

The usability of Burger body model on determination of oriented strand boards' creep behavior

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Abstract

In this work, the usability of the Burger body model (BBM) for determining the behavior of oriented strand boards (OSBs) under long-term loads was evaluated. The actual bending strain data and predicted strain data as a function of different stress levels and load durations under constant environmental conditions ($25 \pm 2^\circ\text{C}$ and 50% relative humidity) were compared. Two test groups, short-term bending tests and long-term creep-rupture bending tests, were performed according to relevant ASTM standards. Specimens were randomly assigned to three groups and loaded at 47% (132.2 kg), 51% (137.4 kg), or 55% (154.9 kg) of the mean static short-term flexural strength. Specimen creep was monitored for 10,000 h using an automated measurement system. The four-parameter BBM parameters were obtained for all specimens at 2000-h time intervals, providing five different estimates. Measured strain values were compared with strain predictions from the BBM and with the goal of evaluating length of experiment on prediction accuracy. Each stress level provided statistical differences based on the error between the actual strain and predicted strain values. Group 3 provided minimum error compared to group 1 and group 2. The 10,000 and 8000 h loading provided the most accurate predictions compared to 6000, 4000, and 2000 h of data. Overall, the longer the actual data is collected the more accurate predictions were obtained. As a result, the BBM was found useful tool for predicting the creep behavior of OSBs under different loads and load durations. It was also shown that the increased duration of practical loading minimizes the error between the prediction. Therefore, the BBM is suggested for use predicting the creep behavior of OSBs over 8000 h load durations.

Keywords

oriented strand board, burger body model, creep behavior, wood composite panels, flexural properties

Introduction

Oriented strand board (OSB) is a panel made of strands bonded together with water-resistant resins, usually phenol formaldehyde or isocyanate, using heat and pressure. Panels are made of crossing layers, usually the outer layers consist of longitudinally oriented strands, in line with the panel length, whereas in the middle layers, strands generally lie in a crosswise direction. With this manufacturing technique, defects, splits, grain discontinuities, knots, and similar imperfections spread out and large defects are minimized¹ The typical vertical density gradient through the material thickness results in faces having higher densities than the core. OSB has comparable mechanical properties to softwood plywood, similar modulus of elasticity (MOE), and modulus of rupture (MOR) in parallel to grain

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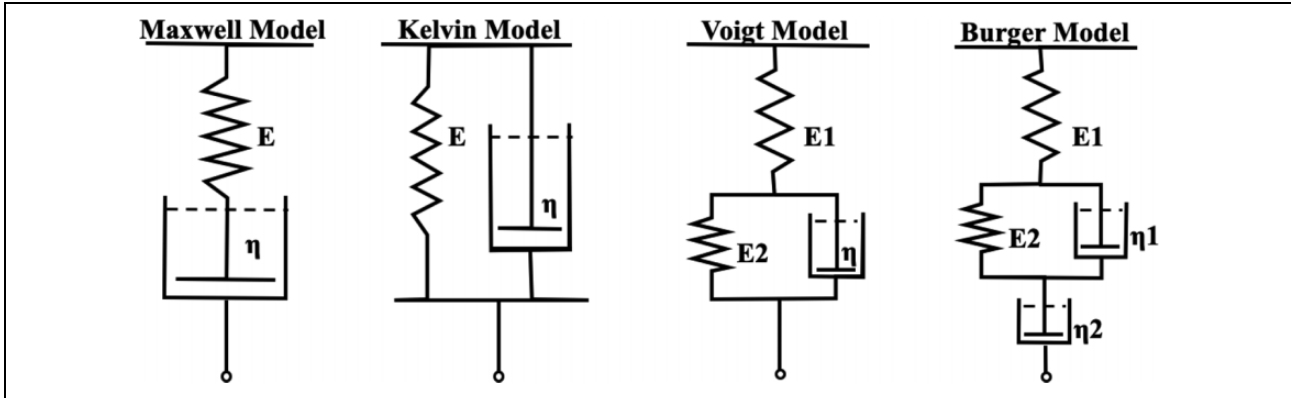


Figure 1. The well-known linear prediction models: (a) Maxwell model, (b) Kelvin model, (c) Voigt model, and (d) Burger model.

