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Structural-Sized Compression Grade Stresses Derived from Malaysian Tropical Hardwood Timber

Zakiah Ahmad[a], Anis Azmi[b*], Nurul Izzatul Lydia Za'ba[c], Wei Chen Lum[d] & Norshariza Mohamad Bhkari[a,e]

[a]*Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor.*

[b]*Department of Civil Engineering, Faculty of Engineering and Built Environment,*

Universiti Kebangsaan Malaysia 43600 Bangi, Selangor, Malaysia.

[c]*Centre for Infrastructure Geo-Hazards and Sustainable Materials, Faculty of Engineering,*

Built Environment and Information Technology, SEGi University, 47810 Petaling Jaya, Selangor, Malaysia.

[d]*Department of Bio and Natural Resources Technology Faculty of Bioengineering and Technology,*

Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia.

[e]*Institute for Infrastructure Engineering and Sustainable Management (IIESM),*

Universiti Teknologi MARA, 40450 Shah Alam, Selangor

[*]*Corresponding author: anisazmi@ukm.edu.my*

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ABSTRACT

Strength properties of Malaysian timbers are given in MS 544: Part 2. However, the strength properties specified in MS 544: Part 2 was derived from the assessment of small clear specimen. In recent decades, there has been a significant and swift progression in the evolution of engineered timber products (ETP), accompanied by a substantial increase in their utilization within the construction industry. Therefore, to provide a reliable design for engineered timber product, it is essential to have the access to the strength properties derived from structural timber size. Thus, the aim of this study was to assess the compressive properties (parallel and perpendicular to the grain) of Malaysian tropical hardwoods utilising structurally sized specimens. The timber species tested ranged in strength group (SG) 1 until 7 in accordance with MS 544: Part 2 namely Balau, Kempas, Kelat, Resak, Kapur, Keruing, Mengkulang, Light Red Meranti and Geronggang. Based on EN 408:2012, the desired properties (compressive strength and modulus of elasticity) were determined for the timber specimens. According to the results of this study, Kempas (SG2) and Resak (SG4) have the highest compressive strength parallel (62.9 N/mm^2) and perpendicular (17.7 N/mm^2) to the grain, respectively. In contrast, Geronggang (SG7) and Light Red Meranti (SG6) shows the weakest compressive strength parallelly (26.9 N/mm^2) and perpendicularly (3.3 N/mm^2) respectively. Based on the findings obtained in this study, the experimental grade stresses are generally much higher than the values given in MS 544: Part 3. In conclusion, the grade stresses of Malaysian tropical hardwoods stated in MS 544: Part 3 are discordant with their genuine value.

Keywords: Compressive strength; Malaysian timber; large size; strength properties; MS544

INTRODUCTION

Bending, compression, and tension qualities of timber are critical for its application and incorporation in the building and construction sector. However, the strength characteristics associated with timber vary according to the species of timber, the age of the tree in which sawn timber are produced, the silvicultural procedures used, and even amongst trees of the same species (Lin et al. 2006). Therefore, to address the problem and to provide simplicity in the design procedures, timber species with similar mechanical properties are congregated together in groups identified as stress grades. This will also fix the shortage issue of certain timber species at a particular time as other species which belong to the same stress grade can be used as substitute. To this date, Malaysia continues to apply the grade stresses values stated in MS 544: Part 2: 2017 and MS 544: Part 3 for construction purposes. Moisture content, and variability of the sawn timber used as well as the appropriate safety factors need to be taken into serious consideration when using the design values.

In 1940, Thomas reported the mechanical properties of many Malaysian hardwood timbers which was considered as the earliest recording of such data. The data were subsequently gathered and compiled by Lee and Engku (1993). The data they worked with was acquired through the testing of small clear specimens and is published in the still-in-use Timber Trade Leaflet No. 34. Burgess (1956), which categorized Malaysian timbers into four (4) strength groups namely strength group A, B, C and D. When classifying timbers into a given strength category, only compressive and bending strength were considered. In 1972, Engku further improvised the strength group by incorporating basic stress and grade stress into the four strength groups which make them more reliable.

In 1997, Chu et al. introduce a new strength grouping system based on grade stresses which group the timbers into seven (7) strength groups, ranges from SG1 (the strongest) to SG7 (the weakest). This relatively new strength grouping system of Malaysian timbers and is still in use today. When timber engineers realize that there was a need for design values derived from structural size specimen particularly when designing glued laminated timber structure in Malaysia, a new standard MS 544: Part 3 was established by Malaysia standard committee to fulfil the requirement. However, the standard was established by adopting the BS 5268: 1996 which utilizes the strength data of the few available Southeast Asia timbers without testing any structural-sized Malaysian timbers. The timbers species used were Balau, Kempas, Kapur, Merbau and Keruing. MS 544: Part 3 in its latest version, has revised the strength table which was adopted from BS 5268: 2002. The strength properties of Mengkulang, Dark Red Meranti, Light Red Meranti and Yellow Meranti have been added to the standard.

