INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT
OPEN ACCESS JOURNAL
Vol 13, Issue 4, (2024) E-ISSN: 2226-6348

Mechanical Properties of Malaysian Chengal Wood Species

Amira Ruzailin Dzulkifli[1], Rohana Hassan[1,2], Azman Zainal[3], Buan Anshari[4], Ali Awaludin[5], Tengku Anita Raja Hussin[6] , Hou Qiwei[6], Norshariza Mohamad Bhkari[1,2]
[1]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Darul Ehsan, Malaysia, [2]Institute for Infrastructure Engineering and Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, [3]Arkitek Azman Zainal, No 17A Jalan Tengku Ampuan Zabedah J9/J, Seksyen 9, 40100 Shah Alam, Selangor, Malaysia, [4]Department of Civil Engineering, University of Mataram, Kota Mataram, Nusa Tenggara Barat, 83115, Indonesia, [5]Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia, [6]Faculty of Engineering and Built Environment, SEGi University Kota Damansara, Jalan Teknologi, 47810 Petaling Jaya, Selangor, Malaysia
Email: anitahussin@segi.edu.my
Corresponding Author Email: rohan742@uitm.edu.my

To Link this Article: http://dx.doi.org/10.6007/IJARPED/v13-i4/23247 DOI:10.6007/IJARPED/v13-i4/23247

Published Online: 27 November 2024

Abstract

Timber is defined as the structural wood used for construction or other purposes. It is one of the oldest building materials and most sustainable resources. In recent years, the availability of high-grade timber species has dwindled due to ongoing deforestation and a decrease in log production. Hence, this study explores the mechanical properties of Malaysian Chengal wood (Neobalanocarpus heimii), a species highly valued for its strength, durability, and resistance to decay and insects. Despite its widespread use in construction, flooring, and marine applications, detailed data on its mechanical behaviour is scarce. This research aims to fill this gap by systematically analysing Chengal wood's mechanical properties through bending, compression, and tensile tests. The study measured vital parameters such as Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). The MOR, indicating the wood's resistance to external forces, was determined to be 54 MPa, while the MOE, reflecting stiffness and deformation properties, was 18400 MPa. These values are crucial for understanding the wood's elastic behaviour and ability to return to its original shape after deformation. Test results revealed a linear and non-linear behaviour, with all specimens exhibiting brittle to brittle-ductile failure patterns. Failures were primarily due to defects like knots, cross grains, and splits, which caused complex stress distributions. Various failure patterns were observed, underscoring the impact of these defects on the wood's mechanical performance. This comprehensive evaluation of Chengal wood's mechanical properties provides essential insights for its use in engineering and construction. The findings confirm its robust

performance and identify potential areas for quality improvement. This study serves as a critical reference for engineers, architects, and wood industry professionals, aiding in the informed selection of Chengal wood in structural applications.

Keywords: Structural Timber, Tropical Species, Sustainable, Stiffness.

Introduction

Wood has been a fundamental material in construction for thousands of years, ever since humanity discovered its potential, workability, and diverse mechanical properties. Moreover, the use of wood can contribute positively to forests when conducted sustainably (Arriaga ., 2023). Ernur *et al*. (2022) assert that when forests are managed for accountability, the trees are harvested and converted into wood products, thereby enhancing long-term carbon storage. Besides, Malaysia is well-known for having a tropical rainforest covering around 62% of its land area (Baharin *et al*., 2020). Around 3000 timber species are suitable for various applications, including hundreds of commercially known species (Wong, 1982). The vast array of tropical hardwoods available for structural applications dramatically increases the challenge of aligning a specific timber species with performance requirements (Hazira *et al*., 2011).

Wood is generally defined as an orthotropic material in engineering elastic models because its mechanical properties vary depending on the direction relative to its grain structure. In contrast to anisotropic materials, which exhibit direction-dependent properties that can vary unpredictably, orthotropic materials such as wood have well-defined and predictable variations in properties along specific axes. According to the Wood Handbook (2010), wood is classified as orthotropic since its mechanical properties are unique and independent along three mutually perpendicular axes: the longitudinal, radial, and tangential directions. The radial axis (R) is perpendicular to the growth rings and the grain, the tangential axis (T) is perpendicular to the grain but tangent to the growth rings, and the longitudinal axis (L) is parallel to the fibre or grain.

Wood's strength and mechanical properties primarily determine its suitability for structural and construction applications, influence its overall quality, and serve as critical indicators of the quality of sawn lumber across various uses (Hossain *et al*., 2012; Hamdan *et al*., 2020). As noted by Mohd-Jamil (2021), the mechanical properties of timber can be characterised by different parameters depending on the mode of applied force. These parameters include the modulus of rupture, modulus of elasticity, compressive strength parallel to the grain, shear strength parallel to the grain, compressive strength perpendicular to the grain, tensile strength parallel to the grain, and Janka hardness. The timber characteristics show considerable variability between species and within individual pieces of the same species (Lavers, 1969; Azlan *et al*., 2020). Regarding durability, timber maintains its structural integrity over long periods when exposed to natural elements, whether above ground or underground (Aziz, 1995). The natural durability of wood depends on the environmental conditions it is exposed to (Pansin and Zeeuw, 1980). According to Razak *et al*. (2020), smart wood materials, particularly their hygroscopic properties and fibre structure, significantly shape their mechanical performance. These characteristics are crucial when considering the mechanical properties of Malaysian wood species, as the fibre composition and grain orientation affect the rate of water diffusion and, consequently, the wood's structural behaviour.

