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ORIGINAL ARTICLE

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Evaluation of the fire endurance of mechanically graded timber in bending

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Abstract This study examined the performance of mechanically graded timber in bending when exposed to fire at various load ratios. The test specimens were 150 pieces, each with the dimensions of $60 \times 120 \times 3500$ mm. The modulus of elasticity (MOE) of 150 specimens was measured, and 60 among them were selected to formulate the prediction equation for MOE and modulus of rupture (MOR), which was used to predict the remaining 90 specimens. These were tested under fire exposure in bending using three-point loading at 11.1%, 16.7%, 33.3%, 66.7%, and 83.3% of the ultimate load. Using mechanically graded timber, which means acknowledging the actual strength of the bending member, permits fairly precise application to the targeted design load. This research confirmed that mechanically graded timber under fire exposure has the following tendencies: under the same load ratio, time to failure is independent of strength class, and, at any load ratio, the critical strength is dependent on the timber strength class. The obtained design bending strength under fire exposure using the reduced cross section method and the reduced strength method conformed to those calculated based on Eurocode 5. Following those findings, mechanically graded timber can be applied to obtain the design bending strength when taking into account the fire attack.

Key words Mechanical stress graded timber · Bending · Fire endurance · Critical stress · *Acacia mangium*

Introduction

Mechanical stress grading is an important process for using tropical timber as structural building materials. The strength of timber as a structural material is basically determined by its density, defects, and species, tests that are difficult to apply to tropical timbers.[1] One reliable parameter for predicting strength of timber is the modulus of elasticity (MOE).[1–3] The flat-wise MOE (MOEf) of mixed tropical timber and timber from fast-growing species shows high correlation with their modulus of rupture (MOR).[1] For acacia mangium, the coefficient of determination (R^2) of MOEf and MOR of timber from two distinct locations in West Java, Indonesia, was 0.61. No significant difference was observed in the strength and stiffness of the timbers obtained between the two locations.[4]

When using timbers as structural materials, contrary to the advantage of high strength to weight ratio, timber is disadvantageous for being combustible. During fire exposure, the depth (h) and width (b) of timber decreases in relation to the charring rate of the species. For members stressed in bending under fire exposure, failure occurs when maximum bending capacity is exceeded due to the reduction of section modulus and also when the subsequent loss in the strength of the member is caused by the elevated temperature. Strength measured at the time to failure under the combined phenomenon is defined as the critical stress.[5] Testing on heavy timber structures under standardized fire exposure test of ASTM E-119 has been done for timber from subtropical areas, i.e., Douglas fir, southern pine, white oak, etc.[6] Charring rates were found to be the dominant factor for fire performance of the structural heavy timber under fire exposure. Analytical models of charring rates on standardized and constant heat fluxes have been produced.[7–13]

The result of previous research on small-scale testing of the fire performance of graded timber showed that the time to failure of a bending member under fire exposure is significantly affected by the load ratios and the timber strength classes.[5] For fire endurance test, only a few studies have

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been conducted for light structures especially focusing on tropical timber. With the result from the former study indicating that mechanical grading is necessary for effective use of the tropical timbers in structural applications, further analysis was conducted. This research would provide data on the fire performance of graded timber using MOEf as the parameter of prediction. The performance of mechanically graded timber of different strength classes and load ratios were exposed to fire, and the time to failure and the critical stress relationship were examined. This is a part of a continuous study on the utilization of acacia mangium timber for structural materials.

Materials and methods

Twelve trees with an average diameter of 34 cm and depth of 28 m of 12-year-old acacia mangium (*Acacia mangium* Wild) were selected and cut to produce timber in the conversion forest of the teak plantation in Gunung Kencana, Banten, Indonesia.

Sixty samples were randomly selected from 150 specimens. The dimensions of the specimens were 60 × 120 × 3500 mm. All of the defects were evaluated; knots, slope of grain, and checks were measured, and pinholes and discoloration were identified. The classification of defects, their numbers, and sizes were measured based on the standard specification of timber for building materials.[14] The static MOEf was measured by center-point loading with a simple grading machine that could magnify the actual deflection by 40. Then the flexural strength was tested edgewise using a universal testing machine in three-point loading based on ASTM D 198–84[15]. The edge-wise modulus of elasticity (MOEe) and edge-wise modulus of rupture (MOR) are presented in Table 1.

