4].

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 structure. Lots of rheological models have been designed by various researchers [5-13] during the last decades with the aim of describing and simulating the time dependent behaviour of a natural viscoelastic material-wood. However, the

*** Corresponding author, tel: +234 – 803 – 313 – 9280**

mathematical models derived contain a great variety of constants to be determined by large sample tests.

The aim of this paper is the determination of compression creep model for Nigeria grown *Terminalia ivorensis* timber specie. The overall objective is to use both linear and nonlinear regression analysis to determine the appropriate mathematical model for compression creep for the *Terminalia ivorenses* timber.

2. MATHEMATICAL MODELS FOR CREEP IN WOOD

Several investigators have been concerned with the development of models to simulate creep behaviour in wood. Rheological models that include "mechano-sorptive elements" were devised to fit experimental data [14]. 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 was introduced by [15]. The creep strain arising from variations in moisture content in integral (hereditary) form on the basis of hydro-visco-elasticity theory was investigated in [16]. The model was applied to published experimental results. Benzant [17] 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 [18] proposed a model for visco-elastic behaviour of wood under moisture change. Good agreement was observed between the model responses and published experimental results. Schaffer [19] was also concerned with the design of structural timber members to sustain loading during fire exposure. He developed a nonlinear (in stress) visco-elastic-plastic model based on thermodynamic constitutive theory [20]. The model was correlated with experimental creep data, and [19] concluded that the resultant qualitative model sufficiently characterizes the visco-elastic- plastic response of dry wood parallel to the grain. Visco-elastic behaviour of wood in changing environments was considered by [21]. Other notable work on creep behaviour of wood include [22], However, the compression creep model for Nigerian timbers has not been investigated and for compliance with the current European code formulations, thus, the essence of it herein.

3. MATERIALS AND METHODS

3.1 Materials

The material used in this study is *Terminalia ivorensis* (Black afara) timber. This specie was chosen 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 ivoresnsis* timber specimens were prepared according to [23], for the creep tests after conditioning to (20±2) ^{0}C and (65±5) % relative humidity, prior to testing.

3.2 Methods

Three specimen each of size 150mm x 150mm x 145mm were prepared for the creep testing. The first specimen (specimen A) was obtain from the bottom of the Termilia ivorensis timber log under investigation, the second specimen (specimen B) was obtained from the middle of the log, while the third specimen (specimen C) was obtained from the top section of the log. Each of the three specimen were subjected to moisture content test prior to the creep testing and mean moisture content of 17.93%, 16.35% sand 17.42% were determined for the specimen A, specimen B and specimen C respectively. Changes in moisture contents were observed for each sample after the one year creep test. The final moisture contents were 15.3%, 15.8% and 16.10% for specimen A, specimen B and specimen C respectively. To measure the creep deformation, dial gauges were mounted on both sides of the sensitive spring of the equipment which is always in constant touch with the specimen flat surfaces at ninety degrees.

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 [23], 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.

Plate 1: Set-up of Creep Testing Machine with Specimen Under Loading

4. RESULTS AND DISCUSSIONS

4.1 The Compression Creep Plots

The creep deformation data was plotted against time for each of the three samples as presented in Figures 1, 2 and 3 for samples A, B and C respectively. It is clear from the plot that, Sample A displayed larger creep than Samples B and C, and Sample C has the least creep deformation at all ages considered. The variability in the creep for the three samples is expected because of the large variability in material properties of timber, due to growth and seasoning.

The results presented in Figures 1, 2 and 3 clearly depicted the nature of the generalized creep laws of materials presented in the literature [24]. As observed from the relationship, the first characteristics of the creep time is the primary creep: which starts at a rapid rate. It is clear that between 0 to about 30 days load duration, the *Terminalia ivorensis* passes through the primary stage of creep. Beyond 30 days, the creep rate slows with time. This is the secondary creep: it has a relatively uniform rate. The test conducted on the *Terminalia ivorensis* lasted for one year (that is, 360 days). After the secondary creep, the tertiary Creep sets in and continues. This has an accelerated creep rate and terminated when the material break or ruptured.