Various international standards outline timber's bending, compression, and tension properties. However, Azmi *et al*. (2022) noted that Malaysia has numerous standards for designing structural timber elements, including Malaysian Standard (MS) 544: Part 2 and MS 544: Part 3. These standards cover solid and glue-laminated timber design based on acceptable stress design. According to Ahmad *et al*. (2010), the tension properties of timber are crucial for structural components such as roof trusses. Meanwhile, the compressive strength properties are vital for designing vertical load-bearing components like columns, posts, and props, which are subjected to loads that reduce their length, as emphasised by Bodig *et al*. (1982), Hassan *et al*. (2004) and Puaad *et al*. (2017). Ali *et al*. (2014) stressed the importance of considering perpendicular-to-grain compression resistance for specific applications, including railway sleepers, wedges, bolted timber, and bearing blocks. This consideration is also essential for building construction, particularly in support configurations connecting beams and columns. Solid wood is used in various regions for domestic interior purposes, such as making doors, windows, furniture, cabinets, panelling, similar applications, and composite timbers.

Among the diverse wood species available in Malaysia, Chengal (Neobalanocarpus heimii) stands out for its exceptional strength and durability. Renowned for its resistance to decay and insects, Chengal is preferred for heavy-duty structures, flooring, and marine environments. Despite its widespread use, comprehensive studies on the mechanical properties of Chengal wood, particularly under various stress conditions, still need to be explored. The mechanical properties of wood are critical for its applications in construction, furniture making, and various other industries.

Thus, this paper aims to systematically investigate the mechanical properties of Malaysian Chengal wood species. A series of mechanical tests, including bending, compression, and tensile tests, will provide detailed insights into their performance characteristics. Understanding these properties is essential for optimising their use in engineering applications and enhancing the sustainability of this valuable natural resource.

Research Methodology and Material Selection

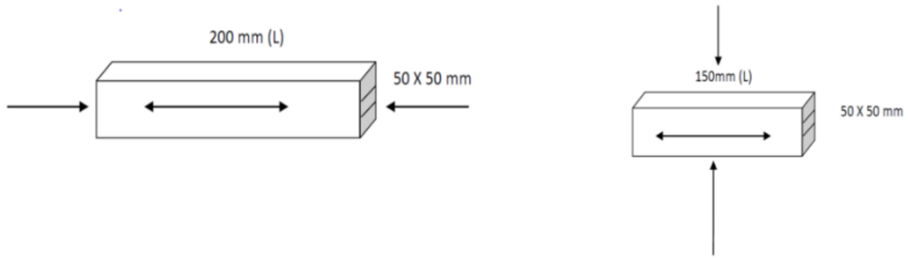
Material for Solid Timber

The selected wood species used in this study is Chengal, known as Neobalanocarpus heimii (Dipterocarpaceae) by its standard Malaysian name. It is naturally durable and typically highly resistant to termite damage and fungal infestation. Moreover, the timber is classified as a dense hardwood, with an air-dried density ranging from 915 to 980 kg/m^3. According to the Malaysian Standard MS 544 Part 2, Chengal is classified under Strength Group 1 (SG 1), and its mechanical properties are listed in Table 1. The Chengal wood samples obtained in this study were supplied and manufactured by a local supplier. The Chengal woods are cut to meet the specific needs of various testing methods, including compression, tensile, bending, moisture content, and density tests.

Table 1
Mechanical Properties of Chengal Wood

Mechanical properties of Chengal wood	
Modulus of Elasticity (N/mm^2)	19000
Modulus of Rupture (N/mm^2)	149
Compression Parallel to Grain (N/mm^2)	31.9
Compression Perpendicular to Grain (N/mm^2)	5.85
Shear Strength (N/mm^2)	3.13

Compression Test
Specimen Preparation
The solid timber beam is divided into 50 x 50 x 200 mm parallel to the grain and 50 x 50 x 150 mm perpendicular to the grain, as illustrated in Figure 2. Each specimen for the compression test was cut from a source of 30 wood pieces.



(a) (b)

Figure 2: Compression Test Schematic Diagram (a) Parallel to the Grain; (b) Perpendicular to the Grain

Test Method
The compression strength of solid timber was evaluated using a UTM-100 Universal Testing machine with a 1000kN load cell, as shown in Figure 3, for compression parallel and perpendicular to the grain. A metal bearing plate, 50 mm in width, positioned across the upper surface of the specimen at equal distances from both ends, oriented at a right angle to its length. The specimens were arranged to transmit the load through the bearing plate to a radial surface. The load was continuously applied during the entire test, with the movable crosshead moving at a 0.6 mm/min rate. Load-compression curves were recorded for all specimens up to a compression of 2.5 mm, at which point the test was discontinued. The tests were conducted according to the ASTM D14. Compression measurements were taken between the loading surfaces, and deformation readings were captured up to 0.002 mm. Transducers were used to measure the deformations.