In current Malaysia construction industry, most timber structures are still designed according to the permissible stress system which utilised the strength data derived from small clear specimen. It is understood that small clear specimens which possess clear and defect-free characteristic behave differently compared with structural sizes timber. Clear or defect free timbers typically shows higher strength performance in tension but lower strength performance in compression. This disagrees with the known characteristics of structural sawn timber with the present of sloping grain or knots. Furthermore, it is expected that the strength qualities of small clear specimens are naturally greater than those of structurally sized specimens, as small clear specimens are usually without defects that degrade strength of the timber (Jamil et al. 2013; Wahab & Jumaat, 2014; Puaad, Ahmad & Yamani, 2015). As a result, strength data obtained from small clear specimens must be multiplied by a greater safety coefficient to accurately determine the real working stress encountered in practice. This is because the weakening factors caused by imperfections in structural sized timber are not taken into consideration when assessing the strength properties of small clear specimens. Naturally, a reduction coefficient is not needed for structural size specimens because all strength degrading factors such as defects are included and thus provide a real in-service loading conditions for timber structure (Dinwoodie 2011). It is believed that the actual mechanical performance of timber structure such as strength and stiffness are less viable to be predicted from the properties of small clear specimens (Wahab, Jumaat & Khaidzir 2012).

With the advancement of technology, engineered or mass timber products such as cross laminated timber (CLT), glued laminated timber and laminated veneer lumber (LVL) have gained popularity in mass timber construction industry nowadays. The building industry is undergoing a transformation as mass timber evolves from emerging technology to an established standard for structural building components. These products are designed to provide improved structural characteristics and overcome some of the limitations of solid timber. Hence, the strength properties derived from structural size timber are important to provide a reliable strength properties for structural size timber used as load-bearing element as well as the performance of the whole timber structure.

Structural engineers in Malaysia as well as around the globe are beginning to explore alternative materials to substitute or complement conventional construction materials such as steel and concrete. The construction industry consumes a significant amount of energy and contributes to substantial carbon dioxide (CO_2) emissions. Using wood-based materials in construction has been proven to require less energy and produce lower CO_2 emissions compared to materials such as concrete and steel (Sanni & Ekundayo 2022). The reliable structural performance of tropical hardwood timbers makes it a viable alternative material. Thus, to provide them with trustworthy design values, it is best to obtain the strength qualities of timber through testing utilizing structural or large size specimens. Hence, the objective of this research was to determine the compressive strength properties of structural size specimens. The strength properties were subsequently used to derive the grade stresses. For this study, Balau, Kempas, Kelat, Resak, Kapur, Keruing, Mengkulang, Light Red Meranti and Geronggang were the nine (9) Malaysian Hardwoods selected. The findings of this study will promote a better knowledge, and hence a greater adoption and utilization of timbers in the building and construction industries.

MATERIALS AND METHOD

MATERIAL

The timber species selected were classified in SG1 to SG7 according to MS 544: Part 2 namely Balau, Kempas, Kelat, Resak, Kapur, Keruing, Mengkulang, Light Red Meranti and Geronggang which reflect the varying densities and strengths of tropical timbers found in Malaysia. The timber specimens were prepared in accordance with EN 408: 2012. To obtain a more accurate depiction of the strength of timber in Malaysia, all specimens were sourced from four (4) distinct regions in West and East Malaysia. Three (3) regions from the North, middle and South region (Kelantan, Pahang and Johor) were selected to represent Peninsular Malaysia and East Malaysia (Sarawak). Table 1 shows the nine (9) Malaysian timbers used for the assessment of compressive strength properties with their corresponding density, size and quantity of specimens tested for parallel and perpendicular to grain.

TABLE 1. Density, size and quantity of specimens tested for parallel and perpendicular to grain

		Parallel		Perpendicular
Size of Specimen (mm)		75x150x450	100x150x600	45x70x95
Species of Timber (Strength Group)	Air-Dry Density (kg/m^3)			
Balau (SG1)	850-1155	100	100	200
Kempas (SG2)	770-1120	100	100	200
Kelat (SG3)	495-1010	100	100	200
Resak (SG4)	655-1155	100	100	200
Kapur (SG4)	575-815	100	100	200
Keruing (SG5)	690-945	100	100	200
Mengkulang (SG5)	625-895	100	100	200
Light Red Meranti (SG6)	385-755	100	100	200
Geronggang (SG7)	350-610	100	100	200

Source: MS 544: Part 2: 2001, [2]Air-dry densities obtained from 100Malaysian Timbers: 2010 Edition

Sawn timbers from the selected species were prepared in accordance with EN 408: 2010. The sawn timbers were first subjected to the kiln drying process and then all the specimens were visually graded. The grading process was carried out by registered grader from Malaysian Timber Industry Board (MTIB) according to BS 5756 and MS 1714 which sawn timbers used only from Hardwood Structural Grade (HSG). Table 1 summarizes the timber species, size, grain direction and the quantity of specimens tested in this study. Compression parallel to grain was determined using two distinct specimen sizes. While compression perpendicular to grain was determined using only one size. There were 1800 specimens tested in each grain direction. The specimens' size was determined in accordance with EN 408: 2012.

