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The Mechanical Strength Properties, Treatability Retention and Hazard Classification of Treated Small-Clear Fast-Growing *Acacia mangium* Superbulk at Different Age Groups

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Abstract: The slow growth rate of primer species has affected the supply available to accommodate the market demand. To overcome these problems, a study was carried out to fully utilise fast-growing timber as the primary resource to ensure the demand for timber logs continues. This paper aimed to determine mechanical strength properties, treatability retention, and hazard classification of 7-, 10- and 13-year-old small-clear samples of *Acacia mangium* superbulk collected from Daiken Plantation Sdn. Bhd. Bintulu, Sarawak, following treatment with 10% copper chrome arsenic. As a result of this study, the maximum strength was obtained from the 10-year-old age group, with the modulus of rupture (MOR), the modulus of elasticity (MOE), and compression parallel to the grain values of small-clear treated *Acacia mangium* superbulk reaching 118.76 N/mm^2, 15,020 N/mm^2, and 57.82 N/mm^2, respectively. In addition, the treatability retentions obtained were 149.27 L/m^3, 147.25 L/m^3, and 141.09 L/m^3, which were recorded from the 7-, 10-, and 13-year-old samples, respectively. Meanwhile, the dry-salt retentions obtained from the 7-, 10- and 13-year-old samples were 14.93 kg/m^3, 14.73 kg/m^3, and 14.11 kg/m^3, respectively. Hence, this species is classified as moderately difficult to treat under CCA (treatability retention: 80–160 L/m^3) and is categorised under the hazard class of H4 (dry salt retention: 12–16 kg/m^3).

Keywords: *Acacia mangium* superbulk; fast-growing timber; small clear; copper chrome arsenic; treatability retention; hazard classification; mechanical strength properties

1. Introduction

The Malaysian Timber Industry Board (MTIB) and several other participating government agencies with timber-based industries have shown a serious commitment to establishing the National Forest Plantation Programme (NFPP). The NFPP was introduced with the aim of focusing on the plantation of fast-growing timber as a way to meet the current and future demand from the timber industry without disregarding the conservation of natural forests, and the NFPP plan requires Sarawak to achieve one million ha of planted forests for future planning and forest industry products. In other words, this programme is capable of yielding a high volume of timber per unit area with shorter rotations. One of the most critical strategies that can help improve forest plantation is focusing on the rotation type of the trees in the ecosystem of forests in Malaysia [1]. The fast-growing timber targeted in this programme was *Acacia* species and Rubberwood. To achieve their goal, the Sarawak Government takes proactive measures to ensure the timber industry is continually progressing. Thus, 72% of the total planted forest areas in Sarawak are planted with fast-growing *Acacia* species [2].

The *Acacia* species includes two major species, which are *Acacia mangium* and *Acacia* hybrid, and the *Acacia mangium* superbulk is a selected tree from the seed of *Acacia mangium* that has gone through many years of tree improvement. Jusoh et al. [3] stated that these superbulk species have characteristics of a high growth rate, high volume, good stem form, and resistance to heart rot compared with the origin species. The *Acacia mangium* is a species of the family Leguminosae, which was introduced into Sabah in 1967 [4,5] and was also found in Queensland, Australia; Papua New Guinea; the Islands of Sula, Ceram, and Aru; and Irian Jaya [6]. The trees of this species are generally large and can grow to a height of 30 m with a straight bole [7]. The *Acacia mangium* is a well-known fast-growing planted tree species, and it is tolerant to various soils and environments. In the timber industry, this species is widely used in the production of attractive furniture and cabinets, door frames, window parts, mouldings, and sliced veneers [8]. Initially, the *Acacia mangium* in Sarawak was targeted as the premier resource for wood pulp and paper. Nowadays, it is fully utilised as a potential source in the production of furniture, structural components for indoor and outdoor uses, and other value-added products of commercial value [9]. There were no detectable diseases while the *Acacia mangium* plantations were young. However, as the plantations grew, they were found to be prone to a number of diseases [10,11]. Ting and Teng [2] also mentioned that the *Acacia mangium* has a higher tendency to have defects. Lim et al. [4] reported that *Acacia mangium* is susceptible to both fungal and insect attacks. Thus, this species needs to be protected in order to prolong its service life. To accomplish this, it can undergo timber treatment with preservatives such as copper chrome arsenic (CCA), creosote, or boron [12].

This study used CCA preservative, as it is widely used in the timber industry in Malaysia [10]. The treatability assessment of the timber was driven by the ability of the CCA preservative to penetrate the timber, or, in other words, the maximum amount of the preservative solution absorbed by the timber. Generally, strength refers to the timber's ability to resist and withstand different types of external forces. Thus, this study is necessary to discover more applications of this *Acacia mangium* superbulk species and fully utilise it in the timber industry. In order to achieve the aims of the study, several objectives were identified. Firstly, we sought to compare the mechanical strength properties between untreated and treated samples and the density of small-clear samples of *Acacia mangium* superbulk timber before and after the treatment process at different age groups. Secondly, we aimed to determine the treatability retention and hazard class at different age groups according to *Testing Methods for Plantation Grown Tropical Timbers: ITTO Project on Improving Utilisation and Value Adding of Plantation Timbers from Sustainable Sources in Malaysia* [13], which was adopted from MS 360 [14], MS 1921 [15], MS 544 [16], AS/NZS [17], and AS 1604.1 [18]. Thirdly, we aimed to identify the industry's end-user applications of *Acacia mangium* superbulk timber as forest industry products.

2. Materials and Methods

2.1. Preparation of Samples

The sample for the study was *Acacia mangium* superbulk species collected from Daiken Plantation Sdn. Bhd. at Bintulu, Sarawak. The procedures of sampling trees and allocation of logs were established according to ITTO's *Testing Methods for Plantation Grown Tropical Timbers*, which is stated that the criteria for the selection of tree samplings that need to be considered are the locality of the plantation, terrain, and accessibility [13]. The selected trees should have acceptable levels of bole straightness, no excessive defects, and a good cylindrical form [19]. The age groups of the timber species that were involved were 7 years old, 10 years old, and 13 years old.