Vol. 13, No. 4, 2024, E-ISSN: 2226-6348 © 2024

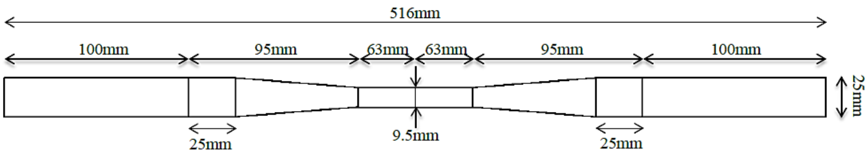
(a) (b)

Figure 3: Compression Test Set Up for (a) Parallel to the Grain; (b) Perpendicular to the Grain

Tensile Test

Specimen Preparation

The tensile wood specimens were shaped into a dog bone whose dimensions complied with ASTM D-143, as illustrated in Figure 4. To determine Poisson's Ratio, two strain gauges must be positioned in the middle section of the dog bone specimen. The test specimen has a gauge length of 2mm and a thickness of 5 mm. Before testing, all exact measurements and weights of the samples were documented.



(a)

(b)

Figure 4: Dog-bone specimens (a) Dimensions of sample; (b) Actual sample

Test Method

Thirty (30) identical specimens with a length of 516 mm were prepared. All samples were evaluated in a room environment. The test was conducted using a 1000kN Universal Testing Machine (UTM), illustrated in Figure 5. A whole specimen cross-section is subjected to continuous tensile loading at a 1mm/min rate and tested using a UTM-1000 machine. Two strain gauges were attached in the middle section of the dog-bone specimen to measure both

Vol. 13, No. 4, 2024, E-ISSN: 2226-6348 © 2024

longitudinal and transverse strain. These strain gauges were placed in two directions (x and y), corresponding to parallel and perpendicular orientations to the grain. The deformation of the specimen was measured using a mechanical extensometer. A continuous crosshead speed of 1.5 mm/min was applied. The load continued until the specimen failed.

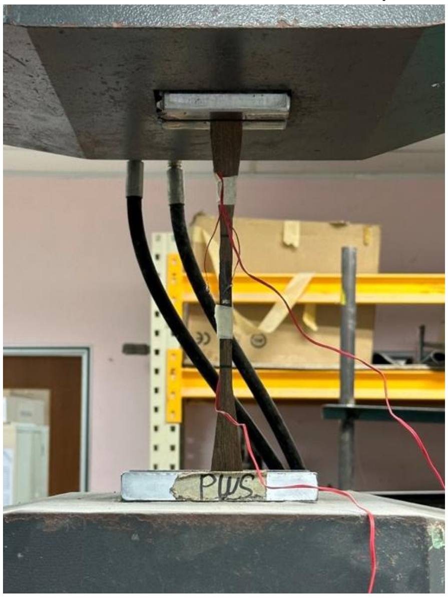


Figure 5: Tensile Test Set Up using 1000kN Universal Testing Machine (UTM)

Bending Test

Specimen Preparation

The tensile wood specimens were shaped into a dog bone whose dimensions complied with ASTM D-143, as illustrated in Figure 4. To determine Poisson's Ratio, two strain gauges must be positioned in the middle section of the dog bone specimen. The test specimen has a gauge length of 2mm and a thickness of 5 mm. Before testing, all exact measurements and weights of the samples were documented. Five (5) solid timber beam samples with dimensions of 2000 mm x 50 mm x 100 mm, as shown in Figures 6 and 7, were employed.

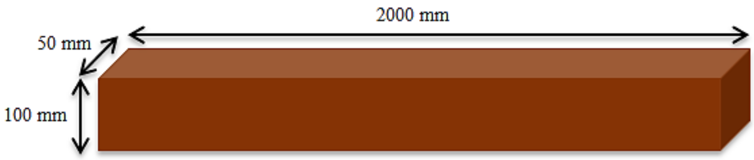
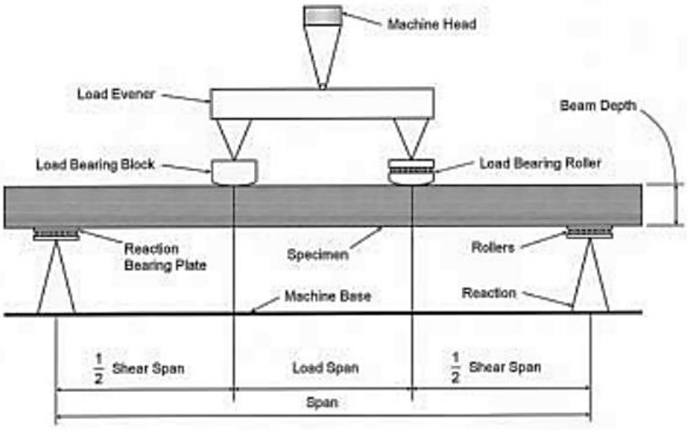