TESTING METHOD

All structural specimens had their compressive strength determined in line with EN 408: 2012. Prior to testing, an initial test was undertaken to assess the rate of loading for each timber species, ensuring that specimens fail or achieve the ultimate load, F_{max} within 300s ± 120s (420s). Two Linear Variable Displacement Transducers (LVDTs) were diagonally installed on both major cross-sectional surfaces of the specimens to measure the deformation during testing. The deformation was then utilized to evaluate the specimens' modulus of elasticity as stated in EN 408: 2012. Figure 1 and Figure 2 illustrate the experimental configuration and placement of LVDTs during testing. Specimens parallel to the grain were tested on a Universal Testing Machine (UTM) having a maximum capacity of 2500 kN. While specimens perpendicular to the grain were tested using a UTM with a maximum capacity of 450 kN. According to EN 384: 2016, the material properties (i.e., compressive strength, compressive modulus of elasticity, and density) of all specimens obtained during testing must be adjusted to the standard's specified reference moisture content (u_{ref}) of 12% using the standard's formula. Thus, for the purpose of comparison, all the results provided in this study are the strength properties adjusted to a reference moisture content of 12%.

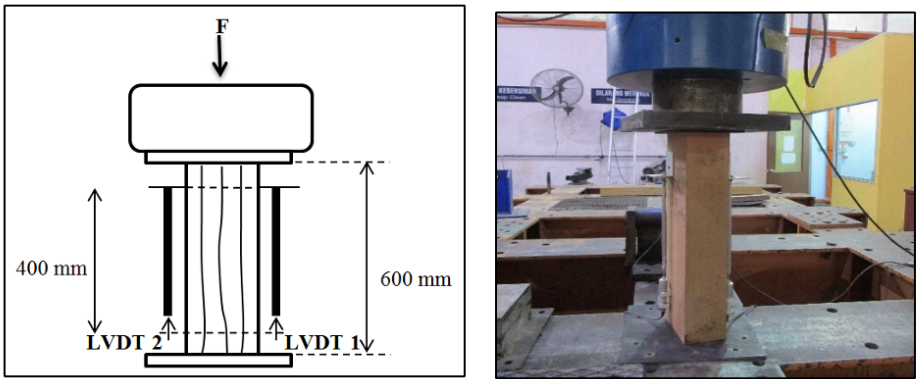


FIGURE 1. The configuration test setup of compression parallel to grain

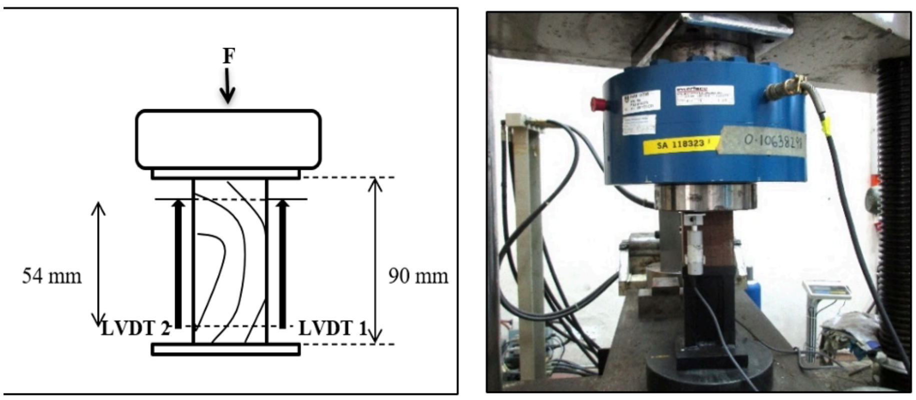


FIGURE 2. The configuration test setup of compression perpendicular to grain

RESULT

COMPRESSION FAILURE CHARACTERISTIC

For each specimen, the failure mode characteristic was recorded throughout the test. Figure 3 depicts the main failure characteristics that occur in compression parallel to the grain. There were five distinguish failure characteristics identified during the test: shearing, crushing, splitting, wedge splitting and crushing with splitting. Among these failure modes, shearing and crushing are the most frequently observed. As per Bodig and Jayne's research in 1982, specimens that are crushed have a higher compressive strength than those that fail in shear. It was also observed that timber density significantly affects failure characteristics. Timber with lower density tends to have a bigger cell structure and thinner cell walls than timber with higher density. (Azmi et al. 2019; Ahmad et al. 2010). Shearing is the predominant failure mode in denser timbers like Balau, Kempas, Resak, Kapur, and Keruing. On the other hand, medium and heavy hardwood timbers tend to exhibit splitting and a combination of crushing and splitting as failure modes, which are far less common in lower density timber. More than 50% of specimens from Mengkulang, Light Red Meranti, and Geronggang fail in crushing.

