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THE FLEXURAL STRENGTH BEHAVIOUR OF BALAU AND CHENGAL TIMBER SPECIES USING THE ANALYSIS OF MODULUS OF RUPTURE (MOR) AND MODULUS OF ELASTICITY (MOE) PARAMETERS

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Abstract: Wood is one of the oldest materials used as a major structural element before concrete and steel which has a greater ability to withstand loads. Engineered wood products (EWP) are a new type of wood created by wood engineers to address the increasing need for wood as a building resource. The growing interest in timber beams, aligned with sustainable development goals 9 & 11, reflects the rising demand for building materials that are both sustainable and structurally efficient. The strength of each wood species that has been classified in the strength grade is the most critical issue in the wood structure. The main objective of this research is to determine the optimum strength, modulus of rupture (MOR), modulus of elasticity (MOE), and failure of the Balau and Chengal species. For Balau and Chengal wood, the three-point bending test was applied to determine the bending strength for different species. From the results, it is observed that Balau is stronger than Chengal, with a strength of 218.17 kN and 189.05 kN, respectively. Balau has a greater MOR and MOE than Chengal species by 10.29% and 23.27%, respectively. When compared to Balau wood, Chengal wood cracks and deforms more readily when subjected to lesser loads.

Keywords: Chengal; Balau; flexural; SDG 9, SDG 11

1. Introduction

The United Nations 2030 Agenda for Sustainable Development outlines 17 Sustainable Development Goals (SDGs) which aims at addressing global challenges and fostering a more sustainable and equitable future. Two particularly relevant goals in the context of construction and infrastructure development are SDG 9: Industry, Innovation, and Infrastructure, and SDG 11: Sustainable Cities and Communities (United Nations, 2015).

SDG 9 focuses on the need to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. Achieving this goal requires advancements in materials, technologies, and construction practices that not only enhance infrastructure resilience but also contribute to environmental sustainability. On the other hand, SDG 11 aims to create inclusive, safe, resilient, and sustainable cities and communities. It emphasizes the importance of access to safe and affordable housing, sustainable transport systems, and the preservation of cultural and natural heritage (Chan *et al.*, 2022). Sustainable and resilient construction materials play a crucial role in achieving the objectives of SDG 11 (United Nations, 2015).

In this context, our research investigates the flexural strength behaviour of two prominent timber species, Balau and Chengal, using the analysis of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) parameters. By understanding the mechanical properties of these timber species, this paper contributes valuable insights to the sustainable development goals of enhancing infrastructure, promoting resilient construction practices, and fostering the creation of sustainable and safe communities. It is easy and safe to work with and what is more, extremely cost-effective. Moreover, there is little carbon footprint by using timber as compared to steel for the building material.

The calculated strength of the timber material will establish if it is an appropriate candidate for a specific purpose. (Pajchrowski *et al.*, 2014). Moreover, very little knowledge has been gathered on timber in general regarding its reusability and general usage, especially when it comes to its flexural behaviour.

Flexural strength, often known as bend strength, is a material's capacity to endure deformation under load. The flexural strength represents the maximum stress experienced in the material at the time of rupture. It is determined by the amount of stress. Because nearly all materials fail under tensile stress before they fail under compressive stress, the flexural strength is the highest tensile stress value that can be sustained before the specimen collapses.

The flexural strength would be like the tensile strength if the material were homogeneous. (Leguillon *et al.*, 2015). Therefore, the study focuses on finding the optimum strength and failure behaviour of the MOR and MOE for Balau and Chengal species using 3-point load testing and aligns with the broader agenda of utilizing environmentally friendly materials in construction, ultimately supporting the global efforts toward a more sustainable and resilient future.

2. Materials and Methods

For the three-point bending test, two types of glued laminated timber composed of homogeneous grade timber were used. The flexural test determines the amount of force required to bend a beam when subjected to three-point loading conditions. The longitudinal modulus of elasticity along with ultimate strength in bending, shortly termed MOE and MOR are a few of the highly useful parameters to articulate the impacts of static strain in timber/wood. MOE can be assessed on wood specimens by employing non-destructive examination methods and MOR by utilizing destructive and secondarily, with a variety of non-destructive examination processes (Pang *et al.*, 2020).