Figure 6: Solid Timber Beam Schematic Diagram

Figure 7: Actual Specimens for Bending Test

Test Method

Figure 8 shows the bending strength test with a 4-point bending configuration by BS EN408, where a simply supported beam with a clear span measuring 18 times the beam height (18 x 100 = 1800 mm); undergoes symmetrical loading through two equal forces at the third points of the free span, positioned at 6 x 100 mm = 600 mm. The load on the beam was pressed by uniformly displacing the loading pistons, ensuring that the maximum speed (in seconds) did not exceed 0.003 times the beam height (0.003 x 100 mm = 0.3 mm/s).



(a)

(b)

Figure 8: The 4-Point Bending Test Set Up According To BS EN408 (a) Schematic Diagram and (b) Actual setup

Moisture Content and Density

Specimen Preparation

To assess the moisture content, the specimens from the compression parallel to the grain test were cut to 50mm x 50mm x 50mm with five (5) replicates. Each specimen's width, thickness, and length were precisely measured for density.

Test Method

The moisture content (MC) was precisely calculated based on CEN EN 13183-1 (2002) standard (oven dry method), as stated in the CEN EN 408 (2010) standard using Equation (1). The sample's moisture content was determined by weighing it in the air-drying state and drying it in the oven for 48 hours at 105°C. Figure 9 shows the setup of the moisture content test.

$$H = \frac{M_1 - M_0}{M_0} \times 100\% \quad (1)$$

Where;

M_1 = weight of sample at test in gram (g)

M_0 = Oven-dry weight of the sample after drying at 105°C in gram (g)

Figure 9: Samples in the oven for determination of moisture content

Results and Discussion

Compressive Strength

When the deformation caused by low stress is recoverable after the stresses are removed, this is called elasticity. Plastic deformation or failure happens when subjected to increasing stress levels. Elastic behaviour is commonly found in timber that has been compressed to failure. The elastic properties of tensioned wood are more sensitive to moisture content. Figure 10 shows the elastic and plastic behaviour in timber after being compressed through the load-displacement curve.

The initial segment of the curve displays a linear relationship between load and displacement up to 28.83 kN, signifying the elastic behaviour of Chengal wood where the material deforms proportionally to the applied load. Beyond this linear region, the curve deviates into a non-linear phase, indicating the onset of plastic deformation, where the wood starts to yield and undergo permanent deformation. After this initial yielding, the curve enters another linear region with a different slope. This second linear segment suggests a different stiffness characteristic, possibly due to the rearrangement or crushing of the wood fibres. The curve peaks at 83.75 kN, representing the ultimate compressive strength of Chengal wood. Beyond this point, any further load results in failure and significant deformation, as evidenced by the increasing displacement without a corresponding increase in load. The change in slope between the two linear regions reflects a change in the wood's resistance to compressive loads. The initial slope (before W1) represents the elastic modulus. In contrast, the reduced slope in the second linear region (after W1) indicates diminished stiffness due to internal damage or yielding within the wood structure.

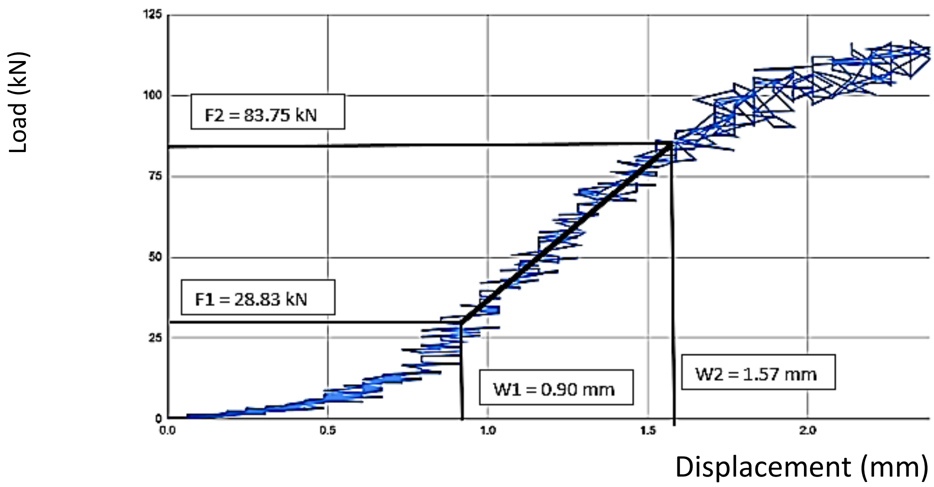


Figure 10: Typical load-displacement curve in a compression test

Compressive Strength Parallel to the Grain

Thirty (30) specimens were tested at 0.01 mm/sec for the compression test parallel to the grain. Table 2 shows the maximum load and deformation of the test parallel to the grain for Chengal wood. The test will be repeated until the specimen breaks or deforms by 150 mm.