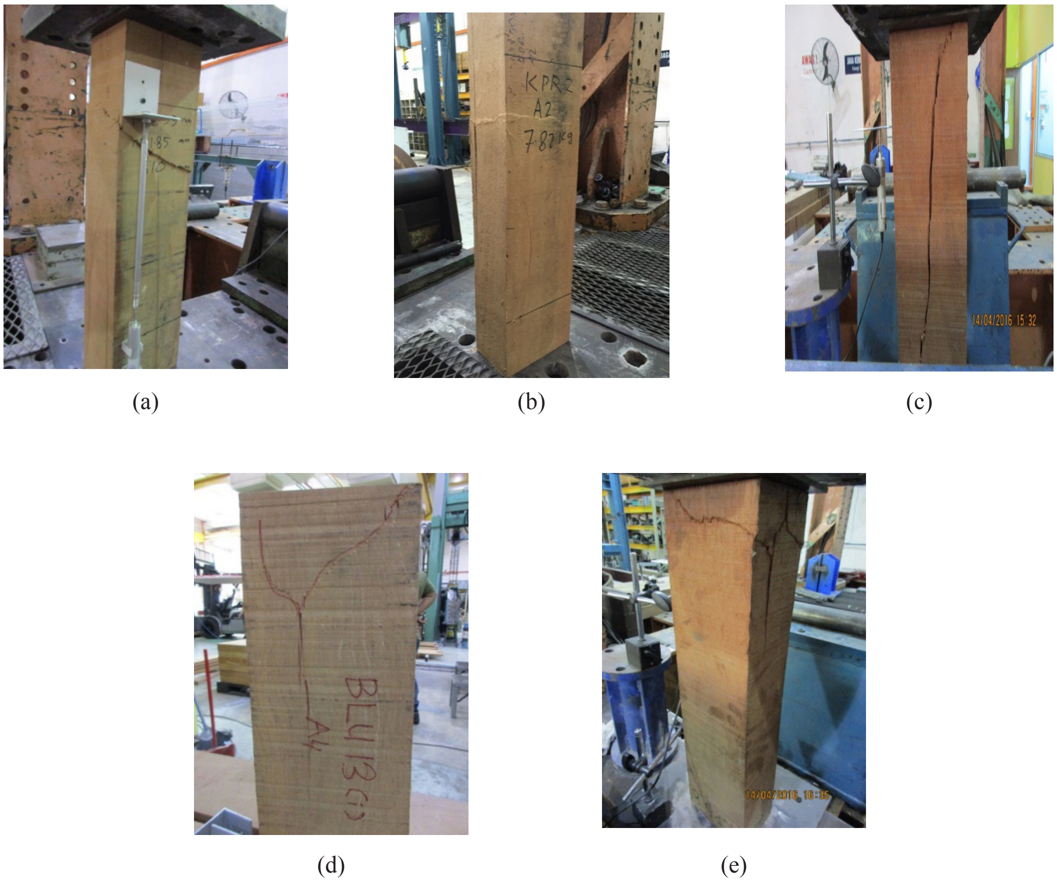
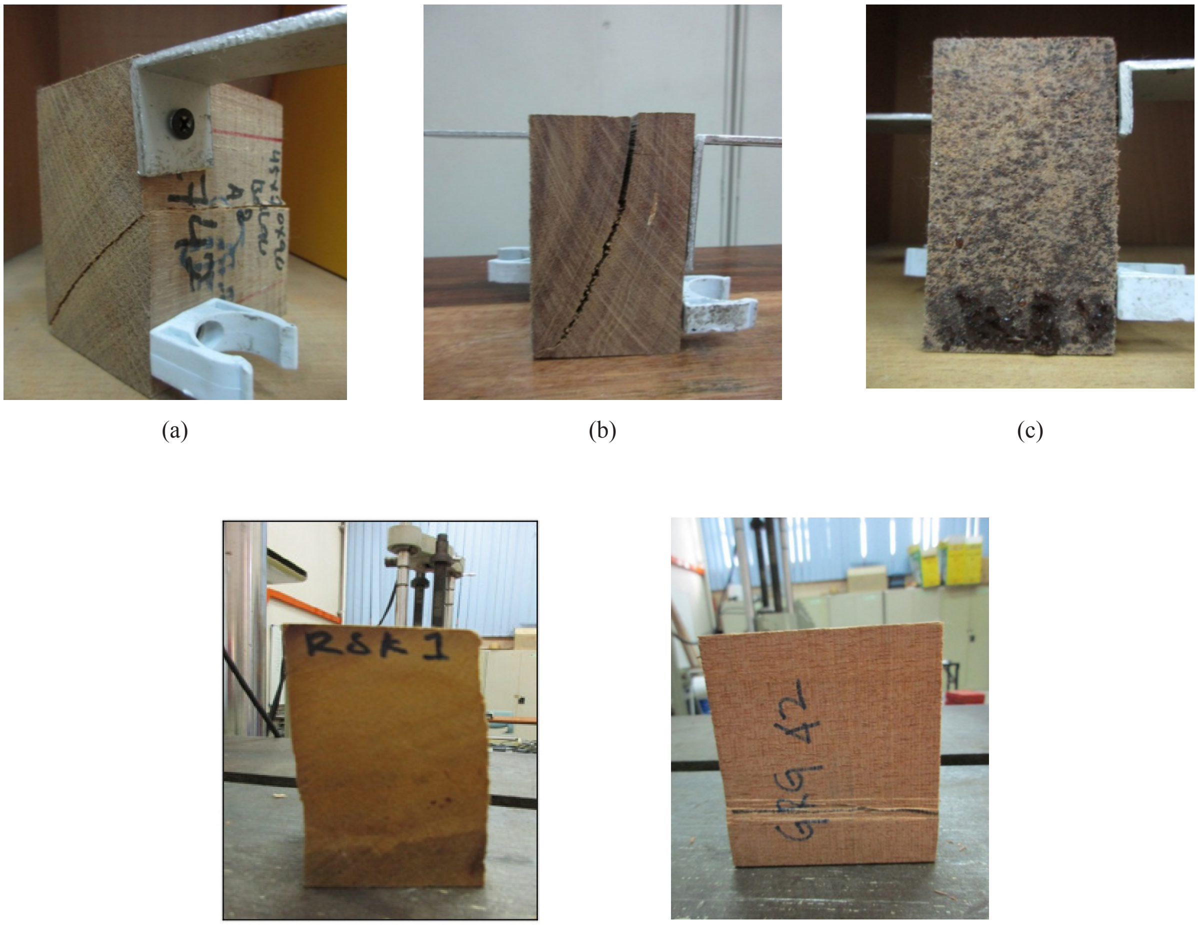