direction, therefore, their performance is similar to the structural plywood performance. As a lower-cost material, OSB commonly replaces plywood in construction applications. OSB is suitable for load-bearing applications in construction and is commonly used in sheathing, roofing, and flooring.² Design guidelines for load duration impacts incorporate impacts up to a 100-year duration. Therefore, understanding the mechanical behavior of OSB under long-term loads is important. Current standards in the United States for certifying long-term performance wood-based materials involve a 90-day pass/fail procedure (ASTM D6815-09) and is based on the proven experience of successful use of solid wood in structural applications. The viscoelastic character of wood-based composite materials is impacted by that behavior of wood itself, the adhesive (typically thermoset). The response can be nonlinear with respect to stress level and can exhibit mechanosorptive creep due to moisture variations.^{3,4}

The most accurate evaluation would be an actual (practical) testing, which can take up to 100 years. Instead of testing materials for long time frames, different prediction models—Maxwell, Kelvin, Voigt, and Burger—were governed by the researchers,⁵ as shown in Figure 1.

As shown in Figure 1, the E represents the spring constants, the elasticity deformation, which is instantaneously and completely recoverable. The η represents the dashpot constant, which represents viscous flow (permanent deformation), deformation which increases over time under stress but is not recoverable. The spring ($E2$) and dashpot ($\eta2$) constants associated with the delayed elastic deformation, which is completely recoverable but happens so over time.

Under long-term loads, the dashpot strain will change linearly in the Maxwell model. With the increase in the duration of load, the spring strain contributes less. The second model that includes one spring and one dashpot located parallel is named Kelvin model.^{6,7} The three element model named Voigt. The Burger body model (BBM) also known as four-element linear viscoelastic model is one of the well-known prediction models for long-term test

predictions.^{8,9} The OSBs are wood-based panels that are very sensitive to the humidity due to their nature. Also, the previous studies showed that the creep behavior of wood products like OSBs is very sensitive to relative humidity.¹⁰ The BBM is the most effective model that included the environmental effects (relative humidity, temperature, etc.) in the calculations through the predictions. Even if the environmental conditions were constant in this study, researchers preferred to use the BBM to minimize the errors that could be created due to environmental condition changes.

In this effort, the usability of the BBM for determining the creep behavior of OSBs under different loads and load durations was investigated. The practical tests were applied for up to 10,000 h (417 days). The BBM was applied using the results obtained and calculated from short-term tests and predetermined stress levels. The predicted results and the actual (practical) results were compared and discussed.

Materials and methods

Materials

Material used for this study was 18-mm-thick OSB; a structural composite wood panel bonded with resins and wax and used in subfloor, wall, and roof sheathing applications. The short-term test specimens were prepared using $120 \times 120 \text{ cm}^2$ panels. The panels cut to $45 \times 5 \times 1.8 \text{ cm}^3$ samples. For short-term tests, 10 specimens from each group were prepared and tested. For long-term tests, three groups with different stress levels—G1 (47%), G2 (51%), and G3 (55%)—were studied.

Methods

Short-term performance analyses: Practical

To obtain necessary material properties to determine long-term loadings, the center-point flexure test (three-point bending test; Table 1) was performed according to ASTM D3043-11.⁶ Dimensions of specimens for testing were $107 \times 5 \times 1.8 \text{ cm}^3$. The test samples were stored in the

Table 1. Three-point bending test results.^a

Repetition (n)	F_{max} (N)	MOE (N/mm ²)	MOR (N/mm ²)	MC (%)
10	390 (15.30)	6866 (7.07)	33 (15.30)	4.9 (5.50)

MOE: modulus of elasticity; MOR: modulus of rupture; MC: moisture content; COV: coefficient of variation.

^aThe parentheses indicate the COV (%).

laboratory conditions ($25 \pm 2^\circ\text{C}$ and 50% relative humidity) for at least 48 h to acclimatize to atmospheric conditions in laboratory before testing.