The bending test under fire was done in a one-dimensional fire test as shown in Fig. 1. To obtain a clear picture of the effect of load ratios on the fire resistance performance of a bending member of graded timber, load ratios of 11.1%, 16.7%, 33.3%, 66.7%, and 83.3% of the ultimate load at ambient temperature were applied.

The deflections were measured in the constant moment region or shear-free region of 1000 mm on both two sides and in the center during the fire exposure. With the center as the critical point, a thermocouple was attached to measure the top of the flame temperature. The energy source was liquid propane gas (LPG) with an oxygen supply pump to maintain uniform flame along the burner. The flow of the gas was maintained at 0.03 kg/min. The temperature at the top of flame was maintained at 800°–825°C.

Results and discussion

Mechanically graded timber under fire exposure

Figure 2 shows the relationship between MOEf and MOR of the tested acacia magium timber from Banten, West Java, Indonesia. The obtained coefficient of determination (R^2) of the relationship between MOE and MOR of the tested acacia mangium was 0.63. The R^2 values of the relationships between MOEf and MOR of mixed timber species from natural forest were in the range of 0.53 to 0.71. The R^2 values for the timber of planted hardwood were in the range of 0.61 to 0.71. Those for the timber of planted softwood were in the range of 0.60 to 0.68.[1] Other research on Norway spruce collected from some sawmills showed R^2 to be in the range of 0.51 to 0.70.[2] Because combining MOE with detailed information such as density and visual defects can only decrease predicted error slightly, the MOE alone is determined to be sufficient.[2]

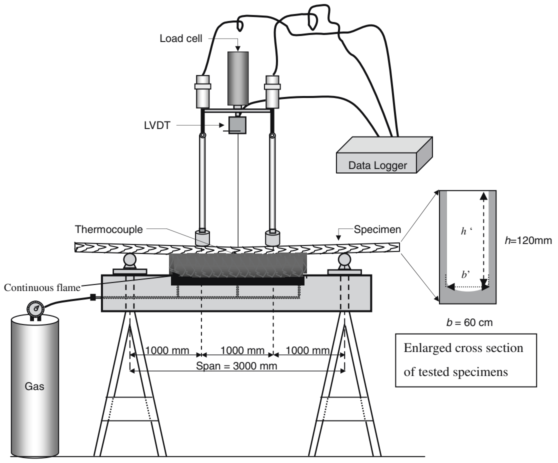

Fig. 1. Testing on full-scale bending member under fire exposure; *b* and *h*, width and depth of specimens at ambient temperature; *b′* and *h′*, width and depth of specimens after testing under fire exposure; *LVDT*, linear variables displacement transducer

Table 1. Properties of tested acacia mangium timber

Timber properties	Minimum	Maximum	Average	Standard deviation	Coefficient of variation
Moisture content (%)	15.2	19.4	16.9	1.8	0.10
Density (g/cm^3)	0.45	0.67	0.56	0.1	0.11
MOEf (GPa)	5.3	15.8	9.3	2.3	0.24
MOEe (GPa)	5.7	29.1	10.1	2.8	0.28
MOR (MPa)	11.6	75.7	41.6	15.8	0.38

MOE, modulus of elasticity; MOEf, flat-wise MOE; MOEe, edge-wise MOE; MOR, modulus of rupture

The MOE of the remaining 90 pieces of timber were measured and then the MOR based on the equation was predicted as shown in Fig. 2. The timbers were also classified by the strength classification of the proposed standard specification of timber for building materials.[16] The strength classes of the tested acacia mangium timber assigned to E6 to E27 as shown in Fig. 3. From the strength distribution, the number of timber in E10 was the greatest among the strength classes.

As shown in Table 2, the strength characteristics of acacia mangium in bending using parametric and nonparametric procedures were determined as a predicted uniform allowable value of 19.6 MPa (determined from lognormal distribution as the best-fit distribution for planted hardwood timbers)[1] and 15.2 MPa, respectively. While the two former procedures defining allowable values limit the optimum usage of timber strength, mechanical grading can provide appropriate strength prediction based on strength capacity, which is different for each timber, as shown in Table 3.

Based on the previous research on tropical fast-growing species, the timber strength classes were established in two different classifications: strength classes without regard for timber species and timber strength classes for certain species of hardwood timber. Timber strength classes for acacia mangium provide a slightly higher prediction than the general strength classes that are not species specific.[1] The strength classification of graded acacia mangium timber is presented in Table 3.