FIGURE 3. Compression Parallel Failure Characteristics: (a) Shearing (b) Crushing (c) Splitting (d) Wedge Splitting (e) Crushing with splitting

Material strength is defined by its ultimate stress, which signifies the point of failure during mechanical tests. Yet not all mechanical tests can measure the maximum stress, particularly in specimens tested in compression perpendicularly. In such cases, failure can be diagnosed by either excessively severe deformation or an initial sign of fracture (Bodig and Jayne, 1982). Figure 4 depicts the types of failure characteristics found in structural specimens perpendicular to grain. Three (3) types of failure modes have been observed: shearing, buckling, and crushing, which are related to specimen densification. The observations indicate that shearing tends to occur more frequently in higher-density specimens like Balau and Kempas, while crushing is more prevalent in lower-density timbers such as Light Red Meranti. Most specimens do not show apparent failure within 300s ± 120s. Figures 4(a), (b), (c), (d), and (e) show examples of the timber specimens that fail within 300s ± 120s.

Figures 4(a) and 4(b) depict shearing where fiber deviation or grain slope is visible, and the specimen is loaded at a specific grain angle, particularly a small grain angle, as seen in Figure 4(b). This specimen is prone to a brittle failure, characterized by a breaking sound during slippage. The slippage occurs due to failure plane of the specimen subjected to compression and shear forces which the stress-strain curve shows a dramatic drop in stress because of the plane's shear failure. For crushing and buckling failure (Figure 4c), stress increases faster with bigger deformation because the fibres collapse and densify, allowing the specimen to withstand a higher load (Yang and Zhang 2018). A distorted specimen can be observed in Figure 4(d), where on the stress-strain curve, a definite stress plateau in the plastic zone was observed following specimen yielding. The loads applied to the specimen are insufficient to generate shear failure; instead, they cause deformation of the specimen. Figure 4(e) shows a noticeable densification at the bottom of the specimen, where a linear elastic area forms initially, followed by a plastic stress plateau after the yield point.



(a) (b) (c)

(d) (e)

FIGURE 4. Types of Failure Characteristic: (a) and (b) Shearing (c) Crushing and buckling (d) and (e) Densification

COMPRESSION PROPERTIES FOR PARALLEL AND PERPENDICULAR TO GRAIN

The average compressive strength, modulus of elasticity (MOE), density and coefficient of variation (COV) of each species were tabulated in Table 2 and 3 which the results referring to previous research by the same author (Azmi et al. 2022). The results reveal that the variance within the specimens in the same species is in the range of low to moderately scatter. The COV within species ranges from 11.9 % to 18.2 % for compressive strength parallel to grain, while the values fluctuate from 15.4 % to 27 % for MOE. The deviations of the strength values are on the lower spectrum considering that the timber specimens were sampled from four different growth regions and the testing conducted involved a large quantity of specimens. Balau, with a density of 912 kg/m^3, was assumed to exhibit the highest compressive strength and MOE parallel to the grain. However, the results obtained from the study show that Kempas has highest compressive strength (62.9 N/mm^2) and MOE (22180 N/mm^2) parallel to the grain despite having second highest density. Both Balau and Kempas have similarly high density. It was suspected that as the density increases to a certain range the influence it has on the strength properties is less significant. Geronggang displayed the lowest compressive strength and MOE.