Table 2
Load and Displacement of the Compression Test Parallel to the Grain

Specimen	Load (kN)	Deformation (mm)	Specimen	Load (kN)	Deformation (mm)
1	120.67	5.9	18	117.878	5.7
2	108.473	5.2	19	145.866	5.9
3	134.079	6.5	20	149.471	6.9
4	116.108	5.2	21	116.188	5.9
5	122.671	5.3	22	125.086	7.0
6	132.921	6.2	23	168.591	7.1
7	129.932	6.0	24	103.355	6.0
8	88.964	4.6	25	116.947	6.5
9	116.627	6.0	26	108.65	7.6
10	129.187	5.7	27	122.69	6.5
11	162.001	6.1	28	119.364	5.7
12	127.502	5.7	29	109.137	4.9
13	110.519	5.3	30	122.183	5.8
14	137.104	6.1	Max	**168.591**	**7.6**
15	92.466	5.9	Mean	**122.992**	**5.98**
16	115.425	6.1	Std Dev	**17.499**	**0.650**
17	119.698	6.1	CV (%)	**14.2**	**10.88**

Compressive Strength Perpendicular to the Grain

Thirty (30) specimens were evaluated at a speed of 0.005 mm/sec for the compression test perpendicular to the grain. Table 3 shows the maximum load and deformation of the test perpendicular to the grain. The test was repeated until the distortion reached 2.5 mm.

Table 3
Load and Displacement of the Compression test Perpendicular to the Grain

Specimen	Load (kN)	Deformation (mm)	Specimen	Load (kN)	Deformation (mm)
1	105.983	2.381	18	56.616	2.500
2	91.331	2.259	19	32.211	2.500
3	113.309	2.381	20	22.795	2.500
4	99.145	2.503	21	35.027	2.500
5	116.728	2.381	22	40.531	2.500
6	126.496	2.259	23	41.077	2.500
7	123.077	2.381	24	42.234	2.500
8	141.636	1.587	25	66.563	2.500
9	69.353	1.893	26	55.876	2.500
10	88.4	1.465	27	47.346	2.500
11	141.636	1.648	28	49.286	2.500
12	138.217	1.832	29	47.283	2.500
13	54.701	2.259	30	34.410	2.500
14	134.799	2.259	Max	**151.893**	**2.5**
15	97.68	1.954	Mean	**82.599**	**2.28**
16	151.893	2.442	Std Dev	**40.399**	**0.31**
17	112.332	2.076	CV (%)	**48.91**	**13.59**

Tensile Strength

Table 4 and Figures 11 and 12 show the behaviour of dog-bone specimens during the tensile test. The detailed values of tensile properties recorded here are tensile strength, Poisson's Ratio, and modulus of elasticity.

Table 4
Results from the Tensile test on Dog-Bone Specimens

Sample	Tensile Strength, σ (N/mm²)	Poisson's Ratio, v	Modulus of Elasticity, MOE (N/mm²)	Sample	Tensile Strength, σ (N/mm²)	Poisson's Ratio, v	Modulus of Elasticity, MOE (N/mm²)
1	112.07	x	18660.65	16	80.03	0.079	22273.58
2	109.77	x	14639.75	17	109.06	0.070	20485.38
3	x	x	x	18	x	x	x
4	x	x	x	19	x	x	x
5	x	x	x	20	x	x	x
6	x	x	x	21	x	x	x
7	154.58	0.123	24436.78	22	129.64	0.071	21475.23
8	x	x	x	23	x	x	x
9	50.66	x	19804.69	24	x	x	x
10	112.16	0.054	23168.36	25	x	x	x
11	x	x	x	26	x	x	x
12	114.90	0.127	21084.65	27	x	x	x
13	x	x	x	28	133.60	0.046	20455.62
14	73.60	0.055	19131.74	29	135.06	0.077	25388.92
15	86.93	0.107	33828.17	30	123.56	0.113	20454.94
				Ave.	108.97	0.084	21806.32

Note: x = Specimen failed during test (split at grip)

The graph in Figure 11 illustrates the relationship between stress (σ) and strain (ε) for six different specimens, each represented by a distinct curve. Initially, each curve shows a linear relationship between stress and strain, indicating the elastic behaviour of Chengal wood, where the material deforms proportionally to the applied load. The slope of this linear region represents Young's Modulus (modulus of elasticity), which measures the material's stiffness. A steeper slope indicates a stiffer material. Specimen-7 has the steepest initial slope, suggesting it is the stiffest among the specimens, while Specimen-22 has the gentlest slope, indicating the lowest stiffness. Each curve deviates from the linear path as the load increases, transitioning to a non-linear region. This behaviour suggests the onset of plastic deformation, where the material begins to yield and undergo permanent deformation. The peak point on each curve represents the ultimate tensile strength (UTS) of the material, beyond which failure occurs.