Two types of Heavy Hardwoods (HHW) were chosen, Balau and Chengal from Strength Grade (SG1) as stated in the strength groups of timber (MS544: Part 2, 2001). The HHWs are extremely dense types of wood, with densities ranging from 800 to 1120 kg/m^3 with a moisture content of 15% and treated with a preservative so that it does not become infested and destroyed (Menon, 1993). Furthermore, tropical timber beams possess the capacity to play a substantial role in enhancing the structural resilience of buildings located in areas susceptible to severe weather conditions, aligning with SDG 9 on Industry, Innovation, and Infrastructure.

2.1. Design Overview and Procedure

Figure 1 shows the procedure of the experiment. The experiments for this study was done at SEGi University, where the testing machines and equipment are available. Four (4) samples of Balau and four (4) samples of Chengal timber with variation in density are shown in **Table 1**. **Table 2** shows the timber specimen after the three-point load test. The specimens of Balau and Chengal timber were loaded into the machine and tested.

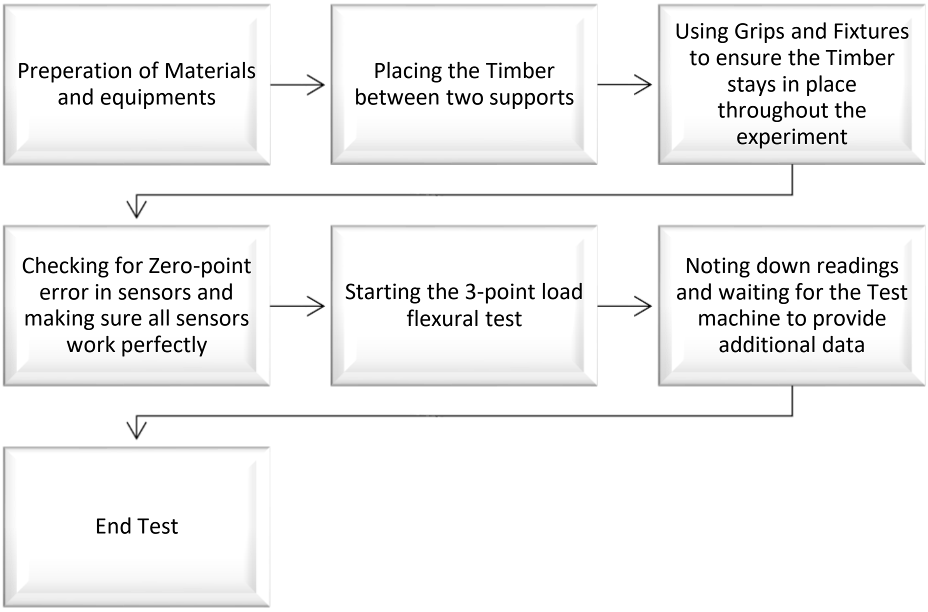
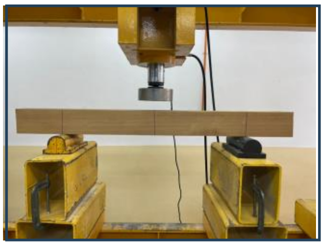
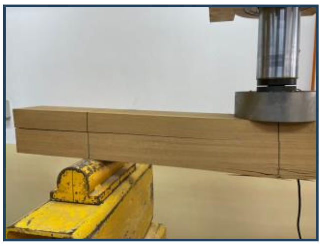
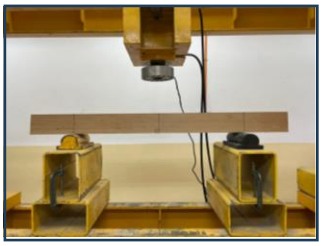
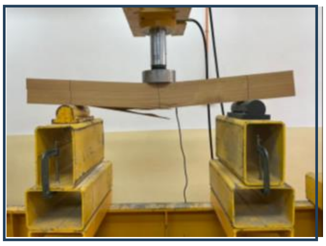
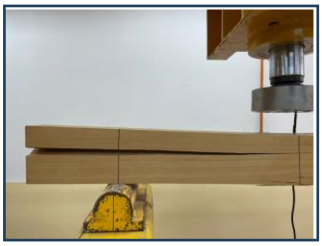