4.2 Development of the Compression Creep 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 relationships are presented in Figure 4.

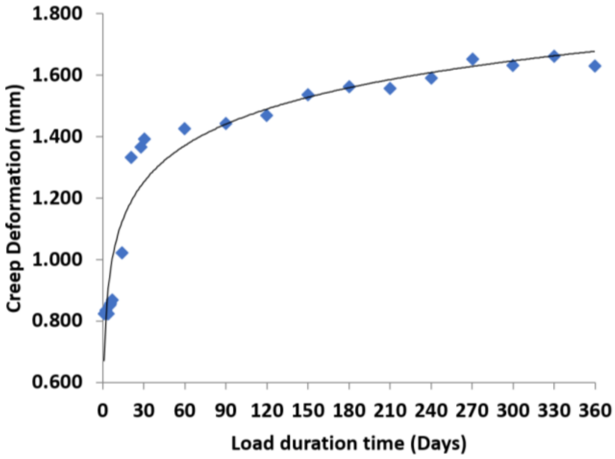

Figure 1: Relationship of Creep deformation to Load Duration Time for Sample A.

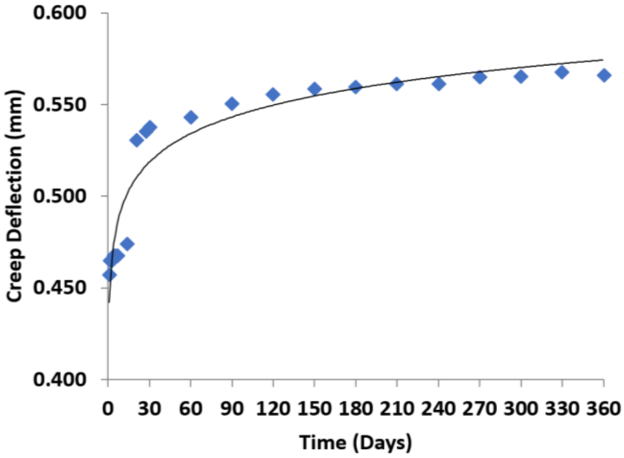

Figure 2: Relationship of Creep deformation to Load Duration Time for Sample B.

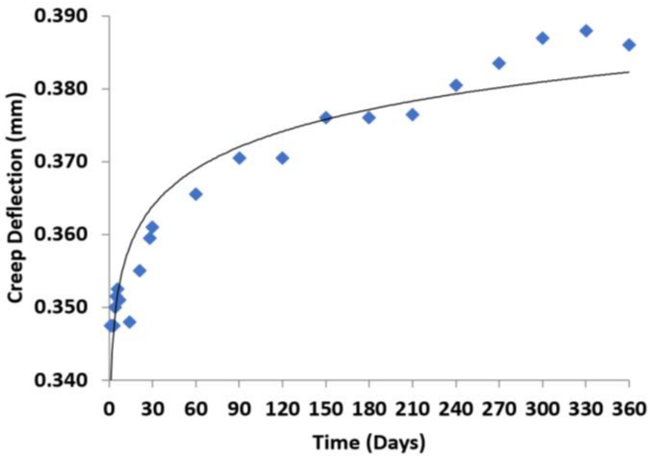

Figure 2: Relationship of Creep deformation to Load Duration Time for Sample C.