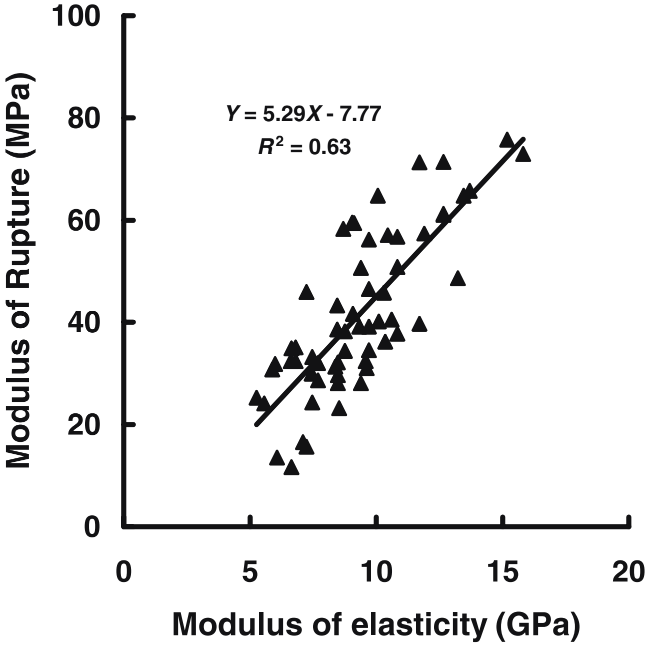

Fig. 2. Relationship between modulus of elasticity in flat-wise and modulus of rupture in edge-wise of acacia mangium timber

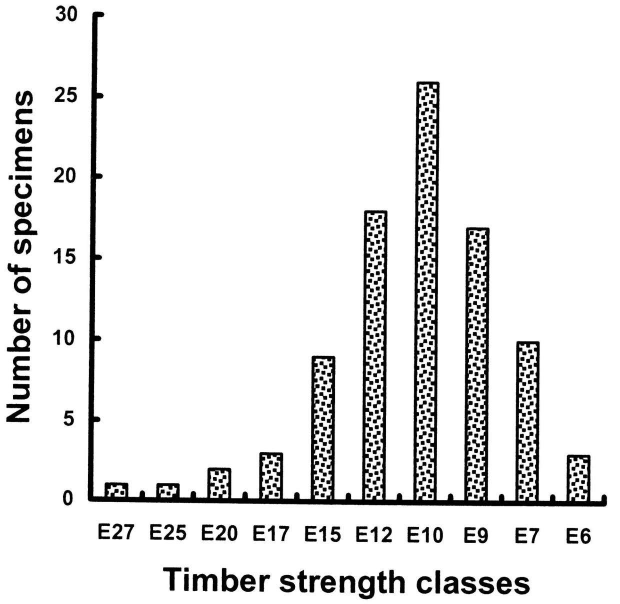

Fig. 3. The strength class distribution of tested timber

Table 2. Estimates of population parameters for acacia mangium

Parameter	MOEf (GPa)	MOEe (GPa)	MOR (MPa)
Normal			
μ	8.9	10.9	42.2
σ	2.6	3.2	15.9
5% Lower tolerance limit	4.4	5.1	14.5
Lognormal			
λ	2.2	3.2	3.7
ξ	0.3	0.3	0.4
5% Lower tolerance limit	5.1	6.3	19.6
2 P-Weibull distribution			
η	9.8	11.8	47.3
m	4.2	5.6	3.1
5% Lower tolerance limit	4.9	6.4	16.3
Nonparametric			
5% Point estimate	5.1	6.5	16.6
5% Tolerance limit	4.6	6.2	15.2

μ, Mean of normal distribution; σ, standard deviation; λ, mean of lognormal distribution; ξ, standard deviation of lognormal distribution; η, scale parameter of Weibull distribution; m, shape parameter of Weibull distribution

Table 3. Strength grades of acacia mangium timber and design critical strength under fire exposure

Grades	MOE (GPa)	$\bar{\sigma}_0$ (MPa)	$\bar{\sigma}_C$ based on reduced cross section method (MPa)		$\bar{\sigma}_C$ based on reduced strength method (MPa)	
			Obtained[a]	Eurocode[b]	Obtained[c]	Eurocode[d]
E 15	15.0	25.2	15.1	18.9	10.8	11.0
E 13	13.5	22.7	13.6	17.0	9.7	9.9
E 12	12.0	20.3	12.2	15.2	8.7	8.9
E 10	10.5	17.8	10.7	13.4	7.6	7.8
E 9	9.0	15.4	9.2	11.6	6.6	6.7
E 7	7.5	13.0	7.8	9.8	5.6	5.7
E 6	6.0	10.5	6.3	7.9	4.5	4.6