Figure 1. Flowchart of the experimental procedure

Table 1. Specimens tested in this study

Type of timber	Density (kg/m^3)	Specimen Number	Beam size (mm)
Balau	1100	1	140×140×1500
	960	2	
	970	3	
	1050	4	
Chengal	975	1	
	960	2	
	960	3	
	970	4	

Table 2. Timber specimen under three-point load test

Type of timber	Before Test	After Test (Front view)	Failure
Balau			
Chengal			

3. Results and Discussion

The data from the three-point load test for Balau and Chengal timber species on the strength of timber is presented. The different types of failure modes that also can occur in Balau and Chengal timber were discussed. All data from the laboratory testing was analyzed at this stage. To ensure a better understanding of the research findings, all collected data is presented in tables, graphs, and illustrations.

3.1. Moisture Content

The samples for the moisture content test were from the same production cut off from the same beam for the pull-out test and kept under the same ambient temperature. It is found that the moisture content is in the range of 12% to 13%. The results show satisfactory performance in the range of 8% to 15% for non-treated timber according to MS758:2001 standard (MS758, 2001).

Table 3 shows the average results of Balau and Chengal specimens of moisture content to be 12.75% with a density of 1020 kg/m^3 and 12.5% moisture content with 966.25 kg/m^3 density respectively. The results are shown in the range as stipulated in the MS758:2001 standard (MS758, 2001). Previous study reported that the moisture content will increase, and the modulus of elasticity decreases for the dry timber (Baglietto *et al.*, 2013). Increasing the heterogeneity of the material by layering timber sections such as laminated veneer lumber and glulam decreases the moisture-related warping (Alam *et al.*, 2009).

Table 3. Average moisture content and density test results for Balau and Chengal specimens

Sample	Specimens Size (mm)	Balau (SG1)		Chengal (SG1)	
		Moisture Content (%)	Density (kg/m^3)	Moisture Content (%)	Density (kg/m^3)
S1	140 ×140 × 1500	12	1100	12	975
S2		13	960	13	960
S3		13	970	12	960
S4		13	1050	13	970
Total Average		12.75	1020	12.5	966.25

3.2. Shear Strength of Balau

There were four (4) beams tested which were tabulated in **Table 4**. For example, S1 is the specimen code meant for specimen no 1. The table shows the standard deviation (SD) for maximum load and displacement of Balau timber species. The coefficient of Variation (CoV) for maximum load and deformation is 9.977% and 17.22%, respectively. The average load is 200.28 kN and displacement is 315.38 mm.

The typical performance behaviour of load versus displacement for Balau species is shown in **Figure 2**. It can be seen from the trend that all the specimens show a similar pattern and specimen S1 gave the highest load of 218.17 kN. The red graph line shows the average of all Balau species. The average MOE for Balau species is shown in **Figure 3**.

Table 4. Specimen for Balau

Specimen	Maximum Load (kN)	Displacement (mm)
S1	218.17	266.4
S2	178.5	270.5
S3	188.18	358.2
S4	216.25	366.4
Average	200.28	315.38
Standard Deviation (SD)	19.98	54.31
Coefficient of Variation (CoV)	9.977%	17.22%