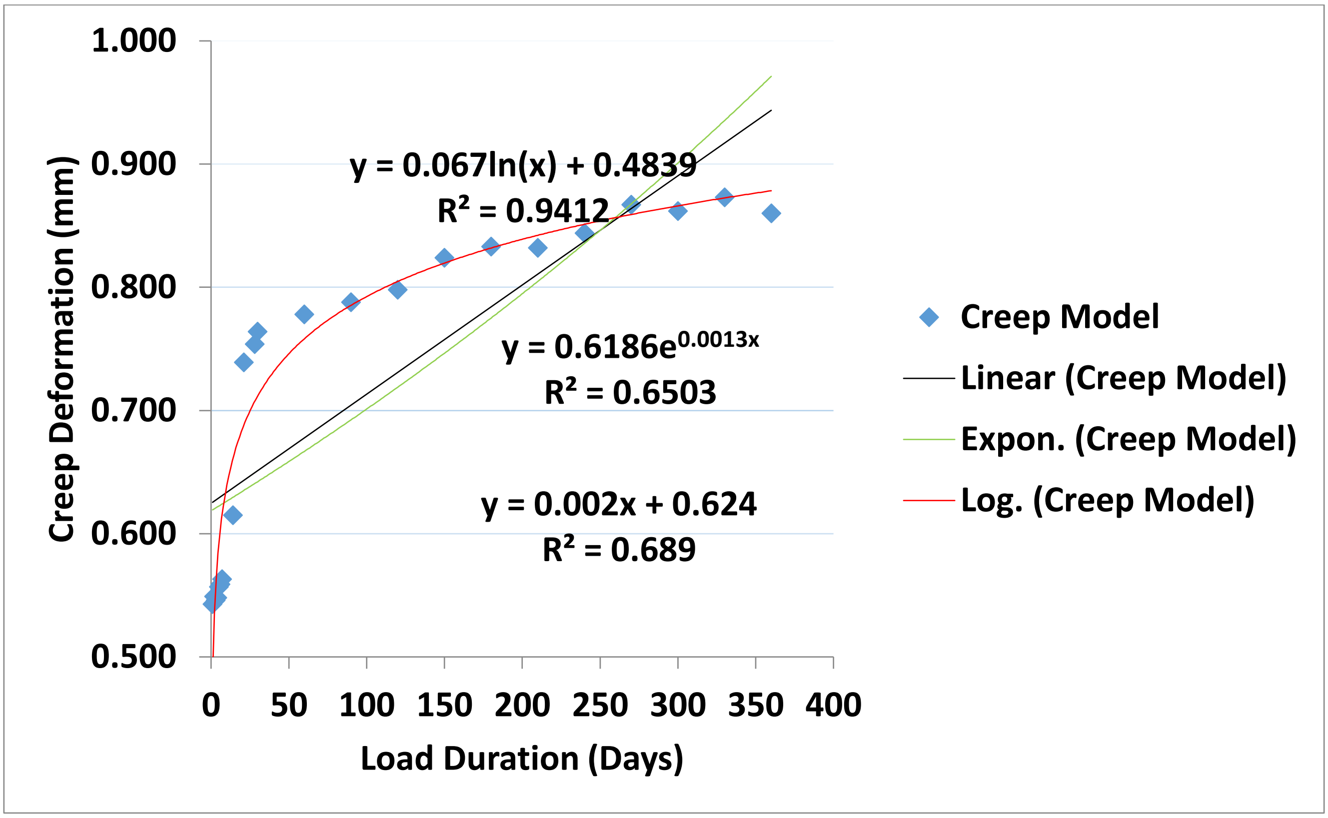

Figure 4: Regression analysis for the compression creep of Terminalia ivorensis

As observed from Figure 4, the coefficients of determination are 0.689, 0.650 and 0.941 respectively for the linear, exponential and logarithmic models. The developed linear, exponential and logarithmic creep deformation prediction models are given by equations (1), (2) and (3) respectively at the bottom of this page.

The developed creep prediction models (Equation (1), (2) and (3)) were used to predict the deformation of the timber specie (*Terminalia ivorensis*) for a one-year period. The predicted creep deformation based on the regression models were compared with the actual creep obtained from the laboratory as shown in Figure 5.0. 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. Thus, the model of $u_{creep} = 0.170\ln(t) + 0.670$ is chosen.