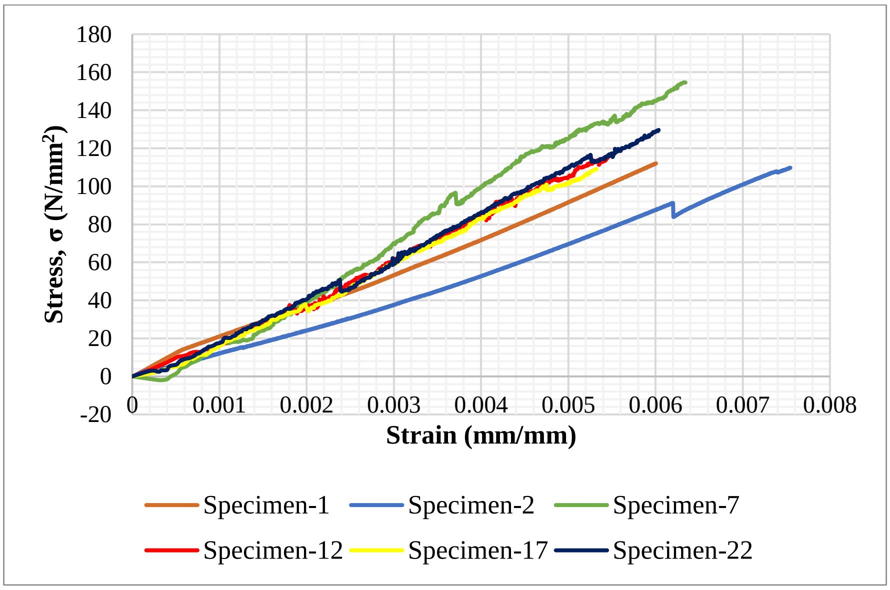


Figure 11: Stress versus strain for Chengal wood

The graph in Figure 12 illustrates the transverse strain versus longitudinal strain for tensile tests on dog-bone specimens of Chengal wood. Each curve represents a different specimen, highlighting the distinct behaviour under tensile loading. Specimen-7 shows a relatively steep initial slope, indicating a high level of transverse strain for a given longitudinal strain. This behaviour suggests that Specimen-7 has a higher degree of anisotropy, where deformation in one direction significantly influences the other. Specimen-22 and Specimen-10 have gentler slopes, indicating lower transverse strains for given longitudinal strains, which suggests less coupling between the two strain directions and potentially higher uniformity in their mechanical properties. The ultimate strain points for each specimen vary, reflecting differences in their tensile strengths and failure points. Specimen-7, for example, reaches a higher transverse strain before failure compared to other specimens. Additionally, Specimen-12 exhibits a sudden increase in transverse strain just before failure, suggesting that it might have experienced a localised failure or crack propagation leading to a rapid change in strain distribution.

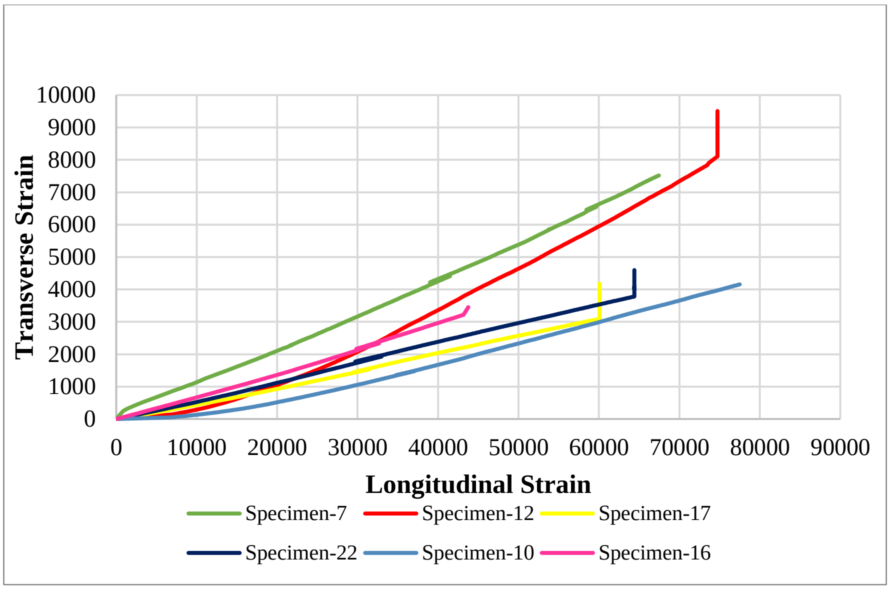


Figure 12: Transverse strain versus Longitudinal strain for Chengal wood

Bending Strength

Figure 13 depicts the load versus displacement behaviour for five Chengal wood beams subjected to bending stress, with displacement measured at the midspan. The curves illustrate linear and non-linear behaviour under bending stress for each sample until failure. Initially, all specimens exhibit ductile behaviour, transitioning to brittle behaviour as they reach their maximum load capacities. Sample 1 demonstrates the highest stiffness and load capacity, while Sample 5 shows the most significant displacement before failure.