$\bar{\sigma}_0$, Allowable MOR of acacia mangium timber at ambient temperature; $\bar{\sigma}_C$, allowable critical strength of acacia mangium timber under fire exposure

[a] Derived from $\bar{\sigma}_0$ and factor obtained from the relationship between MOR at ambient temperature and critical strength

[b] Derived from $\bar{\sigma}_0$ and 20% fractile and reduction of cross section method for tensile strength[22]

[c] Derived from $\bar{\sigma}_0$ and general bending adjustment factor for hardwood of 0.427[6]

[d] Derived from $\bar{\sigma}_0$ and factor in strength and stiffness properties at elevated temperatures ($k_{\mathrm{mod,fi}}$) = 0.35 partial safety factor for timber in fire ($\gamma_{\mathrm{M,fi}}$) = 1, and 20% fractile (f_{20}) = 1.25 xf_{05}[12]

As a combustible material, timber decreases in its dimensions, weight, and eventually its load-bearing capacity when under fire exposure. To know the performance of graded timber under fire exposure, timber in various strength classes were loaded in various load ratios to their predicted ultimate load. The major parameter recorded was the time from which the member was loaded and exposed to fire, until it reached the critical condition at which the member ruptured. The stress $\sigma(t)$ of the bending member exposed to fire for a certain time (t) could be calculated as:

$$\sigma(t) = \frac{M}{Z(t)} \tag{1}$$

where M is the moment, a load-dependent factor related to timber strength class and load ratio; and Z is the section modulus, a fire-dependent factor related to the time to failure and charring rate. The $Z(t)$ is calculated as:

$$Z(t) = \frac{(b - v_1 t)(h - v_2 t)^2}{6} \tag{2}$$

where b is the width of the timber, h is the depth of the timber, and v_1 and v_2 are the charring rates in the vertical and horizontal directions, respectively.

Time to failure is affected by the ratio of the applied load as shown in Fig. 4. The relationship between the load ratios and time to failure is expressed by the equation:

$$Y = 1.02e^{-0.058X} \Rightarrow Y = e^{-0.058X}, \quad R^2 = 0.97 \tag{3}$$

where Y is the load ratio, X is the time to failure (min), and R^2 is the coefficient of determination.

From Eq. 3, it could be seen that the load ratio strongly affects the time to failure, having a coefficient of determination of 0.97 for the exponential equation. The exponential equation appeared to be better for the relationship between load ratio and time to failure than the linear and logarithmic equations (see Fig. 4).

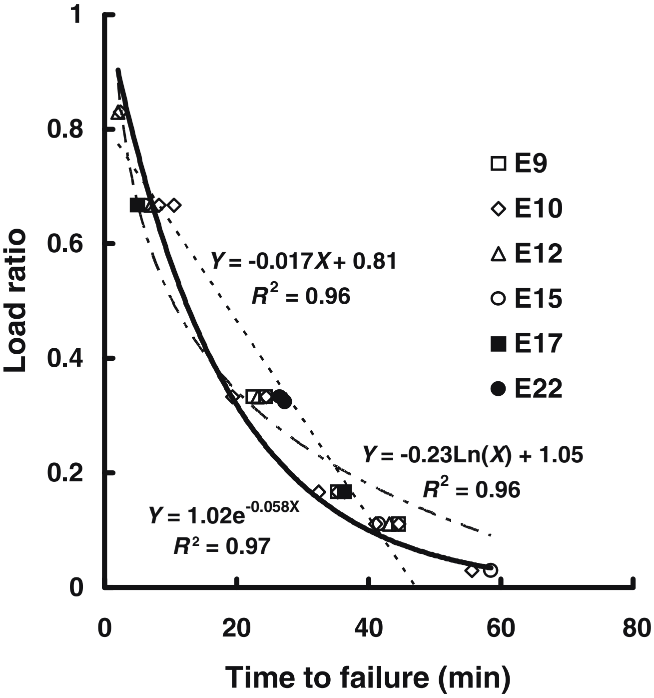

Fig. 4. Times to failures for various load ratios on the bending member under fire exposure. *Broken line*, linear equation; *hashed line*, logarithmic equation; *solid line*, exponential equatioin