The conventional compression testing machine was used to apply the forces with the crosshead speed calculated using equation (1), as given in ASTM-D3043-11¹¹ and each test completed between 30 s and 90 s

$$N = zL^2/6d \quad (1)$$

where N is the rate of motion of moving head, mm/min, z is the unit rate of fibre strain, mm/mm.min of outer fiber length = 0.0015, L is the span, mm, and d is the depth of beam, mm.

A total of 10 samples were loaded until failure. The MOE and MOR were calculated using equations (2) and (3). After breaking, samples were put in an oven and dried until the mass was constant to obtain the moisture content at the time of testing each sample

$$\text{MOE} = ((L^3/48)(P/\Delta))/I \quad (2)$$

where MOE is the modulus of elasticity, N/mm², L is the span, mm, I is the moment of inertia, mm⁴, P/Δ = Slope of load – deflection curve, N/mm.

$$\text{MOR} = 3PL/2bh^2 \quad (3)$$

where MOR is the modulus of rupture, N/mm², P is the maximum load, N, b is the width, mm, and h is the thickness, mm.

Long-term performance analyses: Practical

The long-term tests were conducted according to ASTM D6815-09.¹² Five samples for each group were sized to $102 \times 30 \times 1.8 \text{ cm}^3$. Loads for the long-term tests were calculated using the results from short-term bending test and the predetermined stress levels—SL1: 47%, SL2: 51%, and SL3: 55%. The stress levels were multiplied with the lower 5% point (5% PE) estimate obtained from short-term bending test, as given in equation (4)

$$f_b = \text{SL} \times (5\% \text{PE}) \quad (4)$$

where f_b is the minimum applied bending stress, 5% PE is the lower 5% point estimate of MOR, as determined from the short-term testing, and SL is the stress level (%).

Then, the long-term test samples were loaded according to ASTM D6815-09⁷ using four-point bending procedure, the data (deflection/time) were taken at approximately 1 min after the application of the constant load and each minute till 2000, 4000, 6000, 8000, and 10,000 h. Other variables that influence the creep behavior were monitored daily and the air humidity and room temperature were set constant ($25 \pm 2^\circ\text{C}$ and 50% relative humidity).

Long-term performance analyses: Theoretical BBM

Creep is defined as time-dependent deformation exhibited by the material under constant load. BBM also known as four-element linear viscoelastic model is one of the models that used to describe components of creep. There are four parameters associated with the BBM:

1. The spring constant ($E1$) represents the elasticity deformation, which is instantaneously and completely recoverable.
2. The dashpot constant ($\eta1$) represents viscous flow (permanent deformation), deformation, which increases over time under stress but is not recoverable.
3. The spring ($E2$) and dashpot ($\eta2$) constants associated with the delayed elastic deformation, deformation which is completely recoverable but happens so over time.
4. Strain as a function of time is calculated using equation (5)

$$\varepsilon(t) = \sigma_0 \left(\frac{1}{E_1} + \frac{1}{E_2} \left(1 - e^{-\frac{t}{\eta_1}} \right) + \frac{1}{\eta_1} t \right) \quad (5)$$

where E_1 is instantaneous MOE (N/mm²) and E_2 is delayed MOE (N/mm²).

In this research, the bending strain values at 2000, 4000, 6000, 8000, and 10,000 h under three different stress levels (47%, 51%, and 55%) were determined using practical tests and theoretical model. As a result, the behavior of the OSBs under long-term loads was practically determined and compared with the predicted results obtained from theoretical model (BBM) using the Wolfram Mathematica 11 software.

Statistical analysis

A two-way factorial analysis of variance was used on the strain data to assess whether the actual (measured) response was significantly impacted by stress levels (loads or groups) or load duration time or whether an interaction effect was present. Significant differences between groups were evaluated by the use of a Tukey–Kramer honestly significant difference (HSD) test, with $\alpha = 0.05$.

Results and discussion

The overall results were detailed and discussed under the following subsections.

Short-term performance test results

In the short-term flexural testing, a total of 10 samples were prepared and tested. The proportional limit was visually determined by plotting the load deflection values, and slope of the graph within proportional limit was determined according to ASTM D3043.¹¹ The mean MOE value was 6866 N/mm² with 7.07% coefficient of variation (COV). The MOR was 33 N/mm² with 15.3% COV. The distribution was found normally distributed (Kolmogorov–Smirnov; $p = 0.98$).