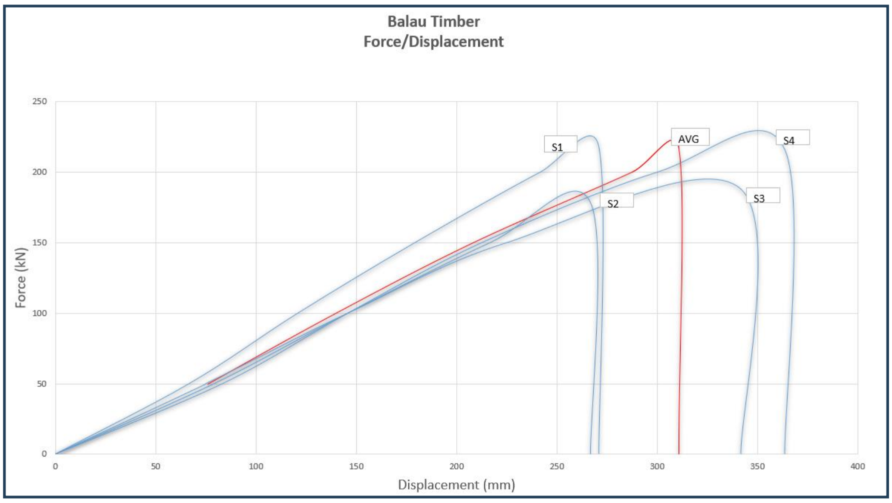


Figure 2. Force/displacement graph for Balau timber specimens

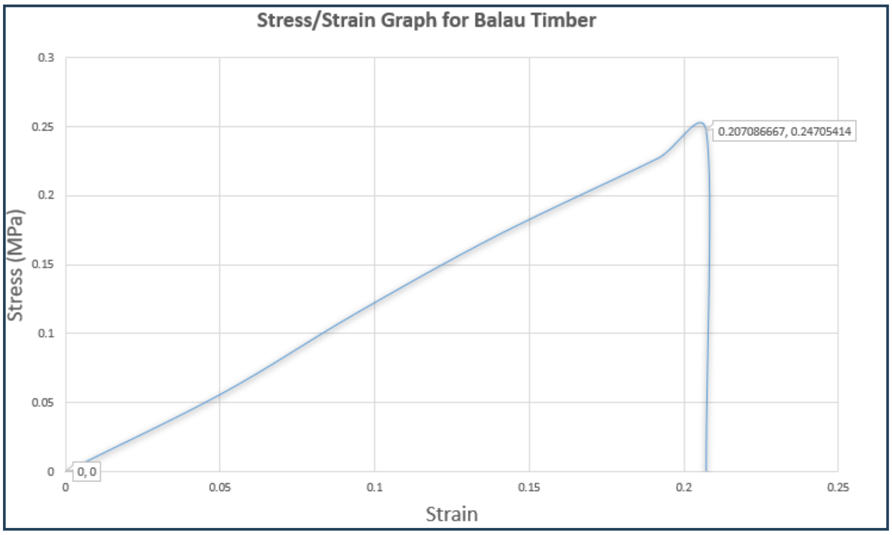


Figure 3. Average MOE graph for Balau timber species

3.3. Shear Strength of Chengal

As for the Chengal species, the coefficient of Variation (CoV) for maximum load and deformation is 8.706% and 8.32%, respectively (**Table 5**). The average load is 181.6 kN and displacement is 331.98 mm.

Table 5. Specimen for Chengal

Specimens	**Maximum Load (kN)**	**Displacement (mm)**
S1	198.05	366.4
S2	166.17	300.0
S3	170.11	324.6
S4	192.07	336.9
Average	181.6	331.98
Standard Deviation (SD)	15.81	27.61
Coefficient of Variation (CoV)	8.706%	8.32%

The typical performance behaviour of load versus displacement for Chengal species is shown in **Figure 4**. It can be seen from the trend that all the specimens show similar patterns and specimen S1 gave the highest load of 198.05 kN compared to specimens S2, S3 and S4 with the value of 166.17 kN, 170.11 kN and 192.07 kN respectively. The red graph line shows the average of all Chenal species. **Figure 5** shows the average MOE for Chengal species.