Figure 4 also shows that, in the same timber strength class, the load ratio significantly affects the time to failure. The higher the load ratio, the shorter the time to failure becomes in the same timber strength class. MOR is assumed to have the same value within the same strength class. With regard to Eq. 2, in the same timber strength class, the different load applied on the tested specimens could be explained as:

$$\sigma(t_1)=\frac{M_1}{Z(t_1)} \quad \text{and} \quad \sigma(t_2)=\frac{M_2}{Z(t_2)}$$

when

$$\sigma(t_1)=\sigma(t_2), \quad M_1>M_2, \quad \text{the} \quad Z(t_1)>Z(t_2).$$

With reference to Eq. 2, with the same charring rate of the timber, the greater the section modulus, the shorter the time to failure became.

From Fig. 4, it was found that with the same load ratios, various timber strength classes demonstrated similar time to failure. It could be explained as below:

$$\sigma_1(t_n)=\frac{1/\mathrm{n}P_1L}{(b-v_1t_n)(h-v_2t_n)^2} \tag{4}$$

$$\sigma_2(t_n)=\frac{1/\mathrm{n}P_2L}{(b-v_1t_n)(h-v_2t_n)^2} \tag{5}$$

At ambient temperature, σ_1 and σ_2 are at constant difference and when the load ratios are equal, they produce the same fractions to the ultimate loads. Using Eq. 2, the time to failure of the members is again equal. With the same values of the denominators of Eqs. 4 and 5, the critical stress of the timbers due to the reduction of section modulus depends on the moment resistance of the members. The observations confirm that $\sigma_1(t_n)$ and $\sigma_2(t_n)$ are at constant difference as at ambient temperature. With similar time to failure of the timber among different strength classes at the same load ratio, it can be assumed that the effects of elevated temperature on strength are identical.

Using Eq. 3 and Fig. 4, if the fire endurance time and applied load are determined, any timber strength class could be utilized depending upon the design load of the member. Equation 3 showed the danger or the ineffective utilization of timber with respect to strength and fire endurance of the member. Lower estimates of the strength produce ineffective utilization of the timber, and contrarily, overestimates would be unsafe for both strength and fire endurance of the member. In practice, when single species are used, mechanical grading is rarely applied to predict the timber strength. The average density is mostly used as a predictive parameter along with the rough visual grading on the surface of the timber. Such prediction produces the overestimate or underestimate of the timber strength due to the lower or the higher prediction of strength ratio based only on the surface defects of the timber. Some defects such as interlocked grain and slope of grain are quite difficult to detect in some timber species. Through the discussion presented above, predicting the strength of timber using MOE, as usually applied in mechanical grading, is important to guarantee the strength as well as the fire resistance of timber members, especially in bending.

Times to failure for all classes show insignificant difference, as shown in Fig. 4, and the relative reduction of cross section due to the fire exposure was also similar for all strength classes. The observed phenomenon is supported by previous research on pair matching of low-grade spruce specimens with knots and high-grade, knot-free specimens, which showed that the relative residual strength in terms of formal bending stress is identical for the high-grade timber and the low-grade timber with knots.[17] It was concluded that tests did not reveal any danger in estimating the time to failure under fire exposure conditions for structural timber with knots in comparison with that of clear timber in the same size and loading ratio.

Charring rate of the graded timber

Mechanical grading was performed to predict the strength of timber, and the results were applied as the basis for loading variations of the experiment. Equations 1 and 2 showed the importance of charring rate in relation to the applied load of the bending member under fire exposure. Based on the charring depths and times to failure, the obtained charring rate of acacia mangium timber was 1.2 mm/min with the standard deviation (SD) of 0.01 mm/min and coefficient of variation of 11.1%. The low coefficient of variation of the charring rates of the tested timber generated similar times to failure for timber in various strength classes at the same load ratios. It was reported that density showed similar effects on the charring rates and times to failure for different load ratios and there was no influence of density on the loss of bending strength.[18]

Because the higher load ratios produced the shorter time to failure, the charring depths in both the horizontal and vertical directions are also significantly affected by the load ratios and the exposure time, as shown in Fig. 5. The charring depth in the vertical direction is slightly larger than that in the horizontal direction due to the more intensive fire exposure in the vertical direction. At the corners, the fire exposure produced nonrectangular charring, as shown in