The obtained short-term test results were used to determine the long-term loads as a function of predetermined stress levels. The accuracy of the short-term test results is critical while determining the long-term loads. The determined MOR values were compared under the following paragraph and found comparable with the previous studies, which proves the usability of the short-term results obtained in this work.

Thomas¹³ investigated the mechanical properties of OSBs and showed that bending MOEs vary between 2000 N/mm² and 8000 N/mm² as a function of OSB thicknesses. In the same study, Thomas showed that the MOR values vary between 10 N/mm² and 30 N/mm². The higher MOE and MOR values obtained in this study can be related to high performance product used in this study. In another study, on determination of the mechanical performance properties of the high-performance OSB composites, the research found that the MOR values change from 20 N/mm² to 60 N/mm². In the same study, the MOE values found varying between 2000 N/mm² and 7000 N/mm².¹⁴ Yapici et al.¹⁵ reported that the MOE of OSBs was between 4488 N/mm² and 5992 N/mm² (with the standard deviation of up to 2245 MPa) and MOR was between 25 N/mm² and 35 N/mm², which are comparable with the results from this study. These variations were influenced by different production parameters, namely the pressure and press time. Other factors influencing the performance of OSBs were studied.² In varying relative humidity conditions, the mean MOR, for 194 samples tested, was from 21 N/mm² to 27 N/mm². For 65% relative humidity, MOE had very similar value to the one in this work, 6835 N/mm². Depending on the wood species used in the production, MOE was found to be around 5000 MPa for the boards made out of pine and around 7000 N/mm² made out of aspen.¹⁶

Long-term performance test results

Using the data obtained from short-term tests, and the predetermined stress levels, the long-term loads were calculated using equation (4), as given under “Long-term

Table 2. The applied long term loads.

Group number	Stress levels (%)	Stress (N/mm ²)	Load (kg)
1	47	11.7	132.2
2	51	12.8	144.5
3	55	13.7	154.9

performance analyses: Practical” section and given in Table 2.

The long-term loading stations were setup, as shown in Figure 2. The samples were located in vertical position and the deflection measurements were performed using the strings attached in the center of the OSBs using tiny magnets. The actual strain values were calculated by the software using the deflection values collected by the server.

The actual long-term strain values were compared with the predicted strain values obtained using BBM. The demonstration of errors between actual and predicted strain values (strain error) by hours of data (the total data used to compare the strain errors under different stress levels) used was shown in Figure 3.

As shown in Figure 2, the BBM prediction provided more accurate results with the increase in load duration time. In each case, accuracy increases with the increase in hours of data used. The poor fit at 4000 h is thought to be related to the viscoelastic behavior of the OSBs. The plots in Figure 2 are connected with an exponential function due to its best fit with the data. It is expected that this information will provide a good foundation for the researchers planning to work on the creep behavior of the OSBs using BBM. The negligible strain errors obtained in this work provided positive motivation on the usability of the BBM for determining the OSBs creep behavior under long-term loads. Other researchers have also demonstrated that the BBM can be used to predict the creep response in wood,^{17,18} wood-based products,^{19–21} and nonwood-based products.²²

In one of the studies, the BBM was modified to include the moisture and temperature parameters.¹⁸ The applicability of BBM was confirmed with an error of 7.3% for the total strain value. It was also discovered that the accuracy of the model was constant throughout the study for different samples and temperatures. This study is a pioneer work that focuses on investigating the usability of the BBM for OSBs under different loads and load durations.

The statistical analyses performed to understand the effect of stress levels on strain error values are shown in Figure 4. The significant differences between groups were evaluated by the use of a Tukey–Kramer HSD test with $\alpha = 0.05$. The letters A, B, and C under “level” column means the result of HSD. It shows that no significant difference was recognized between the groups, which has the same letters. The LS means column includes the data obtained by the smallest strain error generated as a function of applied stresses.