Eight trees from each age group were selected to be cut down, located at Plot 1, Plot 2, and Plot 3, with 7-, 10-, and 13-year-old *Acacia mangium* superbulk, respectively. Plot 1 at Block No. 41, with GPS location of N 03°18′18.3″ E 113°25′01.2″ and an elevation of approximately 97 m on a steep slope, has termite activity and has some windblown or fallen trees. Meanwhile, Plot 2 is at Block No. 46, with a GPS location of N 03°19′07.8″ E 113°26′42.8″ and an elevation of approximately 71 m on a steep slope, and it has termite activity and some windblown or fallen trees. Plot 3 at Block No. 14, with GPS location of N 03°20′42.1″ E 113°26′57.4″ and an elevation of approximately 46 m, is located on flat land with trees infected by Ceratocystis. Timber logs were transferred out from the Daiken Plantation Bintulu Sdn. Bhd. (Figure 1a) and moved to Samling Plywood Bintulu Sdn. Bhd. for further processing, which included cutting and sawing before being transported to Sarawak Forestry Corporation (SFC), Kuching (Figure 1b).

(**a**) (**b**) (**c**)

Figure 1. *Acacia mangium* superbulk timber collection: (**a**) the timber logs were transferred out from the plantation site; (**b**) the timber logs were cut into the plank size; (**c**) the timber planks were arranged and stacked according to tree numbers for drying.

According to ITTO's *Testing Methods for Plantation Grown Tropical Timbers* [13], for the selection of the sample trees when the mean DBH of e-numerated healthy trees is more than 22 cm, the minimum DBH over bark should be 18 cm, and the sample trees should also be healthy with no decays or termite or tree borer infestation and have a minimum bole length of 6 m from the root collar. All timber planks underwent the natural air-drying process at SFC (Figure 1c). The natural air-drying process was chosen for this study to minimise strength failures such as various splits and cracks [10,20]. The timber planks had to achieve the permissible air-dry moisture content (MC), which is ±19% before performing further laboratory procedures, and it takes approximately one year to achieve that moisture content condition. A study by [8] stated that the *Acacia mangium* took more than nine months to reach 19% of moisture content. After the air-dry MC was achieved in all the timber planks, the planks were planed and ripped to the sticks with the dimension of 20 mm × 20 mm. A visual assessment was performed on the timber sticks in order to eliminate defects. Hence, the timber sticks were marked according to mechanical testing: static bending (MOR and MOE), compression parallel to the grain, and shear parallel to the grain. The most suitable method suggested in the literature for testing timber samples is using the defect-free or small-clear sample method [10,21,22]. The samples were prepared in accordance with BS 373 [23]. The dimensions for the mechanical strength test marked on the stick are illustrated in Figure 2. The samples were weighed and measured before conducting the test. The samples were prepared for the static bending test (Figure 3), the compression parallel to the grain test (Figure 4), and the shear parallel to the grain test (Figure 5). Mechanical strength testing was conducted using a universal testing machine (UTM) Instron 5569, Norwood, MA, USA. Furthermore, the Full Cell (Bethell, Manchester, UK) was used for the treatment process. A 10% copper chrome arsenic (CCA) wood preservative solution was prepared to use for treatment. Figure 6 illustrates the laboratory apparatus used, and Figure 7 presents the flowchart for the whole treatment process.

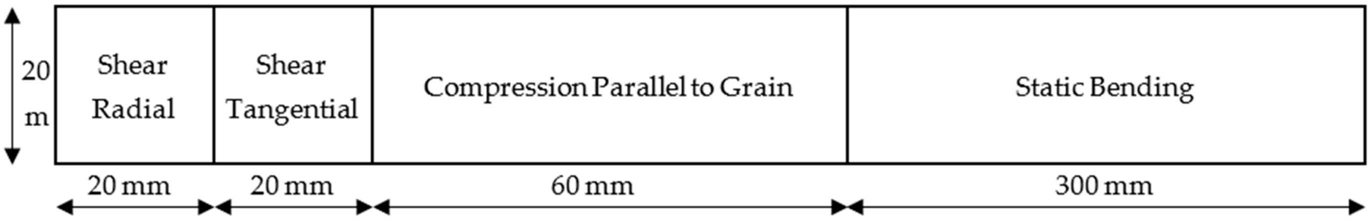

Figure 2. The dimensions for mechanical strength testing.

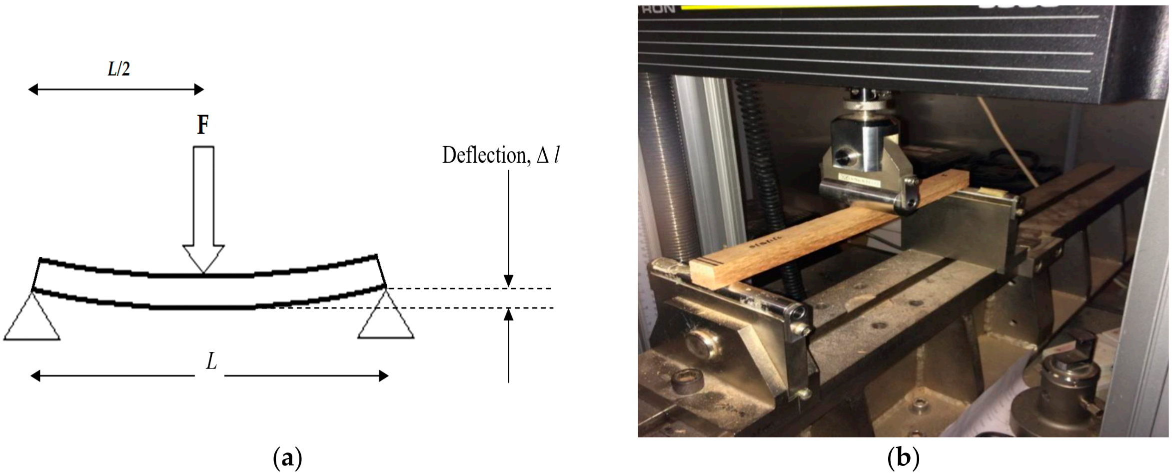

Figure 3. (**a**) The static bending test [24]; (**b**) the static bending test at the laboratory.