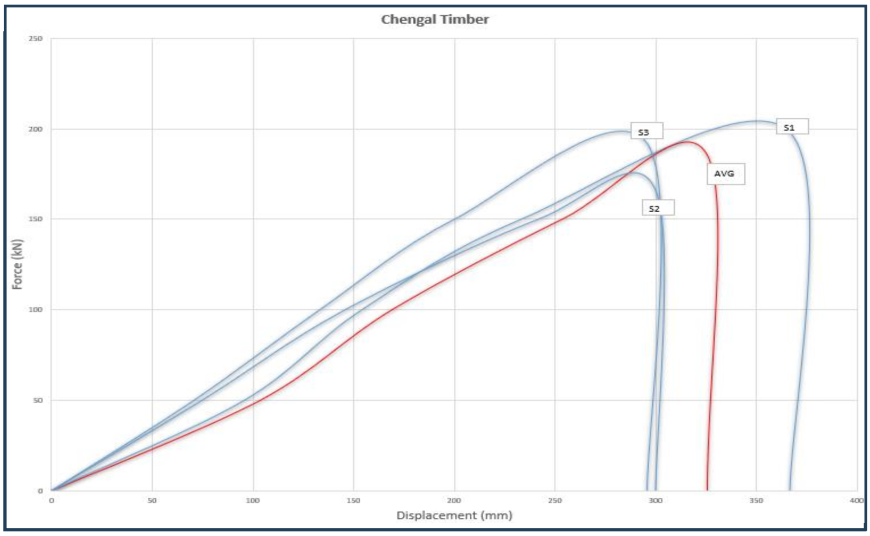


Figure 4. Force/displacement graph for Chengal timber specimens

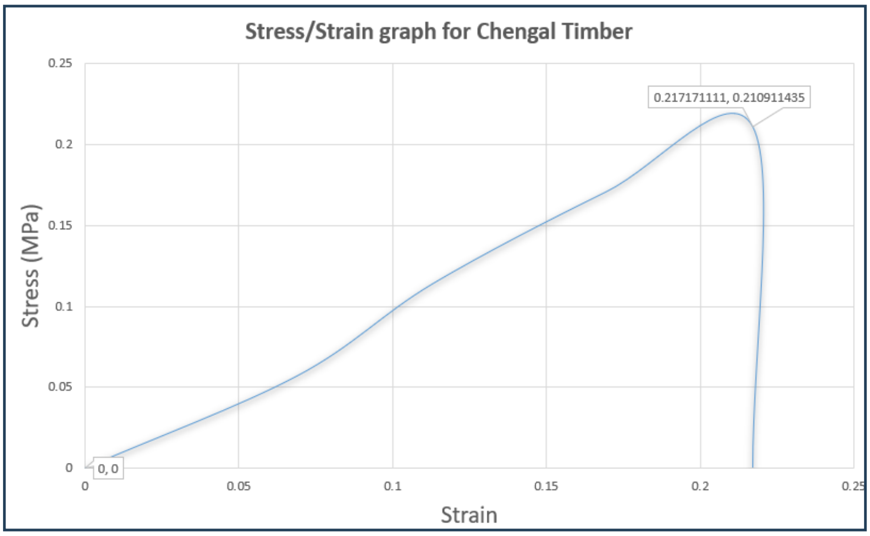


Figure 5. Average MOE graph for Chengal timber species

3.4 MOR and MOE

The three-point load test is most frequently done for timber where the beam is bent until fails using the three-point flexural test. It is to determine the modulus of elasticity (MOE) and modulus of rupture (MOR) or bending strength of the specimens. The specimens were tested after being cured for ten (10) days at room temperature. The modulus of elasticity (MOE) and modulus of rupture (MOR) of wood are critical qualities for its usage as a structural material. The former indicates the material's stiffness, or resistance to bending, whereas the latter indicates its maximum load at failure or bending strength. (Mohd-Jamil, 2021).

MOE $= (\sigma 2 - \sigma 1) / (\varepsilon 2 - \varepsilon 1)$ (1)

where

σ = stress

ε= strain

MOR $\sigma_r = 3Fx/yz^2$ (2)

where

F = Load force

x, y, and z = Size dimensions in three directions, x, y, and z, of the material

The average value of flexural strength properties and MOE for both species are presented in **Table 6**. The average value of flexural strength and CoV% of both MOR and MOE for Balau and Chengal are presented in **Figure 6**.