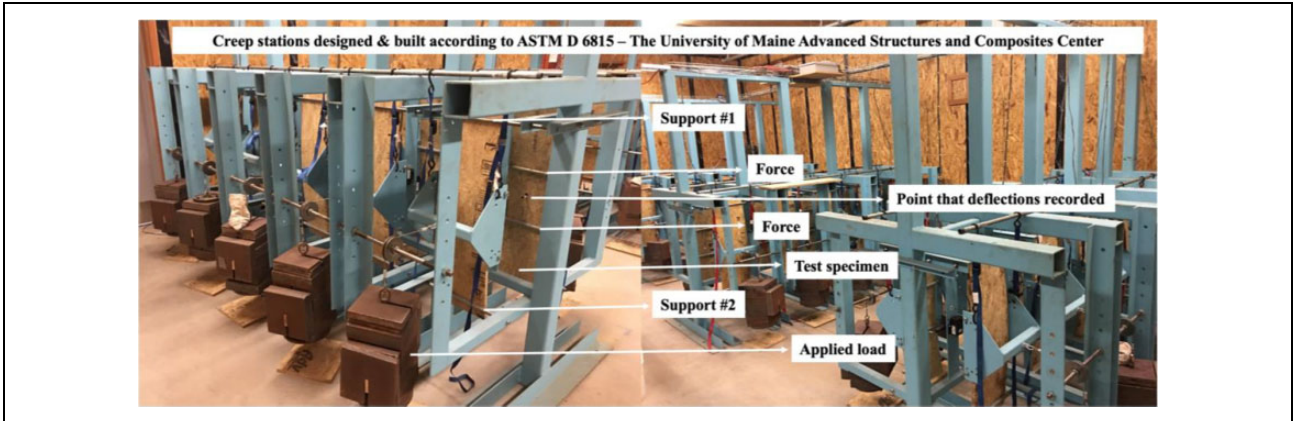


Figure 2. The long-term loading stations.