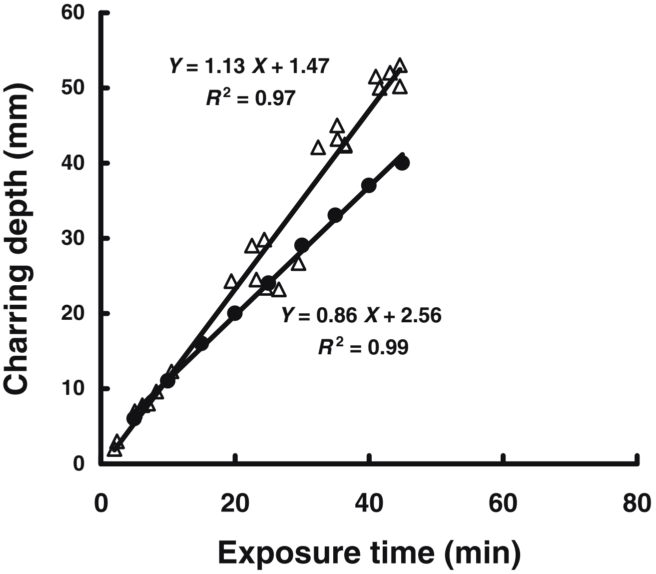

Fig. 5. Relationship between exposure time and charring depth in the fire test using incident constant heat flux. *Triangles*, data from this study using heat flux of 80 kW/m^2; *circles*, data from Silcock and Shields[20] using heat flux of 50 kW/m^2

Fig. 1, but it was assumed that the charring condition was rectangular in shape as shown in the cross section of the tested timber in Fig. 1. A simplified calculation method using notional charring depth is introduced in Eurocode 5 by assuming an equivalent rectangular residual cross section. It has been mentioned that the notional charring depth of solid timber is 1.23 times that of the one-dimensional charring depth.[12,19]

Charring depth of this study showed a linear tendency in the constant difference in the test result of cone calorimeter testing on 50 kW/m^2 as shown in Fig. 5. The calculated incident heat flux of 80 kW/m^2 of this experiment was derived from constant gas flow of 0.03 kg/min and constant exposed area. The test result shown in Fig. 5 demonstrates that the charring depth of the tested timber was 1.2 times greater than that tested under cone calorimeter at 50 kW/m^2 heat flux.[20] A study on various constant heat fluxes showed that the higher the heat flux, the higher the charring rate of the timber. For example, basswood with a density of 0.40 g/cm^3 tested with a constant heat flux of 25 kW/m^2 showed a charring rate of 0.80 mm/min, and when tested at 50 kW/m^2 gave a charring rate of 1.31 mm/min.[7]

The charring rates of timber can be expressed by the weight loss of the tested specimens under fire exposure. With the loss of moisture and production of charred layers, the weight of the specimens decreased during testing. In other words, the percentage of weight loss became higher when the time of fire exposure was longer as shown in Fig. 6. There is a significant effect of load ratios on the weight loss because the load ratios affected the times to failure of the members. The relationships between charring depth and exposure time, and weight loss and exposure time were similar as shown in Figs. 5 and 6.

With reference to Eqs. 1 and 2, having the timbers mechanically graded and the charring rates under fire exposure known, the optimum stress of timber under fire exposure due to the reduction of section modulus could be predicted.