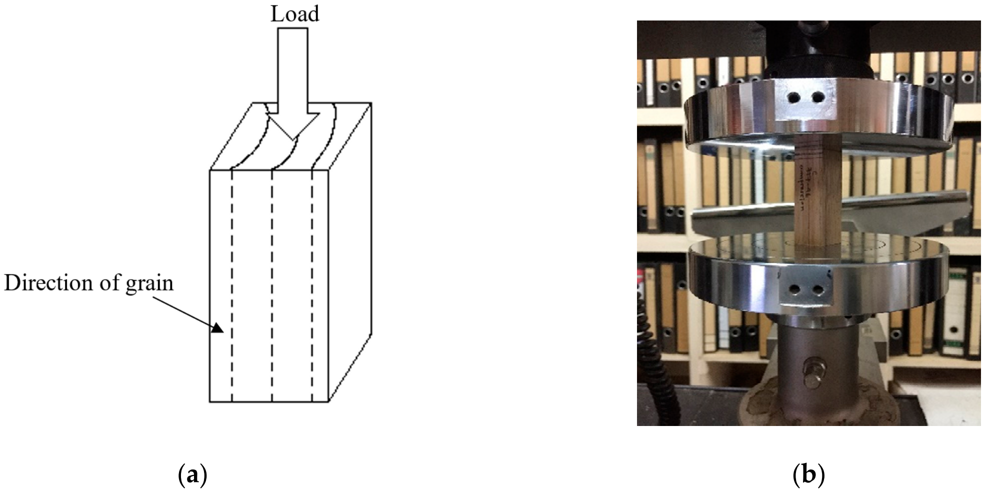

Figure 4. (**a**) The compression parallel to the grain test [13]; (**b**) the compression parallel to the grain test at the laboratory.

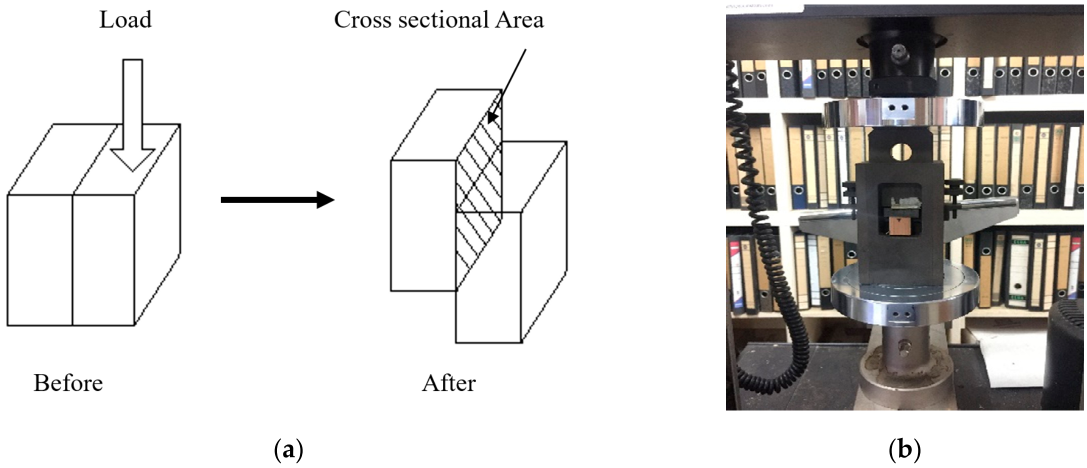

Figure 5. (**a**) The shear parallel to the grain test [13]; (**b**) the shear parallel to the grain test at the laboratory.

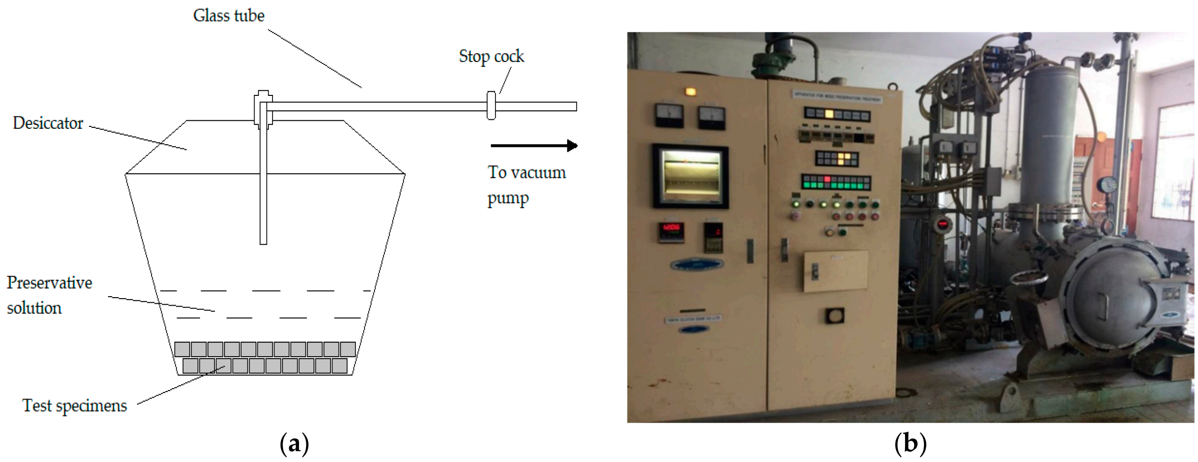

Figure 6. (**a**) The treatability test vacuum desiccators setup [13]; (**b**) treatment process machine.

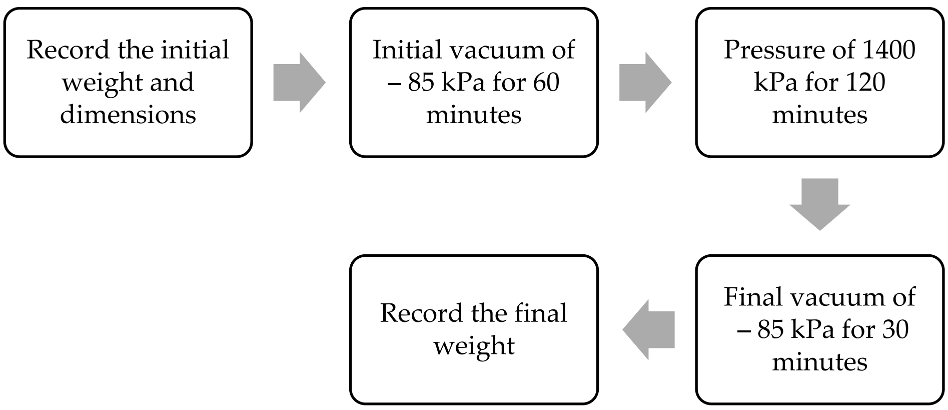

Figure 7. The flowchart for the treatment process.