TABLE 2. Compression Properties Parallel to Grain for all the timber species tested (Azmi et al. 2022)

Species of Timber	Compressive strength (N/mm^2)		Modulus of Elasticity (N/mm^2)		Density (kg/m^3)	
	Mean ± SD	COV (%)	Mean ± SD	COV (%)	Mean ± SD	COV (%)
Balau	54.7 ± 8.3^b	15.1	16439 ± 2534^e	15.4	912 ± 46	5.1
Kempas	62.9 ± 9.4^a	15.0	22180 ± 3442^a	15.5	879 ± 78	8.9
Kelat	44.9 ± 6.2^c	13.7	18109 ± 3565^c	19.7	887 ± 75	8.5
Resak	54.1 ± 8.5^b	15.7	21132 ± 4041^b	19.1	992 ± 98	10.0
Kapur	43.0 ± 5.1^d	11.9	17383 ± 3765^d	21.7	782 ± 59	7.6
Keruing	43.5 ± 7.8^{c,d}	17.9	16588 ± 3076^e	18.5	868 ± 100	11.6
Mengkulang	37.5 ± 5.2^e	13.8	15698 ± 4237^f	27.0	663 ± 67	10.2
Light Red Meranti	29.5 ± 5.4^f	18.2	10913 ± 1735^g	15.9	488 ± 64	13.3
Geronggang	26.9 ± 4.5^g	16.6	10572 ± 2008^g	19.0	557 ± 56	10.1

Note: SD = Standard Deviation; COV = Coefficient of Variation; Mean values with the same superscript are not significant according to Duncan's Multiple Range Test at P-value < 0.05

It is observed that COVs for compressive strength and MOE perpendicular to grain are higher than those for compression parallel to grain. They are approximately 20.3% to 36.9% higher as shown in Table 3. Nevertheless, it is also worth noting that the variation of strength values within species is higher compared than the variation of density within species. It shows that all the specimens within species have desirably consistent density and the variation of strength values might be caused by other factors such as defects, knot or growth ring orientation of the specimens. Based on the results, Resak has the highest compressive strength (17.7 N/mm^2) and MOE (1638 N/mm^2) for perpendicular to grain while Light Red Meranti on the hand, has the lowest compressive strength (3.3 N/mm^2) and MOE (251 N/mm^2). Similarly for density, Resak has the highest density while Light Red Meranti has the lowest density of all the timber species. The COVs for MOE perpendicular to the grain were discovered to be significantly larger than their parallel counterparts. This observation, however, is consistent with the findings of Gerhards (1982), who discovered that the MOE perpendicular to grain deviated to a greater extent than the MOE parallel to grain. Overall, the mean MOE ranges from 251 N/mm^2 for Light Red Meranti (i.e., light hardwood species) to 1638 N/mm^2 for Resak (i.e., heavy hardwood).

The densities for the all the nine (9) timber species tested were in the range as stated in 100 Malaysian Timber book. Most specimens tested have moisture content much higher than the reference 12% which ranged from 10% to 40%. According to Ravenshorst (2015), because tropical hardwoods do not dry as easily as softwoods, they are frequently provided and used with a high moisture content. Furthermore, hardwood utilised in tropical areas typically have a greater equilibrium moisture content in relation to relative humidity. This clarifies for the relatively higher moisture levels found in most of the tested samples, especially those measuring over 100 mm in size. Dinwoodie (1975) and Porteons and Kermani (2013) have also confirmed that once the compressive strength reaches the fiber saturation point, it enters a plateau phase typically occurring at around 20%, and there is no substantial variation in strength concerning moisture content. According to Azmi et al. (2022) it is worth pointing out that for specimens tested with moisture content more than 18%, there is no increment in the compressive strength.

TABLE 3. Compression Properties Perpendicular to Grain for all the timber species tested (Azmi et al. 2022)

Species of Timber	Compressive strength (N/mm^2)		Modulus of Elasticity (N/mm^2)		Density (kg/m^3)	
	Mean ± SD	COV (%)	Mean ± SD	COV (%)	Mean ± SD	COV (%)
Balau	14.7 ± 3.0^b	20.3	1377 ± 435^b	31.6	934 ± 39	4.2
Kempas	12.1 ± 2.8^c	23.3	1167 ± 359^c	30.8	906 ± 59	6.5
Kelat	10.1 ± 2.6^d	26.0	1371 ± 618^b	45.1	911 ± 55	6.0
Resak	17.7 ± 4.7^a	26.7	1638 ± 778^a	47.5	1008 ± 70	6.9
Kapur	5.3 ± 1.3^g	24.3	532 ± 215^e	40.4	739 ± 58	7.8

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Keruing	6.3 ± 2.0[f]	31.9	615 ± 375[d,e]	61.0	725 ± 74	10.2
Mengkulang	7.5 ±1.7[e]	22.5	691 ± 299[d]	43.3	662 ± 79	12.0
Light Red Meranti	3.3 ± 0.7[h]	21.9	251 ± 69[g]	34.0	459 ± 41	8.9
Geronggang	3.4 ± 1.3[h]	36.9	377 ± 227[f]	60.1	473 ± 47	9.9

Note: SD = Standard Deviation; COV = Coefficient of Variation; Mean values with the same superscript are not significant according to Duncan's Multiple Range Test at P-value < 0.05

The acquired data was statistically analyzed. A one-way analysis of variance (ANOVA) with a confidence level of 0.05% was used to determine the significant difference in compressive strength and MOE parallel and perpendicular among the tested species. All species studied had significantly different compressive strength and MOE values at p-value < 0.05 as expected. The Duncan Multiple Range Test (DMRT) was employed to determine the statistical significance of the mean values for each variable analyzed, as denoted by the letters in Tables 3 and 4.