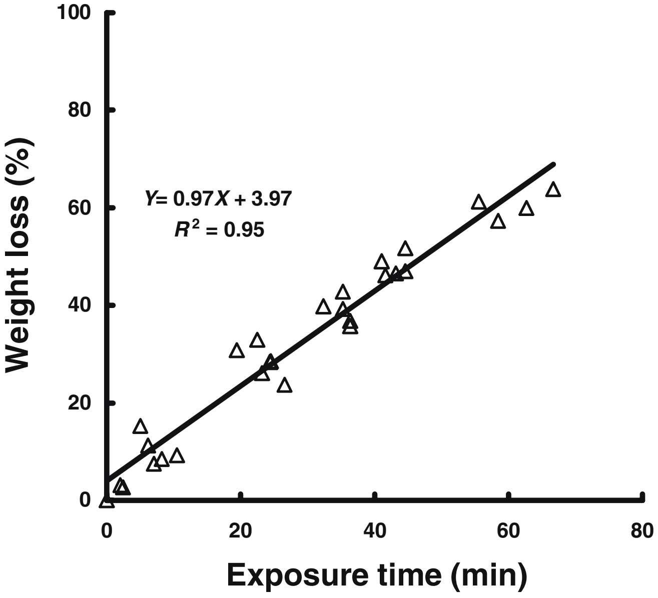

Fig. 6. Relationship between exposure time and weight loss in full-scale test

Critical stress of mechanically graded timber exposed to fire

As described above, time to failure is significantly affected by the applied load, and, for timbers of the same strength class, is demonstrated by identical times to their failures. It is necessary to provide data on the stress of the timber when the bending member ruptures due to the applied load and fire exposure. The ultimate stress when the bending member ruptures under fire exposure is affected by the reduction of the section, and by the reduction of strength at the char front in the elevated temperature, namely the critical stress, σ_c. Because the ultimate stress of the timber is predicted through the MOE, the critical stress can be obtained by the predicted strength, load ratios, time to failure, and obtained charring rate. At the time to failure, the critical stress, $\sigma(t_c)$, can be calculated as:

$$\sigma_c = \sigma(t_c) = \frac{M}{Z(t_c)} c(t_c) \qquad (6)$$

where σ_c is critical stress, t_c is the critical time or the time to failure, M is the bending moment, $Z(t_c)$, is the geometric moment resistance, and $c(t_c)$ is the reduction coefficient due to the elevated temperature which is derived from the effective residual cross section and the section modulus.

As mentioned above, mechanical grading and data on charring rates are important to predict the fire resistance of a bending member under fire exposure due to the reduction of section modulus. On the other hand, some studies reported that there is a significant effect of elevated temperature on the strength reduction of timber. The strength of timber is reduced with high temperature exposure. Test results on some timber strength grades exposed to 23°, 38°, and 54°C indicated a trend toward shorter times to failure at higher temperatures at equal stress ratios. Reduction in time to failure at low stress ratios, however, tended to be greater than the reduction at higher stress ratios, and the effect of temperature is greater for longer duration of load.[21] When the timber in a bending member is exposed to fire, the char front area reduces the strength due to the elevated temperature.

Reduction of strength under fire could be obtained using the reduced cross section method and the reduced properties method.[22] The critical stress at the time to failure of acacia mangium timber was calculated based on the remaining section modulus and applied load with the assumption of $c(t_c) = 1$. The coefficient of determination of predicted MOR (based on the relationship between MOE and MOR as shown in Fig. 2) and the obtained critical stress at the time to failure of acacia mangium was 0.66. From the result, it can be proposed that the reduction factor for bending under fire exposure is 0.6, with a high correlation between predicted MOR and critical stress as shown in Fig. 7.

The allowable critical stress at the time to failure (critical strength) is presented in Table 3. Based on the obtained

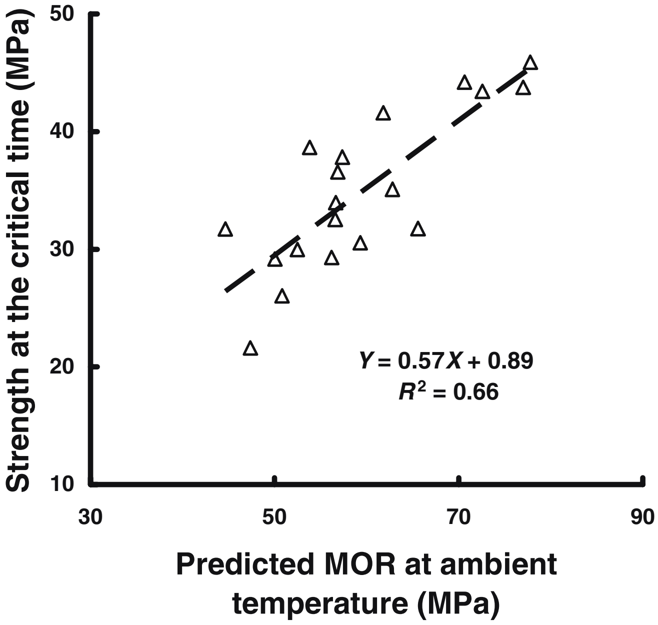

Fig. 7. Relationship between the predicted modulus of rupture (MOR) at ambient temperature and the strength at the critical time of the tested acacia mangium timber

reduction factor as mentioned above, the allowable critical strength or the designed bending strength under fire exposure of acacia mangium was derived from the allowable MOR.[1] With the design load of 1/3, the time to failure is 19.1 min (see Fig. 4), the obtained charring rate of acacia mangium is 1.2 mm/min, and the char layer is 22.9 mm. Using the assumption as adopted by Eurocode 5 of the zero-strength layer of 7 mm or without using the assumption, the relative strength of the tensile strength (as the critical part of bending) based on the distance of the char line is 0.6.[22] The critical strength obtained following Eurocode 5 based on the reduced cross section method is derived from the 20% fractile and a relative strength of 0.6.