$u_{creep} = 0.002(t) + 1.031$	$R^2 = 0.689$	Linear	(1)
$u_{creep} = 1.006e^{0.001t}$	$R^2 = 0.650$	Exponential	(2)
$u_{creep} = 0.170\ln(t) + 0.670$	$R^2 = 0.941$	Logarithmic	(3)

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

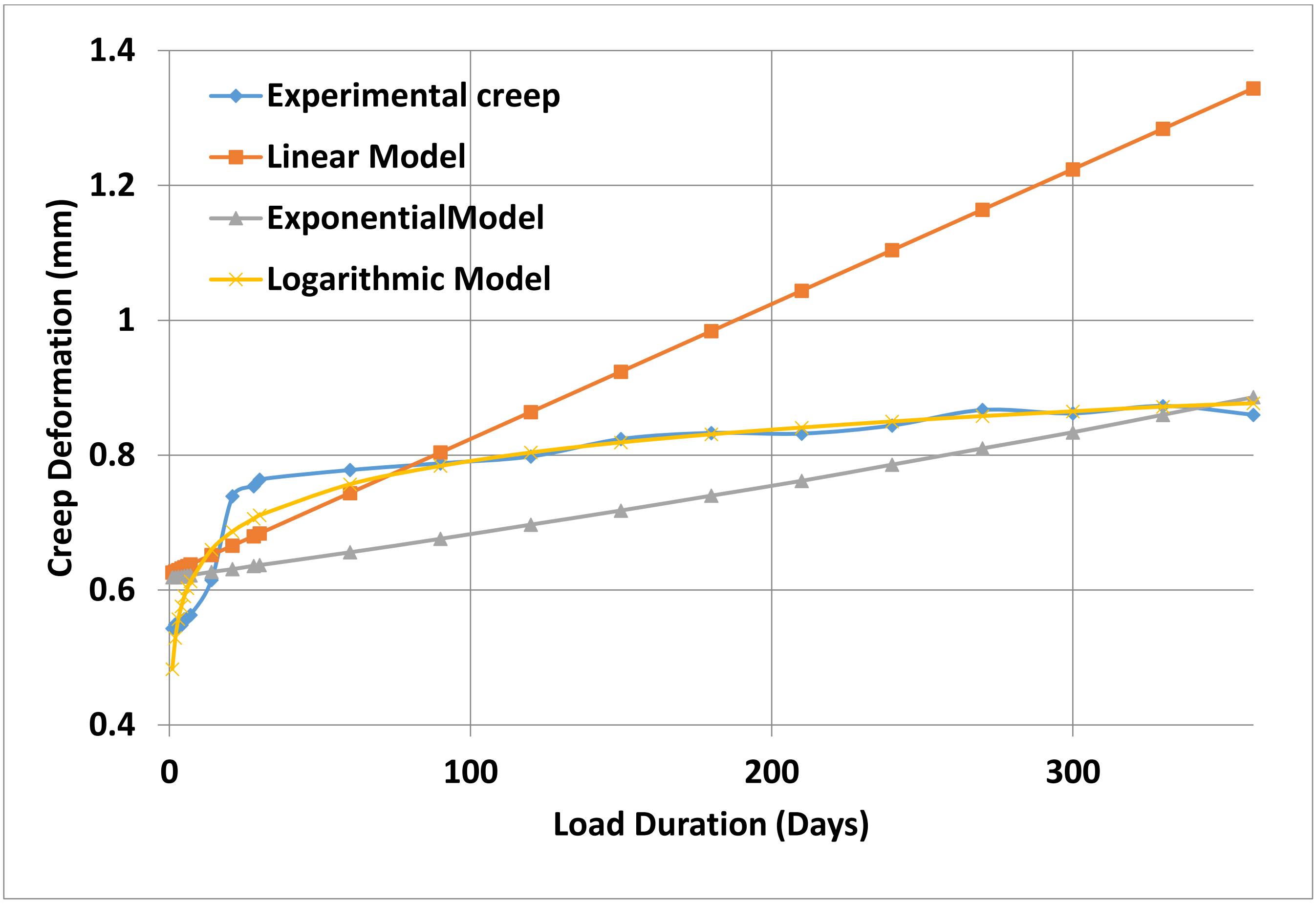

Figure 5: Comparison of predicted and average observed creep

5. CONCLUSION

In this study, the creep behaviour 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 implies that, the logarithmic regression model is the most appropriate. The time-dependent creep deformation model developed in this study is suggested for use in determining compression creep deformation at any age of timber life of timber compression members in Nigeria.

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