2.2. Moisture Content Determination

Moisture content (MC) refers to the percentage of differences between the initial weight of samples and the oven-dry weight of samples. On the other hand, the MC of samples can also be obtained by using a moisture meter. The oven-dry weight was obtained by drying the samples in an oven at 105 °C until a constant weight was achieved. A total of 144 samples from different age groups were used in order to determine the MC of the samples. Hence, the percentage of MC was obtained by using Equation (1).

$$MC\ (\%) = ((W_1 - W_2)/W_2) \times 100 \quad (1)$$

where W_1 is the initial weight (g), and W_2 is the oven-dry weight (g).

2.3. Static Bending Determination

The dimensions of the static bending test samples were 20 mm × 20 mm × 300 mm. The length of the span or the distance between the points of support was 280 mm. The constant loading speed for the test was 6.0 mm/min. The static bending test provided two main strength properties: the modulus of rupture (MOR) and the modulus of elasticity (MOE). A total of 144 treated samples were tested at different age groups and the values were calculated based on Equations (2) and (3).

$$MOR = 3/2\ (FL/WT^2) \quad (2)$$

where F is the maximum load (N), L is the length of the span (mm), and T is the depth (mm),

$$MOE = (L^3/4WT^2)\ (\Delta F/\Delta l) \quad (3)$$

where L is the length of the span (mm), ΔF/Δl is the slope of the graph (N/mm), W is the width (mm), and T is the depth (mm).

2.4. Compression Parallel to Grain Determination

A total of 144 treated samples in different age groups were included in this test. The dimensions of the compression test samples were 20 mm × 20 mm × 60 mm, and the constant loading speed for the test was 0.6 mm/min. To ensure the results' accuracy, the samples' ends were smooth and normal to the axis, and the top compression platen was kept parallel to the bottom platen throughout the test. The compression parallel to the grain strength at maximum load was obtained using Equation (4).

$$\text{Compression strength} = F/A \quad (4)$$

where F is the maximum load (N), and A is the cross-sectional area (mm^2).

2.5. Shear Parallel to Grain Determination

This test was conducted by introducing a shear failure along a plane parallel to the tangential direction of the grain and with the plane of shear failure parallel to the radial direction. A total of 144 treated samples in different age groups with dimensions of a cube of 20 mm were used in this test. The constant loading speed was 0.6 mm/min. The shear parallel to the grain strength at maximum load was obtained using Equation (5).

$$\text{Shear strength} = F/A \quad (5)$$

where F is the maximum load (N), and A is the cross-sectional area (mm^2).

2.6. Treatability Retention Determination

To test the samples in terms of static bending, compression parallel to the grain, and shear parallel to the grain, they had to undergo a treatment process before conducting these mechanical tests. The weight of samples was recorded before and after the treatment process. The dimension of the sample was also recorded to determine its volume. The treatability retention of the sample was obtained using Equation (6).

$$\text{Treatability retention } (L/m^3) = (W_2 - W_1)/(G \times V) \times 1000 \quad (6)$$

where W_1 is the weighted sample before treatment, W_2 is the weighted sample after treatment, G is the specific gravity of timber preservative, and V is the volume of the sample.

After that, the treatability results were assessed by referring to the treatability classification table indicated in Table 1, which was adopted from MS 544 [16] and MS 1921 [15].

Table 1. Treatability classification MS 544 [16] and MS 1921 [15].

Permeability Class	Retention in Wood (L/m^3)
Very easy	Over 320
Easy	240–320
Average	160–240
Moderately difficult	80–160
Difficult	Less than 80

2.7. Hazard Class Determination

The hazard class was determined based on the samples' treatment process, which allowed us to find the samples' dry-salt retention. The dry-salt retention of the samples was determined using Equation (7). Hence, the results of dry-salt retention were assessed by referring to Table 2, which lists the hazard classification values extracted from MS 544 [16] and MS 1921 [15].

$$\text{Dry-salt retention (L/m}^3\text{) = treatability retention} \times \text{\% CCA solution used} \quad (7)$$

where the treatability retention is calculated using Equation (7), and the CCA solution used is 10%.

Table 2. Hazard classification.

Hazard Class	Exposure	Specific Service Conditions	Biological Hazard	Typical Uses	Minimum Net Dry Salt Retention (kg/m^3)	Minimum Depth of Penetration (mm)
H1	Inside, above ground	Completely protected from weather and well ventilated, and protected from termites	Insects other than termites (e.g., lyctid)	Framing, flooring, furniture, interior joinery	-	-
H2	Inside, above ground	Protected from wetting and leaching	Bores and termites	Framing, flooring, and similar, used in dry situations	5.6	3 or 5
H3	Outside, above ground	Subject to periodic moderate wetting and leaching	Moderate decay, borers, and termites	Weatherboard, fascia, pergolas (above ground), window joinery, framing, and decking	8	12
H4	Outside, in-ground	Subject to severe wetting and leaching	Severe decay, borers, and termites	Fence posts, greenhouse, pergolas (in-ground), and landscaping timbers	12	12
H5	Outside, in-ground contact with or freshwater	Subject to extreme wetting and leaching and/or where the critical use requires a higher degree of protection	Very severe decay, borers, and termites	Retaining walls, piling, house stumps, building poles, cooling tower fill	16	25
H6	Marine waters	Subject to prolonged immersion in seawater	Marine wood borers and decay	Boat hulls, marine piles, jetty cross-bracing, landing steps, and similar	32	25

3. Results and Discussion

The moisture content and mechanical strength testing results of treated *Acacia mangium* superbulk are presented in Figure 8 and summarised in Table 3. From Table 3, it can be observed that the moisture content of the samples is in the permissible range of air-dry MC, which is around 18%. Observed with a 95% confidence interval, the mean MC recorded from 7-year-old *Acacia mangium* superbulk was 18.73%, that of the 10-year-old sample was 18.64%, and that of the 13-year-old sample was 18.84%. Meanwhile, considering Figure 9 and Table 4, the study by Alik and Liang [25] also reported the mean air-dry MC of *Acacia mangium* in the range of 18%; specifically, the mean MC of their 7-year-old sample was reported as 18.29%, that of the 10-year-old sample was reported as 18.42%, and that of the 13-year-old sample was reported as18.40%. These results were also confirmed by Alik and Naohiro [26], who found the air-dry moisture content of Sarawak timber to be between 18% and 20%. Thus, the MC of the samples that were tested was within the specified range. Table 3 lists the MOR values observed with 95% confidence intervals. The mean MOR values recorded for the treated *Acacia mangium* superbulk were 97.14 N/mm^2, 118.76 N/mm^2, and 99.16 N/mm^2, which were obtained from the 7-, 10-, and 13-year-old samples, respectively.