The determination of critical stress at the time to failure was also carried out with the reduced properties method using a general bending adjustment factor for hardwood that was 10% of that of softwood.[15] In Eurocode 5, the design bending strength under fire exposure is determined by:[12]

$$f_{\mathrm{d,fi}} = k_{\mathrm{mod,fi}} \frac{f_{20}}{\gamma_{\mathrm{M,fi}}} \tag{7}$$

where $f_{\mathrm{d,fi}}$ is the design strength in fire including bending strength, $k_{\mathrm{mod,fi}}$ is the modification factor for fire taking into account the reduction in strength and stiffness properties at elevated temperature, f_{20} is the 20% fractile of strength property at ambient temperature, and $\gamma_{\mathrm{M,fi}}$ is the partial safety factor for timber in fire ($\gamma_{\mathrm{M,fi}} = 1$).

With the cross section of the tested acacia mangium timber of 60 × 120 mm and the time to failure of 19.1 min, the $k_{\mathrm{mod,fi}}$ was determined as 0.35, adapted from the $k_{\mathrm{mod,fi}}$ of 0.4 of 45 × 120 mm timber with the time to failure at 15 min.[22] Using Eq. 7, the obtained design bending strength under fire exposure is presented in Table 3 as the allowable critical strength or $\bar{\sigma}_{\mathrm{C}}$ based on the reduced strength method of Eurocode 5. The design bending strength obtained under fire exposure using the reduced properties method with a general bending adjustment factor[15] produced a result that was not significantly different from that obtained using Eurocode 5[12] (see Table 3). The reduced strength method produced lower design critical strength than the reduced cross section method. In structural timber design related to fire attack, the reduced strength method must be applied because of the consideration of safety. The design bending strength of acacia mangium timber under fire exposure can be applied for mechanically stress-graded timber. In practice, by applying mechanically graded acacia mangium timber, the design strength can be obtained with or without taking into account the fire attack as also shown in Table 3.

Conclusions

The strength characteristic of acacia mangium in bending using parametric and nonparametric procedures was determined as a predicted uniform allowable value of 19.6 MPa and 15.2 MPa, respectively. Mechanical grading can provide appropriate strength prediction based on strength capacity that is different for each timber. Using mechanically graded timber, which means acknowledging the actual strength of the bending member, permits fairly precise application to the targeted design load. By accurately predicting the MOR of timber using MOEf as a predictor, overestimation and underestimation can be largely avoided.

From the tested specimens, the obtained results were plotted in linear, logarithmic, and exponential relations for comparison. Careful comparative analysis made clear that the exponential equation of $Y = e^{-0.058X}$ is the most suitable equation for the relationship of load ratio and time to failure. In referring to Fig. 4, specifically the bold line of the exponential graph, the significant effect of the load ratio to the time to failure is confirmed. Furthermore, under the same load ratio, time to failure is independent of strength class, which will allow the safe use of graded timber for its strength as the major determining factor.

Through the predicted strength and obtained charring rate, the ultimate stress under fire exposure due to the reduction of section modulus can be predicted. The failure of bending members under high load ratios were mostly affected by the bending moment, while failure under low load ratios were mostly affected by the elevated temperature. These observations were confirmed for timber in different strength classes and load ratios.

The correlation between predicted MOR and critical stress at time to failure under fire exposure was 0.66, which showed that the reduction factor of 0.6 is confirmed. The designed bending strength of acacia mangium timber under fire exposure could be derived using the obtained reduction factor in application of the reduced section method. In practice, with consideration of the safety of the structure, designed bending strength must be determined using the reduced properties method through the application of a general bending adjustment factor as well as factor for reduction of strength at elevated temperature.

This research confirmed that mechanically graded timber under fire exposure has the following tendencies:

1. Under the same load ratio, time to failure is independent of strength class.
2. At any load ratios the critical strength under fire exposure is dependent on the timber strength classes.

From these two findings, mechanically graded timber can be applied to obtaining design bending strength by taking into account the fire attack, further broadening the possibilities of using fast-growing tropical graded timbers for structural usage.

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