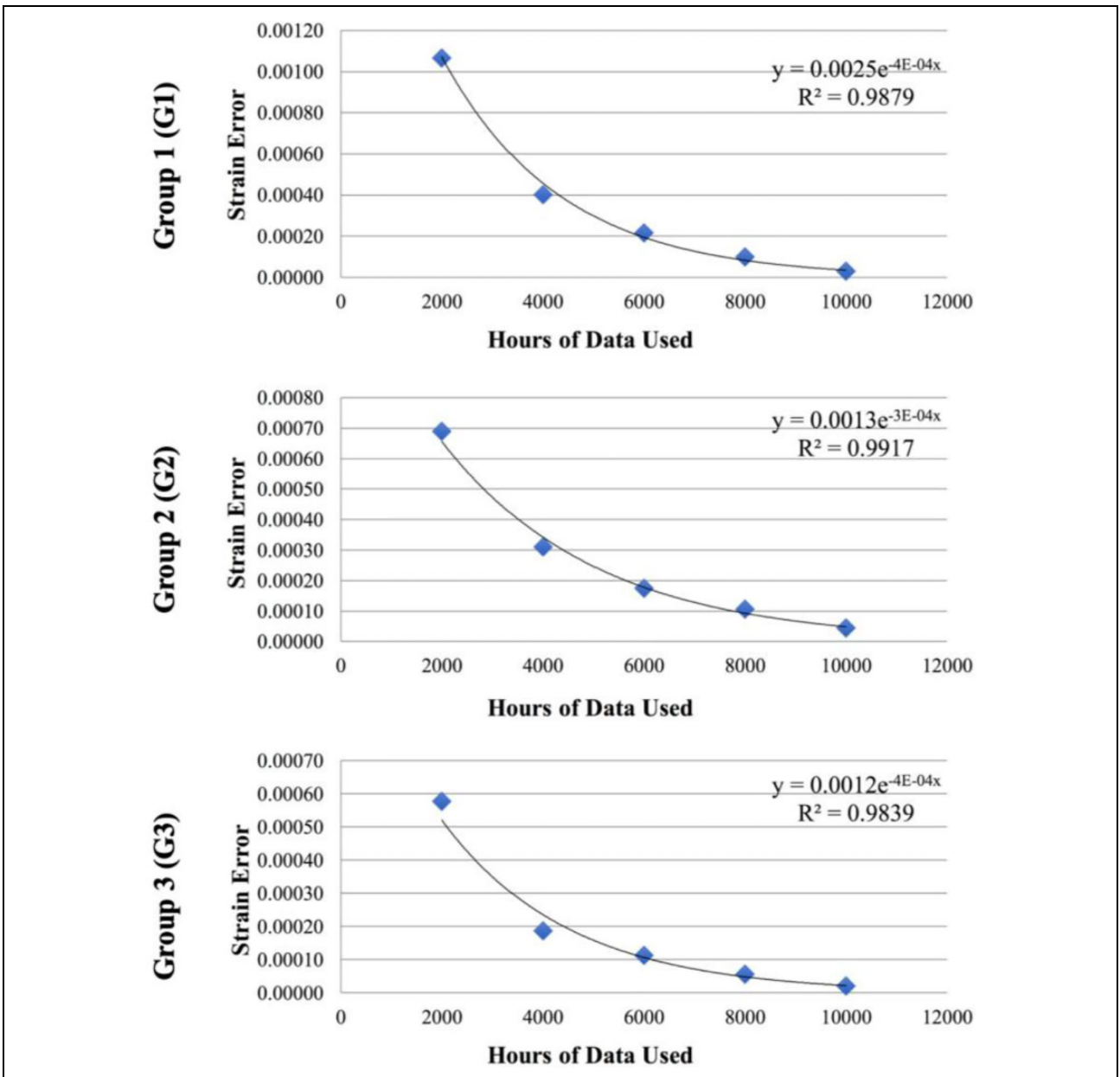


Figure 3. The demonstration of strain errors by loading time. (a) Group 1 (G1), (b) group 2 (G2), and (c) group 3 (G3).

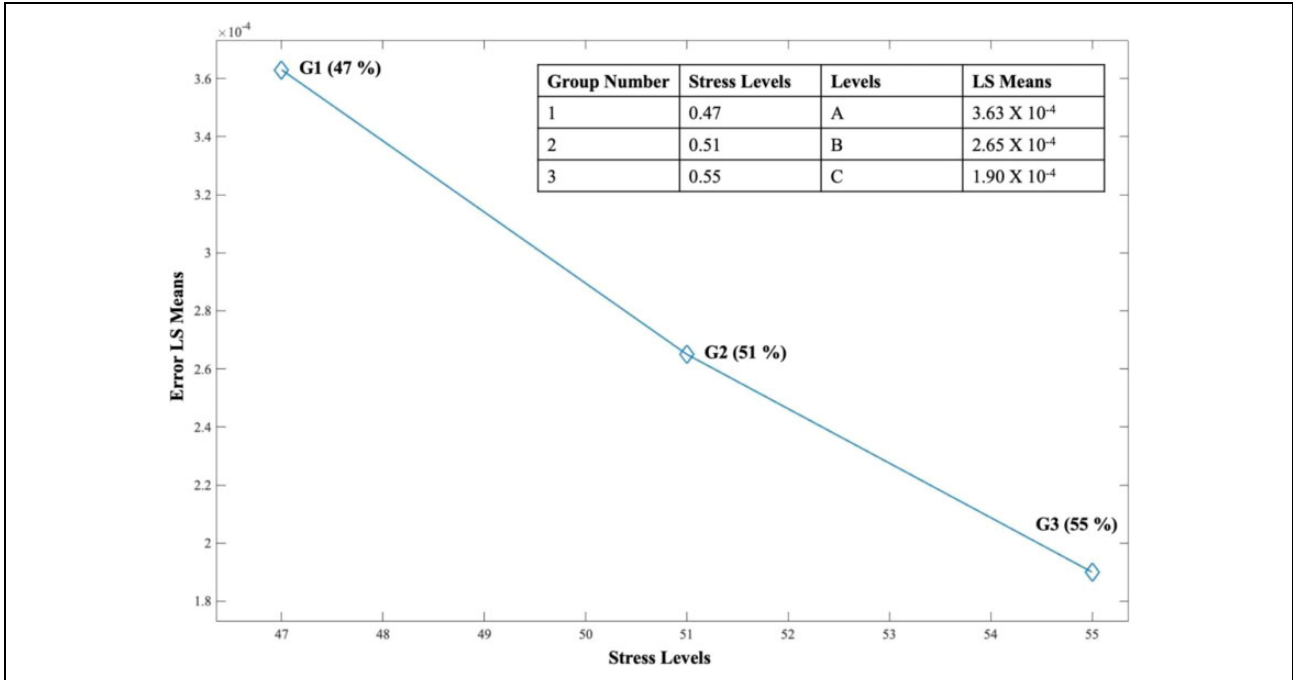


Figure 4. The effect of stress levels on the accuracy.