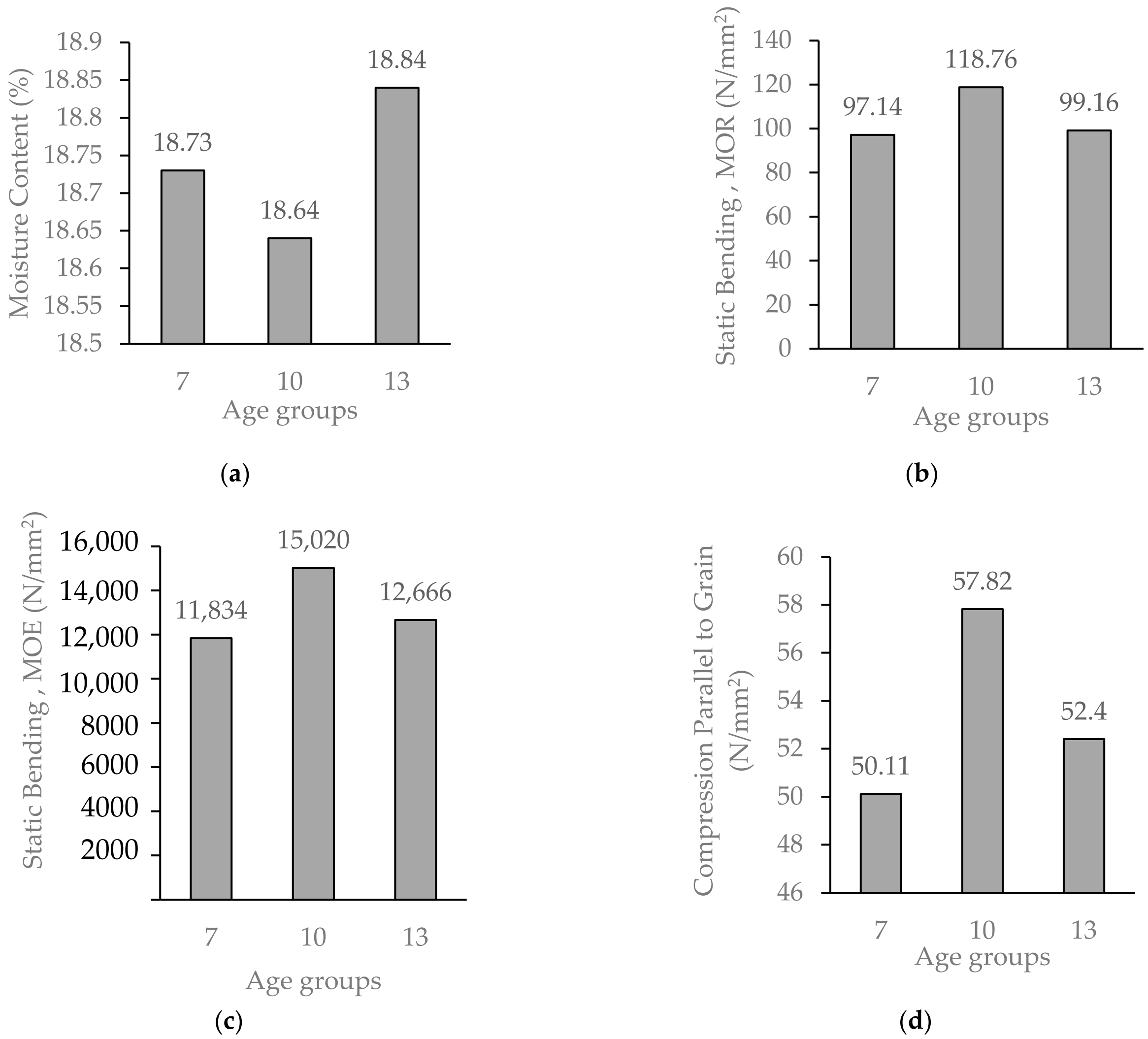

Figure 8. (**a**) Moisture content; (**b**) static bending, MOR; (**c**) static bending, MOE; (**d**) compression parallel to grain results of treated *Acacia mangium* superbulk.

Table 3. Summary of moisture content and mechanical strength properties results of treated *Acacia mangium* superbulk.

Age Group	n	MC (%)	Static Bending (N/mm²)		Comp. Parallel to Grain (N/mm²)
			MOR	MOE	
7	48	18.73 (0.99)	97.14 (19.64)	11,834 (1785)	50.11 (8.09)
10	48	18.64 (0.99)	118.76 (21.24)	15,020 (1621)	57.82 (8.07)
13	48	18.84 (0.95)	99.16 (19.78)	12,666 (1945)	52.40 (9.56)

n: Number of samples, MC: moisture content, MOR: modulus of rupture, MOE: modulus of elasticity, (in parenthesis): standard deviation.