Sample 1 bears the highest load, peaking at approximately 14 kN before failure. Its curve shows a steep, nearly linear rise in load up to around 12 mm displacement, indicating high stiffness. Beyond this point, the load increases slower, showing non-linear behaviour before an abrupt drop, indicating brittle failure. Sample 5, with a maximum load-bearing capacity of around 8 kN, initially shows a linear load-displacement relationship up to about 10 mm displacement. It then transitions to a non-linear phase, ultimately failing at around 25 mm displacement, indicating the highest ductility among the samples but ending in brittle failure.

Sample 3 reaches a maximum load of around 10 kN before failure. Its load-displacement relationship remains relatively linear up to around 10 mm displacement. Beyond this, the load increases at a slower rate until failure at around 20 mm displacement.

Samples 2 and 4 initially exhibit a linear elastic region where the load increases linearly with displacement, indicating elastic deformation following Hooke's Law, where stress is proportional to strain. Sample 4 shows a more brittle failure mode with a sudden load drop, whereas Sample 2 exhibits a more ductile failure mode with a gradual load decrease.

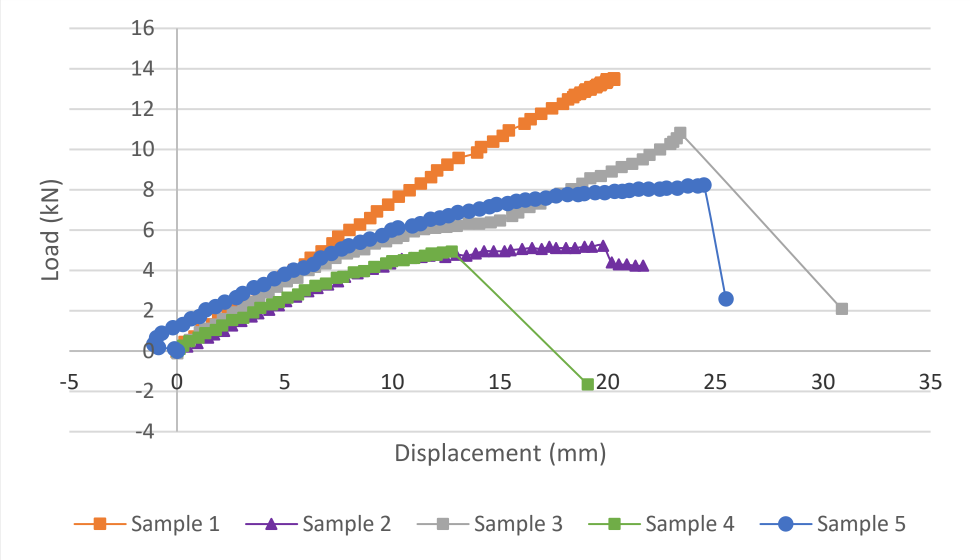


Figure 13: Load versus displacement for Chengal wood at Midspan (LVDT2)

Moisture Content and Density

Table 5 presents the moisture content of five tested samples of Malaysian Chengal wood. The average moisture content across the samples is 8.87%, providing an overall indication of the moisture level in Chengal wood, which is essential for understanding its performance in different environmental conditions and applications. The average moisture content of 8.87% indicates that Chengal wood maintains a moderate moisture level, making it relatively stable for most construction purposes. The observed moisture content range (7.93% to 9.33%) shows that the wood is relatively dry according to MS 544 Part 2: 2017 standards, which typically corresponds to higher mechanical strength and stiffness. Generally, lower moisture content in wood is associated with improved resistance to decay and fungal attack.

Table 5

The Moisture Content of Chengal Wood

Sample	**Weight before oven-dry (g)**	**Weight after oven-dry (g)**	**Moisture Content (%)**
1	463.30	425.30	8.93
2	383.90	351.60	9.19
3	352.10	323.20	8.94
4	448.70	410.40	9.33
5	405.40	375.60	7.93
		Average	8.87

Table 6 shows the density measurements for five samples of Malaysian Chengal wood, calculated as the ratio of weight to volume for each sample. The density values vary, with the highest being 926.60 kg/m³ and the lowest at 704.20 kg/m³. The average density of 821.36 kg/m³ indicates that Chengal wood has a relatively high density, which is typical for hardwood species. For comparison, the specified Chengal density at 19% moisture content according to MS 544: Part 2: 2017 is 980 kg/m³. This density difference of 16.19% indicates a slightly lower density due to the lower moisture content in the samples.

Table 6
Density of Chengal wood

Sample	Weight (kg)	Volume (m^3)	Density (kg/m^3)
1	0.4633	0.0005	926.60
2	0.3839	0.0005	767.80
3	0.3521	0.0005	704.20
4	0.4487	0.0005	897.40
5	0.4054	0.0005	810.80
		Average	821.36

Conclusion

The experimental analysis of Malaysian Chengal wood species reveals significant insights into its mechanical properties. Initial load-displacement curves indicate that Chengal wood exhibits a well-defined linear elastic region where stress and strain are proportional. This behaviour is consistent with the material's high stiffness and resilience under moderate loads. Beyond this linear region, Chengal wood transitions into a non-linear phase, suggesting the onset of plastic deformation. This transition marks permanent deformation, highlighting the wood's ability to endure higher loads before failure.