GRADE STRESSES OF STRUCTURAL SIZE SPECIMEN

The grade stress refers to the maximum allowable stress that a particular piece of wood or timber can endure while maintaining its structural integrity and safety within a specific grade or quality classification. This value is important in construction and engineering applications to ensure that the wood used in a project can withstand the expected loads and stress without failing or deforming beyond acceptable limits. These values help builders and engineers select the appropriate type of wood for their construction projects. To calculate the grade stresses of timber tested using small clear specimens, the 1st percentile of the data is usually taken. However, for structural size specimens, the 5th percentile was employed for the calculation of the grade stress (San, 2003; Säll et al. 2007). Figure 5 shows the cumulative distribution function used to calculate the value of 5th percentile for compression parallel to grain. Table 4 compares grade stresses determined experimentally in this study and the published grade stresses given in MS 544: Part 3. The grade stresses and modulus of elasticity obtained experimentally are subsequently contrasted with those of the six (6) species listed in MS 544: Part 3. The six species specified in Table 3 (MS 544: Part 3) include Balau, Kempas, Kapur, Keruing, Mengkulang, and Light Red Meranti. The standard specifically noted that those data given in MS 544: Part 3 are only temporary as the data were not derived from Malaysian timbers but from timbers in other Southeast Asian countries. The strength table should be updated once the data derived from Malaysian tropical timbers become available.

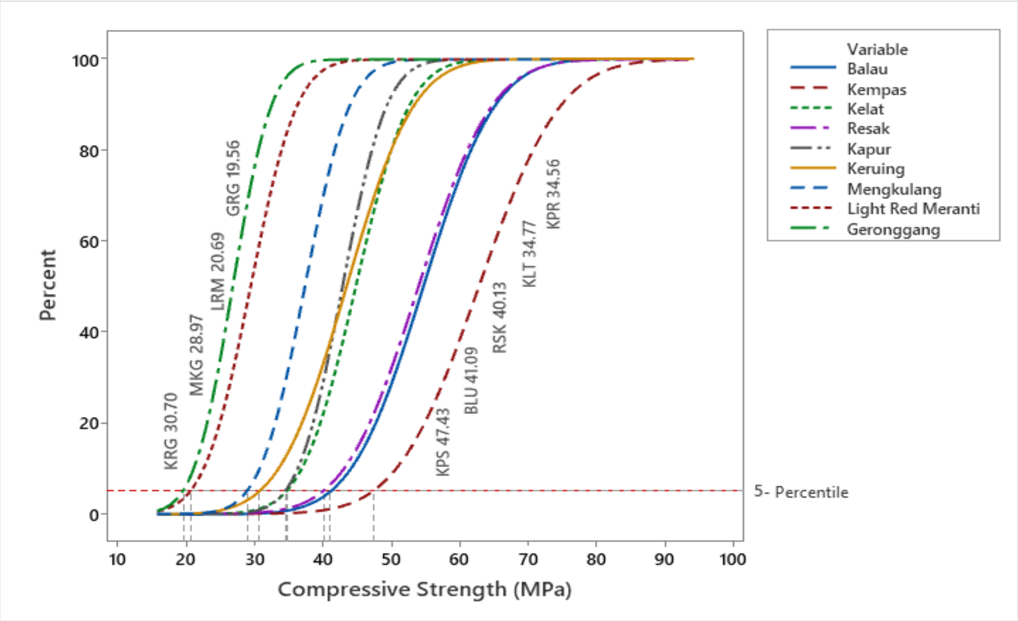
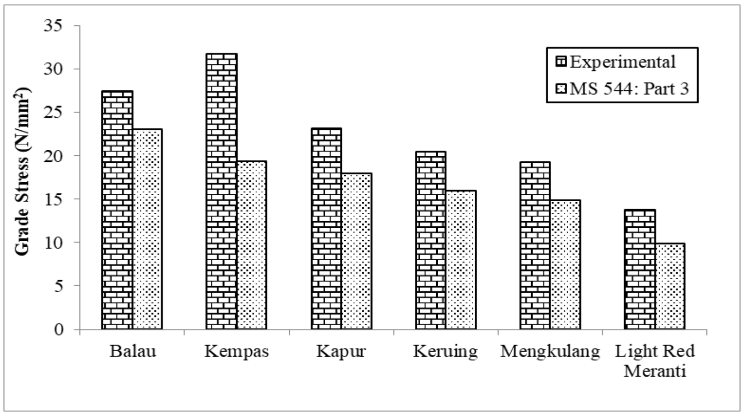


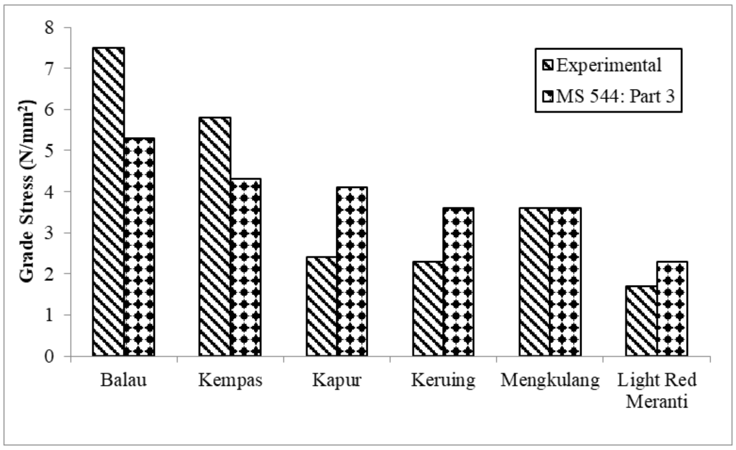
FIGURE 5. Cumulative Distribution Function for 5th Percentile value