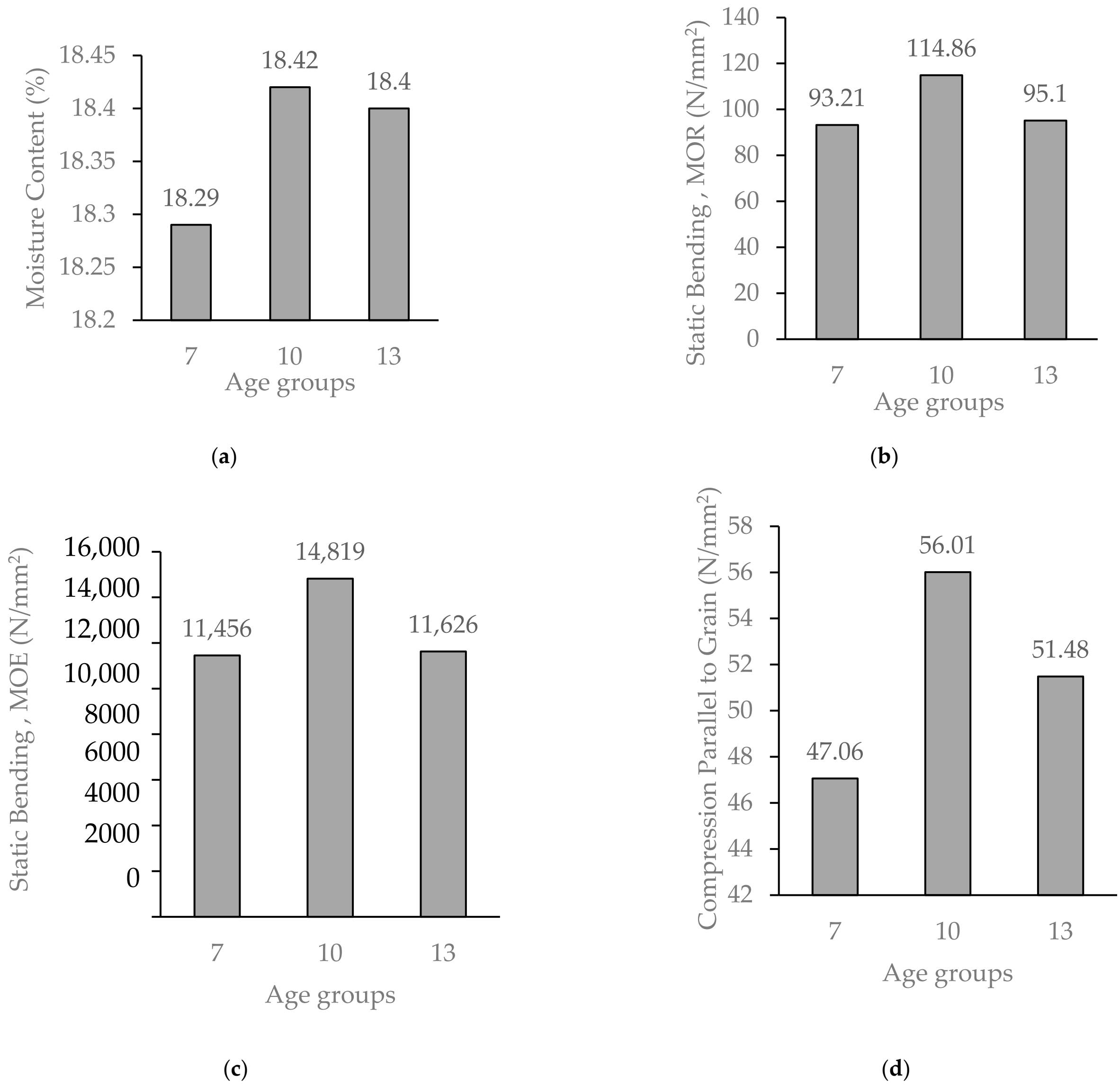

Figure 9. (**a**) Moisture content; (**b**) static bending, MOR; (**c**) static bending, MOE; (**d**) compression parallel to grain results of untreated *Acacia mangium* superbulk [22].

Table 4. Summary of moisture content and mechanical strength properties results of untreated *Acacia mangium* [22].

Age Group	n	MC (%)	Static Bending (N/mm^2)		Comp. Parallel to Grain (N/mm^2)
			MOR	MOE	
7	60	18.29 (0.25)	93.21 (18.40)	11,456 (2334)	47.06 (9.57)
10	60	18.42 (0.38)	114.86 (22.45)	14,819 (2825)	56.01 (10.42)
13	60	18.40 (0.33)	95.10 (12.37)	11,626 (1184)	51.48 (9.18)

n: Number of samples, MC: moisture content, MOR: modulus of rupture, MOE: modulus of elasticity, (in parenthesis): standard deviation.

The MOE values observed with 95% confidence intervals were determined for the treated *Acacia mangium* superbulk of 7, 10, and 13 years old, which were 11,834 N/mm^2, 15,020 N/mm^2, and 12,666 N/mm^2, respectively. Moreover, the mean results of the compression parallel to the grain test conducted on the treated *Acacia mangium* superbulk were recorded at 95% confidence intervals, which were 50.11 N/mm^2, 57.82 N/mm^2, and 52.40 N/mm^2 from the age group of 7, 10, and 13 years old, respectively.

Meanwhile, the mean MORs observed for the untreated *Acacia mangium* were 93.21 N/mm^2, 114.86 N/mm^2, and 95.10 N/mm^2, which were obtained from 7-, 10-, and 13-year-old samples, respectively. The mean MOE results obtained for the untreated samples were lower than the mean MOEs recorded for the treated samples, at only 11,456 N/mm^2, 14,819 N/mm^2, and 11,626 N/mm^2 collected from the 7-, 10-, and 13-year-old samples, respectively. Moreover, the results of the mean compression parallel to the grain strength test obtained for the untreated *Acacia mangium* were recorded as 47.06 N/mm^2, 56.01 N/mm^2, and 51.48 N/mm^2 from the age group of 7, 10, and 13 years old, respectively. In addition, the percentages of increment in the strength for the treated and untreated samples are shown in Figure 10 and Table 5. From Table 5, it can be inferred that the mean MORs of treated *Acacia mangium* superbulk were higher than the MORs of untreated *Acacia mangium* at all age groups, with the percentages of increment being 4.05%, 3.28%, and 4.09%, which were recorded for the 7-, 10-, and 13-year-old samples, respectively. The MOE results also show the increments in the treated samples when compared to the untreated samples at all age groups. The percentages of increment were reported as 3.14%, 1.34%, and 8.21% for the age group of 7, 10, and 13 years old, respectively. Meanwhile, the percentage of increment in compression strength observed in the comparison of the treated and untreated samples was recorded as 6.09% for 7-year-old samples, 3.13% for 10-year-old samples, and 1.76% for 13-year-old samples, as shown in Table 5. A similar pattern was also observed in a previous study by Andy [27], where an increase in the shear strength of the southern pine tree was observed when treated with CCA. Furthermore, a study conducted by Faria et al. [28] also highlighted the influence of CCA preservation on the physical and mechanical properties of *Eucalyptus camaldulensis* wood, and an improvement was observed in the values of the properties analysed. In another study, Soltis and Winandy [29] concluded that the CCA treatment does not affect knot size and location; however, specimens in the higher strength percentiles are more controlled by clear wood strength, which is affected by CCA treatment.