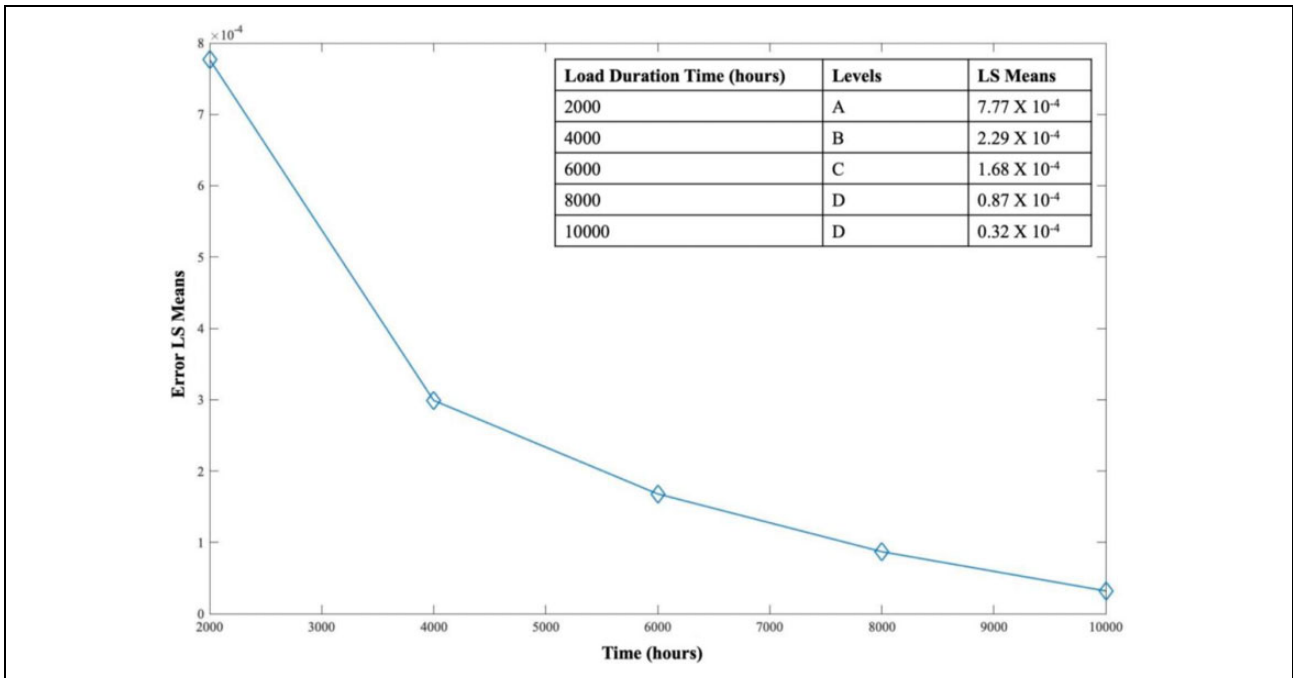


Figure 5. The effect of load duration time on the accuracy.

In previous studies, it was shown that the creep behavior depends on the applied stress levels.^{10,23} The increased stress levels increase the deflection values as expected.²⁴ In this work, it was also found that the applied stress levels affect the creep behavior of the OSBs and the 55% stress levels produce more accurate results when compared to actual data. This can be related to the amount of loading required to get

more accurate response from the OSBs. The effect of the load duration time on minimization of the error between actual and predicted strain values was shown in Figure 5. The LS means column includes the data obtained by the smallest strain error generated as a function of load duration time.