TABLE 4. Comparison of Experimental Compression Properties with MS 544: Part 3

Species	Compression Properties (N/mm^2)					
	Experimental Grade Stress		Grade Stresses MS 544: Part 3		Experimental Mean MOE	Mean MOE MS 544: Part 3
	//	⊥	//	⊥	//	
Balau (BLU)	27.4	7.5	23.0	5.3	16439	20900
Kempas (KPS)	31.7	5.8	19.4	4.3	22180	19100
Kelat (KLT)	23.2	4.5	-	-	18109	-
Resak (RSK)	26.8	7.7	-	-	21132	-
Kapur (KPR)	23.1	2.4	18.0	4.1	17383	19200
Keruing (KRG)	20.5	2.3	16.0	3.6	16588	19300
Mengkulang MKG)	19.3	3.6	14.9	3.6	15698	14300
Light Red Meranti (LRM)	13.8	1.7	9.9	2.3	10913	10200
Geronggang (GRG)	13.0	1.0	-	-	10572	-



(a)



(b)

FIGURE 6. Experimentally Compression Grade Stresses vs MS 544: Part 3 Grade Stresses (a) Parallel to Grain (b) Perpendicular to Grain

The grade stress of parallel to grain values found in this study were significantly greater ranges from 19% to 63% than the grade stresses prescribed in MS 544: Part 3, as demonstrated in Figure 6(a). Table 4 reveals that the experimentally calculated grade stress of Kempas (31.7 N/mm^2) is the highest. It is 63% greater than the value specified in MS 544: Part 3 (19.4 N/mm^2). The experimentally obtained value for Balau is approximately

19 % higher those values given in the same standard. The findings of this research suggested that there has been a significant underestimation of the compressive strength grade stresses of some Malaysian tropical hardwoods. Table 4 additionally illustrates the contrast between the average MOE values presented in MS 544: Part 3 and those obtained through experimentation which are only available for compression parallel to grain. The results indicate that the mean experimental MOE values exceed the values specified in MS 544: Part 3, except for Balau, Kapur, and Keruing, which exhibit 27%, 10%, and 16% lower values, respectively, compared to the published standards. This result is supported by the findings of Za'ba et al. (2024), who observed that tensile grade stresses for Malaysian timbers exceed those given in MS 544: Part 3, with the exception of Balau species, which exhibited no significant differences.

Figure 6(b) clearly shows that experimentally obtained grade stress of perpendicular to grain for Balau and Kempas are 42 % and 35% greater than the grade stresses indicated in MS 544: Part 3. In contrast, the value for Kapur, Keruing, and Light Red Meranti are 41%, 36%, and 26% lower than those given in MS 544: Part 3. Nonetheless, the strength value determined by this investigation for Mengkulang (3.6 N/mm^2) is nearly identical to the grade stress given in MS 544: Part 3.

This proves the inconsistency of the strength data given in the adopted standard with the true strength value of Malaysian timbers which strengthen the need to carry out the test using structural sized timbers from Malaysia.

CONCLUSION

The structural compression properties from nine species of Malaysian tropical timbers were examined, and corresponding grade stresses were determined. The findings reveal significant insights into the performance of these timbers. Kempas exhibited the highest compressive strength tested parallelly at 62.9 N/mm², while Resak demonstrated the highest compressive strength perpendicularly at 17.7 N/mm². In contrast, Geronggang and Light Red Meranti showed the lowest compressive strengths, with values of 26.9 N/mm² parallel and 3.3 N/mm² perpendicular to the grain, respectively.

The experimentally obtained grade stress parallel to grain exceeded the grade stress values specified in MS 544: Part 3 for all tested species. Notably, Kempas (SG2) and Light Red Meranti (SG6) showed 63% and 39% higher grade stress value, respectively, than the standard grade stress. Similarly, for compressive strength perpendicular to grain, Balau (SG1) and Kempas (SG2) exhibited grade stresses that were 42% and 35% greater than those reported in the standard. However, Mengkulang displayed no significant difference in compressive strength values compared to the standard.

These results underscore the variability in compressive properties among Malaysian tropical timbers and highlight their potential for structural applications which can be integrate into structural design practices and explore advanced engineered timber products such as Glulam and CLT. Aligning these findings with international standards like Eurocode 5 can further enhance Malaysia's global competitiveness in the timber industry. Furthermore, given the increasing emphasis on sustainable construction, these findings have global relevance, particularly for tropical regions with similar timber resources, supporting the broader adoption of tropical hardwoods in eco-friendly building practices.

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DECLARATION OF COMPETING INTEREST

None.

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