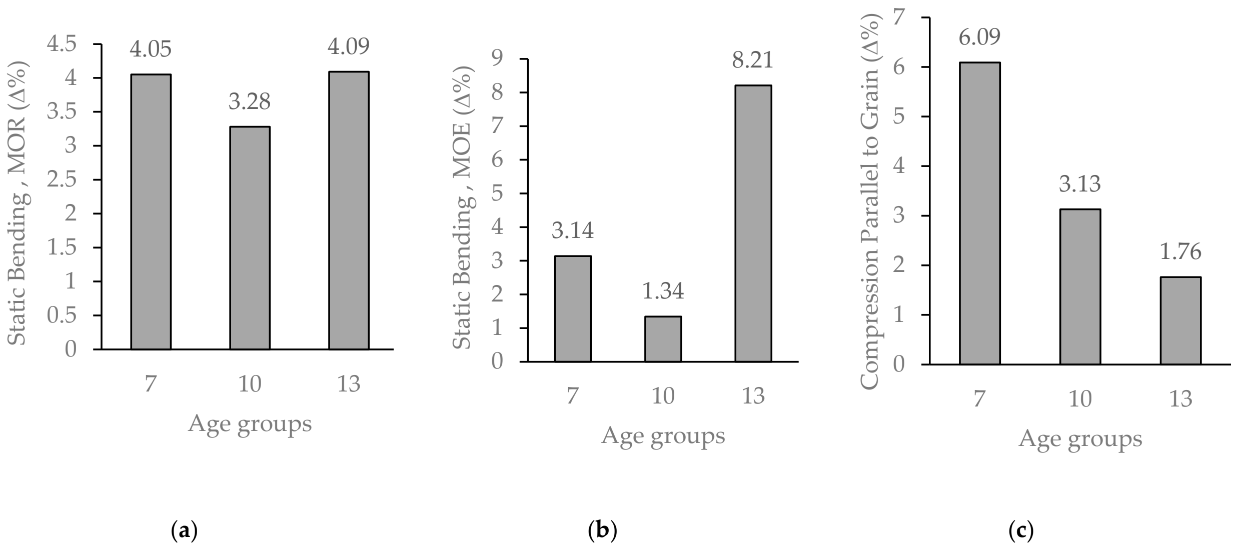

Figure 10. (**a**) Static bending, MOR; (**b**) static bending, MOE; (**c**) compression parallel to grain results of percentage increment between treated and untreated *Acacia mangium* superbulk.

Table 5. The percentage increment of mechanical strength observed when comparing treated and untreated samples.

Age Group	Static Bending		Comp. Parallel to grain (%)
	MOR (%)	MOE (%)	
7	4.05	3.14	6.09
10	3.28	1.34	3.13
13	4.09	8.21	1.76

MOR: modulus of rupture, MOE: modulus of elasticity.

By comparing the mechanical strength properties determined for the three age groups, it was found that the highest strength recorded was from the age group of 10 years old. A similar finding was observed in the study by Alik and Liang [25], which showed that the age group of 10 years old has better strength performance than the age groups of 7 and 10 years old, as clearly shown in Table 4. The results show that the MOR, MOE, and compression parallel to grain observed for the treated samples had higher values for the 10-year-old *Acacia mangium* superbulk. In this study, when the age of *Acacia mangium* superbulk increased to 13 years old, a decline was observed in its mechanical properties. In normal cases, as timber reaches its maturity, its density increases, resulting in an improvement in its mechanical properties. A similar pattern was observed in the study conducted by Alik et al. [30] for *Acacia mangium* species, where 10-year-old samples were found to have better mechanical properties than 13-year-old samples. A study conducted by Ismaili et al. [10] for *Acacia* hybrid species also reported that 10-year-old species had better mechanical properties than 13-year-old species. Thus, these findings indicate that density is not a definitive measure of the strength or mechanical properties of this species [8]. The results of this study indicate that the 13-year-old *Acacia mangium* superbulk had decreased survival rate, causing its density and mechanical properties to decrease. This is also supported by the results of Afifi et al. [31], who studied the growth characteristics of *Acacia mangium* and revealed that the survival rate and stem density decreased as stand age increased. Thus, for further analysis, the strength results obtained for the 10-year-old sample were compared with those of the other two age groups to determine whether there was any significant difference at $p < 0.05$. As presented in Table 6, at $p < 0.05$, there was a significant difference in the mean of treated MORs between 10-year-old and 7-year-old samples. Meanwhile, comparing the mean MOE values of the treated 10- and 13-year-old samples, it was found that there was also a significant difference at a probability level of 0.05. A statistically significant difference was also observed in the mean values of the compression parallel to the grain results of the treated samples between 10-year-old and 7-year-old species, whereas there was no significant difference in the mean values of the compression parallel to the grain test between 10-and 13-year-old samples, as shown in Table 6.

Table 6. Percentage increment of mechanical strength results between treated and untreated samples.

Age Group	Significant Difference *p*-Values ($p < 0.05$)			
	Age Groups	MOR	MOE	Compression Parallel to Grain
10	7	0.0000 *	0.0000 *	0.0000 *
	13	0.0119 *	0.0017 *	0.1024 ns

MOR: modulus of rupture, MOE: modulus of elasticity, *: significant at 5% level, ns: not significant at 5% level.

Furthermore, the treatability retention results for the *Acacia mangium* superbulk reported from the current study and the *Acacia mangium* at 7, 10, and 13 years old reported from the previous study are presented in Figure 11. A treatability retention study of *Acacia mangium* was carried out by Lai and Sammy [9], and their results were compared with the findings of the current study of *Acacia mangium* superbulk. The results observed at 95% confidence intervals show that the mean treatability retention values for the *Acacia mangium* superbulk at 7, 10, and 13 years old were found to be 149.27 L/m^3, 147.25 L/m^3, and 141.09 L/m^3, respectively, and on average, 145.87 L/m^3. Meanwhile, the mean treatability retention values recorded for *Acacia mangium* were 143.8 L/m^3, 147.1 L/m^3, and 129.1 L/m^3 (average: 140 L/m^3), which were obtained from age groups of 7, 10, and 13 years old, respectively, as presented in Figure 8. From this observation, it is evident that the treatability retention results of both studies are in the same range, categorised as moderately difficult to treat, according to the classification presented in Table 1 earlier. The treatability retention of *Acacia mangium* superbulk was the highest in the age group of 7 years old, and it was compared with the other two age groups to determine whether there were any significant differences. At a probability level of 0.05, there were significant differences in treatability retention between the age groups of 7 and 13 years old. Meanwhile, no significant differences were observed in treatability retention between 7- and 10-year-old samples, as tabulated in Table 7. Our observations revealed that the highest treatability retention was obtained for the age group of 7 years old, followed by 10 years old, and the lowest value was observed for the 13-year-old sample. Meanwhile, the highest strength was obtained for the 10-year-old sample, followed by 13- and 7-year-old samples. From these results, it can be inferred that higher strength does not depend on the highest amount of CCA retention. However, CCA retention has an impact on enhancing the overall strength of timber compared with untreated timber.

Table 7. ANOVA of treatability retention of *Acacia mangium* superbulk.