The ultimate tensile and compressive strengths of Chengal wood are notably high, emphasising its suitability for structural applications. During tensile tests, the wood demonstrates a combination of ductile and brittle behaviours, with samples showing varied stiffness and load-bearing capacities. Chengal wood displays a distinct peak load in compression tests, beyond which significant deformation occurs without an increase in load, indicating failure. The variation in peak loads across different samples underscores the inherent variability in wood properties due to natural factors.

Its moisture content and density influence the mechanical properties of Chengal wood. Experimental results show an average moisture content of 8.87%, which is considered optimal for maintaining mechanical strength and stability. The density measurements, averaging 821.36 kg/m^3, confirm that Chengal wood is a high-density hardwood. This high density contributes to its strength and durability, making it a preferred choice for heavy-duty structural applications. The relationship between moisture content and density also aligns with the standards of MS 544: Part 2: 2017, indicating that lower moisture content correlates with better mechanical performance. Comparative studies on different samples of Chengal wood reveal significant variability in stiffness and flexibility. Some samples exhibit higher stiffness, characterised by steep initial slopes in load-displacement curves, while others display greater flexibility with higher displacement before failure. This variability is crucial for selecting the correct grade of Chengal wood for specific structural needs. Samples with higher stiffness are ideal for applications requiring minimal deformation under load, whereas more ductile samples are better suited for applications where flexibility and energy absorption are critical.

Acknowledgements

The authors thank the Ministry of Science, Technology and Environment, Malaysia, for funding the project through the Fundamental Research Grant Scheme (FRGS) FRGS/1/2022/TK06/UITM/02/46.

References

Abdul Razak, A., Shahrin, N.I., Mohd Jani, J., Hamid, N.H. (2020). Performance Evaluation on the Smartness of Malaysian Timber. In: Emamian, S.S., Awang, M., Yusof, F. (eds) Advances in Manufacturing Engineering. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-15-5753-8_13

Ahmad, Z., Bon, Y. C., & Abd Wahab, E. S. (2010). Tensile strength properties of tropical hardwoods in structural size testing. International Journal of Basic and Applied Sciences 10: 1–6.

Ali, K. H., Hussain, T., and Kamali, A., (2014). Compression Perpendicular to Grain in Timber-Bearing Strength for a Sill Plate. Master's Thesis, Linnaeus University, Växjö, Sweden.

Aziz, M. A. (1995). A Text Book of Engineering Materials, Revised Edition, Trans-World Book Company, Dhaka.

Baharin, A., Ahmad, Z., & Chen, L. W. (2020). Bending Strength Properties of Keruing and Light Red Meranti in Structural Size in Accordance with Eurocode 5. In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 4, pp. 1323–1327). Blue Eyes Intelligence Engineering and Sciences Engineering and Sciences Publication - BEIESP. https://doi.org/10.35940/ijitee.c8362.029420

Bodig, J. and Jayne, B. A. (1982). Mechanics of Wood and Wood Composite; Van Norstrand Reinhold Company Inc.: New York, NY, USA.

Ernur, A. M., Akiner, I., Akiner, N., & Pancovska, V. (2022). Using wood as a new generation building material in the context of sustainable development. Zaštita materijala, 63(1), 68-78. https://doi.org/10.5937/zasmat2201068A

Hassan, R., Ahmad, Z., Ibrahim, A. and Mohd Nor, M. S. (2004). Compressive Strength Properties of Structural Size Timber Made from Selected Malaysian Tropical Timber; Institut Penyelidikan, Pembangunan dan Pengkomersilan, Universiti Teknologi MARA Shah Alam, Malaysia.

Hazira, W., Azran, M., and Zakiah, A. (2011). Bending Strength Properties of Glued Laminated Timber from Selected Malaysian Hardwood Timber. International Journal of Civil & Environmental Engineering IJCEE-IJENS. 11: 7-12.

Hossain, M. B., and Abdul Awal, A.S.M. (2012). Mechanical properties and durability of some selected timber species. Malaysian Journal of Civil Engineering, 24(1), 67-84.

Lavers, G. M. (1969). The strength properties of timbers. Forest Products Research, Bulletin No. 50. Ministry of Technology, London.

Panshin, A. J., and Zeeuw, C. D. (1980). Textbook of wood technology. Vol.1, 4th edition. McGraw-Hill Book Company, New York.

Puaad, M. B. F. M., and Ahmad, Z., (2017). Comparing the Compressive Strength Properties of Structural Size and Small Clear Specimens for Malaysian Tropical Timber. Sci. Int. 2017, 29, 25–29.

Wong, T. M. (1982). A dictionary of Malaysian timbers. Malayan Forest Records, No. 30. Forest Department, Kuala Lumpur.

Wood handbook: Wood as an engineering material (2010). General Technical Report FPL-GTR-190. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.508 p.