As shown in **Figure 6**, the flexural strength of Balau is 200.28 kN, and that of Chengal is 181.6 kN. It is also observed that the percentage difference between Balau and Chengal is 1.27% for MOR and 0.82% for MOE. **Figure 7** shows the typical average stress/strain graph between Balau and Chengal. It can be noted that Balau Timber underwent higher loads (stress) with lesser deformation (strain). Chengal has higher deformation when compared to the Balau is refers to how much the materials change shape or size under applied stress.

Table 6. Average flexural strength for MOE

Species	No. of samples	Flexural Strength		MOE	
		Mean (kN)	CoV (%)	Mean (MPa)	CoV (%)
Balau	4	200.28	9.977	1.197	49.37
Chengal	4	181.6	8.706	0.971	48.55

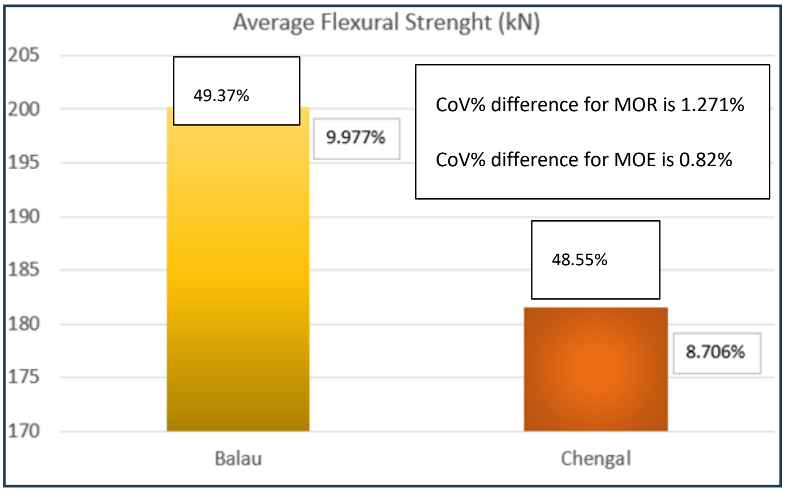


Figure 6. Average MOR and MOE value comparison between Balau and Chengal

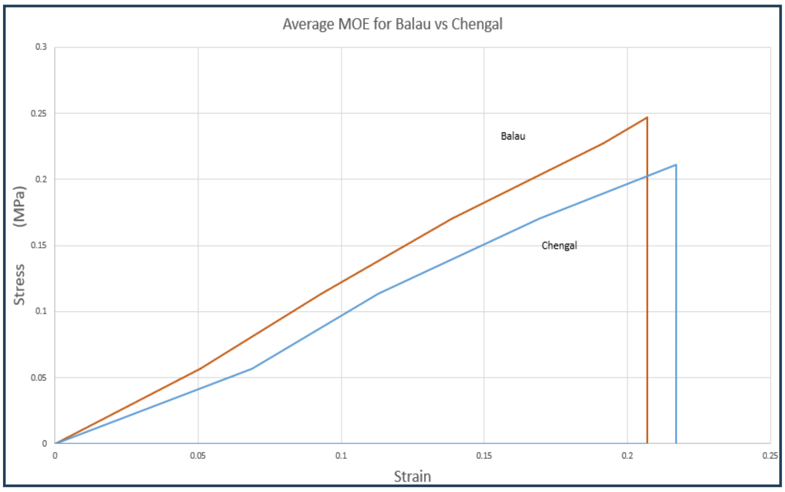


Figure 7. Stress/strain for Balau versus Chengal

3.5. Failure Behaviour of Flexural Strength

The observation made whilst performing the flexural test on Chengal species is that it was quite dense. Before the test, an assumption was made that it might be stronger than the Balau species, but the test proved otherwise. The Balau timber exhibited greater strength and slightly more flexibility compared to Chengal. The details type of failure for these two timber species is shown in **Table 7**. Mechanical failure due to bending load is typically indicated by splintering fractures and loss of strength.