Age Group	Significant Difference *p*-Values ($p < 0.05$)	
	Age Groups	Treatability Retention
7	10	0.5152 ns
	13	0.0125 *

*: Significant at 5% level, ns: not significant at 5% level.

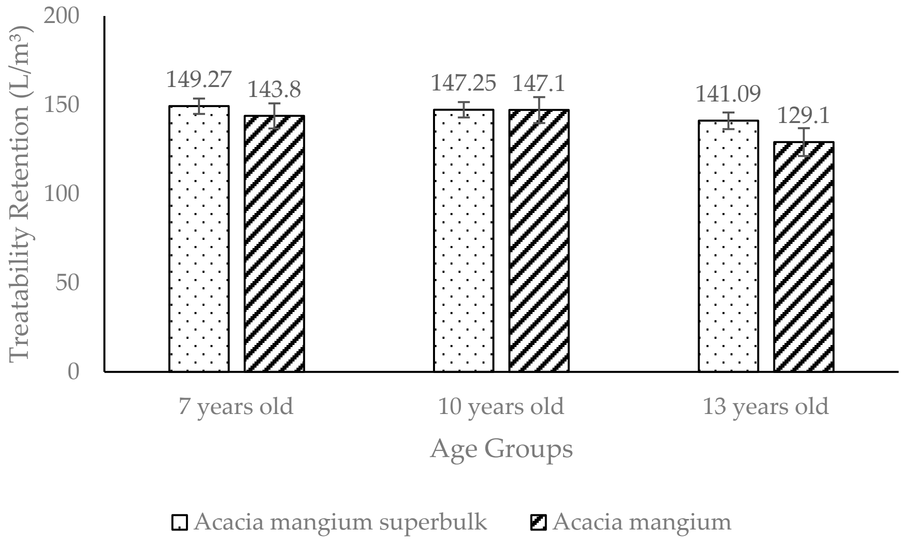

Figure 11. Treatability retention of *Acacia mangium* superbulk and *Acacia mangium* [9].

The strength of timber varies among different species; however, it can be modified to achieve higher strength performance by adding an element that results in improved strength, and in this study, treatment with CCA preservative acted as the catalyst to enhance the strength performance of the timber. The strength of timber is dependent on the species and the effects of certain growth features [32]. According to the physical characteristics reported by Krisnawati et al. [7], the *Acacia mangium* timber is diffuse and porous, and this feature boosted the penetration of CCA preservatives into the samples. This level of CCA penetration into the timber indicates that the timber strength performance is better when treated. Therefore, it can be concluded that the treated *Acacia mangium* superbulk has better strength properties than untreated *Acacia mangium*. The study by Ismaili et al. [10] revealed that the mechanical strength properties of timber are improved after being treated with CCA treatment. Furthermore, the treatability retention level of timber is determined based on its dry-salt retention and the specified hazard classification of the timber. Therefore, in this study, it can be concluded that *Acacia mangium* superbulk was classified as hazard class H4 (average: 14.59 kg/m^3), as presented in Table 8. Lai and Sammy [9] also studied 7-, 10-, and 13-year-old *Acacia mangium* planted in Sarawak and classified them as moderately difficult to treat, which met H4 hazard class requirement (average dry salt: 14.00 kg/m^3). When compared with a study carried out by Salmiah et al. [33], the 16- and 20-year-old *Acacia mangium* were classified as H5, and its permeability was not significantly different between these age groups, which is similar to the results of the current study, indicating a small age gap. Therefore, from this result, it is evident that older trees had a higher hazard class than younger trees. As for the current study, trees 13 years old and younger were only ranked as H4 hazard, compared with trees 16 years old and above, which were ranked as H5 in the previous study. Species under H5 hazard class can be exposed to the outside environment or be in ground contact with or immersed in freshwater. Meanwhile, service conditions may result in the exposure of timber to extreme wetting and leaching conditions. Under biological hazard, the HS hazard class tends to indicate very severe decay and the presence of borers and termites. Timber that has been treated and classified under H5 hazard class can be typically used in retaining walls, piling, house stumps, building poles, and cooling tower fills.

Table 8. Dry-salt retention and hazard class of *Acacia mangium* superbulk.

Age Group	Dry-Salt Retention (10% × Treatability Retention) (L/m^3)	Hazard Class (Refer to Table 2)
7	14.93	H4
10	14.73	H4
13	14.11	H4

Necessarily, the users need to identify the location where to apply or use timber. Timber is probably exposed indoors, outdoors, above ground, underground, in freshwater, or marine environments. Definitely, not all timber species are able to resist most types of exposure. Some timber needs to be preserved and treated before utilisation. In this study, for the treated *Acacia mangium* superbulk, CCA acted as protection for the timber samples. The treatment process of the *Acacia mangium* superbulk species is important as this species has high susceptibility to diseases. Instead of enhancing the durability level of *Acacia mangium* superbulk, the advantage of treatability evaluation is also improving the timber's working qualities by knowing its hazard class. Thus, this results in high demand for timber from either consumers or customers. The treatability assessment of timber species facilitates a more effective application of timber in more hazardous conditions. In this study, the retention level of *Acacia mangium* superbulk was in the range of 14 kg/m^3, which meets the hazard class of H4, and its end-user applications are presented in Table 9.

Table 9. The applications of *Acacia mangium* superbulk based on its hazard class.

Hazard Class	Dry-Salt Retention (kg/m^3)	Applications
H4 (12–16 kg/m^3)	14.59 kg/m^3	Fence posts, greenhouses, pergolas (in-ground), and landscaping timber

4. Conclusions

This study was conducted to determine the mechanical strength properties of treated *Acacia mangium* superbulk at different age groups and its treatability retention and hazard class. Therefore, the conclusions of this study are as follows:

1. The values of MOR, MOE, and the compression parallel to the grain strength increased by 3.81%, 4.23%, and 3.66%, respectively, after the samples were treated with 10% of CCA preservative.
2. The 10-year-old age group is the recommended age group with the highest strength, as reflected in its MOR, MOE, and compression parallel to grain values, with average differences of 17.35%, 18.4%, and 11.35%, respectively, compared with 7- and 13-year-old age groups.
3. *Acacia mangium* superbulk can be classified as moderately difficult to treat as its treatability retention was found to be 145.87 L/m^3.
4. *Acacia mangium* superbulk with dry-salt retention of 14.59 kg/m^3 can be classified under H4 hazard class, and accordingly, its end-user applications are recommended as fence posts, greenhouses, pergolas (in the ground), and landscaping timber.

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