It was found that there is no statistical difference between the 8000 h and 10,000 h of load duration on the

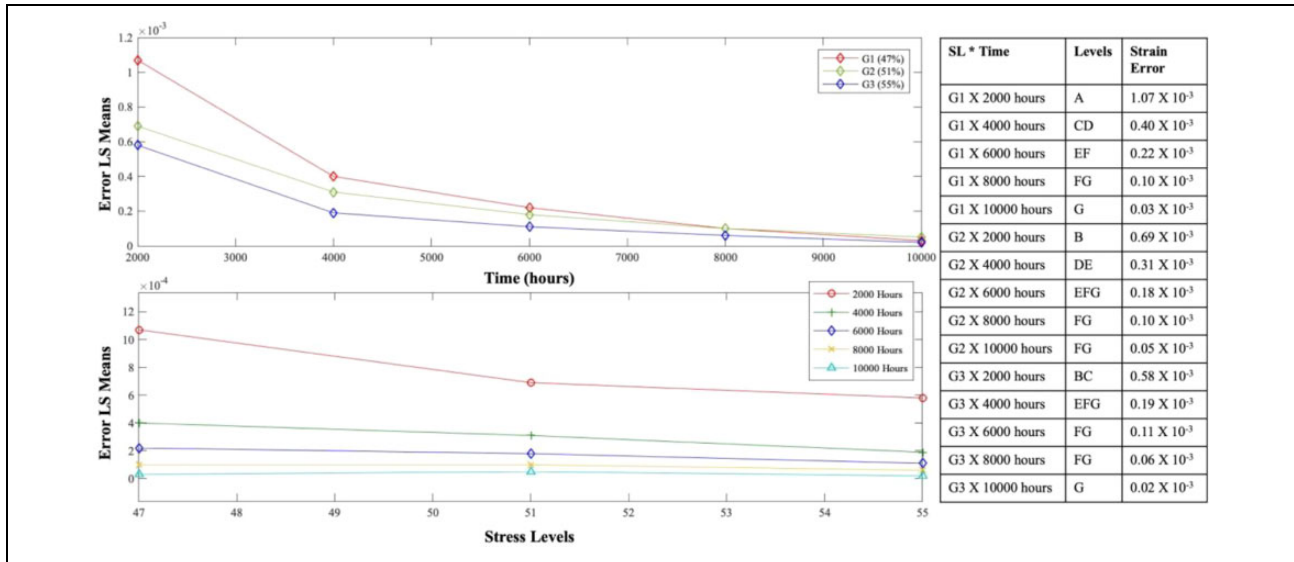


Figure 6. The interaction effect (stress levels \times load duration time) on the accuracy.

accuracy. However, once the load duration time decreases below 8000 h, the statistical differences are observed. The 2000 h loading showed to least accurate results. In the smaller scale work,²⁵ it was also confirmed that BBM prediction has lower performance with the shorter duration of tests.

After determining the effect of each factor, the interaction between the factors was investigated. It was studied whether there was a different effect of stress level depending on load duration time, alternatively whether there was a different effect of load duration time depending on the stress levels. The results were shown in Figure 6.

The most accurate results were obtained from the groups with 10,000 h of load duration time. Statistically, G3 and G1 with 10,000 h of load duration time produced most accurate data. The groups with 2000 h of load duration time provided the least accurate results within the group. No matter what the stress levels were used, the 55% stress levels provided the most accurate results.

Conclusions

In this study, the usability of the BBM for investigating the behavior of OSBs under long-term loads was studied comparing actual strain data and predicted strain data using different stress levels and load durations under constant environmental conditions.

The BBM was found useful tool for predicting OSB's creep behavior between 2000 h and 10,000 h load duration time. The most accurate predictions were obtained for the loading durations over 8000 h.

This research provides increased knowledge about the usability of BBM for investigation of behavior of OSBs under long-term loads. Also provides better understanding on how the BBM is useful for different stress levels and

different load durations. The future studies will include the investigation of creep behavior of OSBs under different temperature and humidity conditions.

Author's note

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Author contributions

NY and SS conceived and designed the experiments; EG, RE, and WW performed the experiments; NY and SS analyzed the data; SS contributed reagents/materials/analysis tools; NY and EG wrote the article.


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