Table 7. Type of failure for Balau and Chengal species

Species	Failure	Description
Balau		Decent-sized cracks noticed for Balau Species
		Cracks were noticed at the sides of the beam
Chengal		Major cracks/splits

4. Conclusion

The study examined the optimal strength characteristics of Balau and Chengal species sourced from SG1 of Malaysian tropical timber. The average MOR for Balau and Chengal species is 200.28 kN for Balau timber and for Chengal being 181.6 kN. Furthermore, the average MOE for Balau and Chengal timber is 1.197 MPa and 0.971 MPa, respectively. It can be observed from the values of MOR that Balau timber is higher by 10.29% when compared to Chengal timber. Moreover, the MOE for Balau timber is 23.27% higher than that of Chengal timber. Chengal timber had major cracks as Chengal specimens were less flexible during the flexural test and sustained major deformations when compared to Balau timber, even whilst being under lesser load. This study significantly contributes to both SDG 9 and SDG 11, showcasing tropical timber's pivotal role in offering sustainable, innovative, and versatile construction materials to meet present and future infrastructure needs while minimizing environmental impact and fostering economic growth. It is recommended to extend the study to include dynamic loading conditions to simulate real-world scenarios more accurately

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Credit Author Statement

Conceptualisation, Hussin, T.A.R., and Khan, M.A.; methodology and investigation, Hussin, T.A.R. and Khan, M.A.; validation and formal analysis, Hussin, T.A.R. and Hassan, R.; resources and data curation, Hussin, T.A.R. and Khan, M.A.; writing—original draft preparation, Za’ba, N.I.L. and Rahman, N.F.A.; writing—review and editing, Mohammad. M.; visualization and supervision, Hassan, R.; project administration, Hussin, T.A.R.; funding acquisition, Hussin, T.A.R.

Conflicts of Interest

The authors declare no conflict of interest.

References

Alam, P., Ansell, M. P., & Smedley, D. (2009). Mechanical repair of timber beams fractured in flexure using bonded-in reinforcements. *Composites Part B: Engineering*, 40(2), 95-106.

Baglietto, J., Kelly, C., & Johnson, C. (2013). Wood Bend Test.

Chan, N., Go, T. F., Moey, L. K., & Chia, C. M. (2022). Short review on renewable energy policy and energy consumption of buildings in Malaysia. *Journal of Engineering & Technological Advances*, 7(1), 64-82.

Leguillon, D., Martin, É., & Lafarie-Frenot, M. C. (2015). Flexural vs. tensile strength in brittle materials. *Comptes Rendus Mécanique*, 343(4), 275-281.

Menon, P.K.B. (1993). Uses of some Malaysian timbers. Revised by Lim, S.C. *Timber Trade Leaflet*, No. 31. The Malaysian Timber Industry Board and Forest Research Institute Malaysia.

Mohd-Jamil, A.W. (2021). Mechanical properties of Malaysian timbers: The weighted mean and combined standard deviation values. *Technology Bulletin*, No. 106, Forest Research Institute Malaysia.

MS758. (2001). Glued laminated timber - Performance requirements and minimum production requirements. *First Revision*, Malaysian Standard.

MS544: Part 2. (2001). Code of practice for structural use of timber: permissible stress design of solid timber. Malaysian Standard.

Pajchrowski, G., Noskowiak, A., Lewandowska, A., & Strykowski, W. (2014). Wood as a building material in the light of environmental assessment of full life cycle of four buildings. *Construction and Building Materials*, 52, 428-436.

Pang, S. J., Ahn, K. S., Kang, S. G., & Oh, J. K. (2020). Prediction of withdrawal resistance for a screw in hybrid cross-laminated timber. *Journal of Wood Science*, 66(1), 1-11.

United Nations (2015). Transforming our world: The 2030 agenda for sustainable development.