

Heat treatment on *keruing* and *light red meranti*: The effect of heat exposure at different levels of temperature on bending strength properties

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Abstract. Heat treatment on timbers is a process of applying heat to modify and equip the timbers with new improvised characteristics. It is environmental friendly compared to the common practice of treating timber by chemical preservatives. Malaysian hardwood timbers namely Keruing and Light Red Meranti which are in green condition were heat treated at temperature 150°C, 170°C, 190°C and 210°C, in a specially designed electronic furnace within one hour duration. The objectives were to determine the effect of heat treatment on bending strength properties of heat treated timbers in terms of Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) and to examine the significance changes at each temperature level. Untreated samples for each species were used as a control sample. The results indicated that the bending strength properties for both species of timbers were affected by the heat exposure. Both MOE and MOR values for heat treated Keruing were increased when subjected to the temperature levels at 150°C, 170°C and 190°C except at 210°C. Heat treated Light Red Meranti shows the same pattern of increment on its MOE and MOR values after exposure to heat at three temperature levels applied and the values dropped at 210°C. However, for both of species, even though there were decrement occurred at 210°C, the value is still higher compared to the control sample. The increments of MOE and MOR values are an indicator that heat treatment had successfully improvised the bending strength properties of these two species of hardwood timber.

1. Introduction

One of the oldest structural materials used by human to build their shelters and home is timber. Other than useful to build a building and house, timber also useful to build other structure such as bridge, boats, and the other civil engineering works in the construction industry [1]. Timber comes with good natural durability and characterization is good to be used structural members but this kind of timber is limited in numbers and high in price. Timber is unique as it is one kind of material which comes with non fix properties. It is depend on its species, surrounding and condition of the weather [2]. Due to the limitation of numbers of timbers with natural durability and good properties, an alternative way to solve the issue is by using the timber with non natural durability and low in properties [3]. The timber with low durability and properties need to be modified to equip the timber with new and improvise character before it can be used. Most of the timber in Malaysia which need to be modified had been treated by using chemical water based preservative known as Copper Chromium Arsenic (CCA) [4]. CCA has proven to improvise the lifespan and the properties of the treated timber [5]. This kind of treatment is world most used timber preservative. One of the big countries which applied CCA as



timber preservative to modify the timber is United State (US), but in 2004 US Environmental Protection Agency (EPA) had announced that manufacturing of timber treated by CCA can no longer be produced [9]. Other big countries which applied CCA on timber earlier but had banned this application are Canada, Japan, Denmark, Switzerland, Vietnam and Indonesia. According to EC Scientific Committee on Toxicity, Eco-toxicity and the Environment (CSTEE), the chemical used in CCA may lead to the risk of cancer and genotoxic. Human may face lung, liver, kidney and bladder cancer. The ability of hearing may be reduced, decrease the immune system and can caused skin ulcer [6]. In Malaysia, the alternative method need to be applied in order to modified the properties of timber as Malaysia still allows CCA to be applied on the timber modification. An alternative treatment with no chemicals usage which is possible to make available is heat treatment. This treatment will modify the properties of timber with high level of temperature during the process of modification without any preservatives [10]. Timber treated with heat treatment may be equipped with new and improvised properties in term of physical, chemical and mechanical properties. Two species used in this study are Keruing which comes from strength group 5 (SG5) and Light Red Meranti from Strength Group 6 (SG6). Both of these species are local Malaysian hardwood timber species in Malaysia and specified as species of timber that need treatment to help in improving the durability and strength properties as stated in Malaysian Standard MS544: Part 2: 2001. The main objective in running this study is to determine the bending strength properties in term of Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) for these two selected species after had been treated by four different level of temperature.

2. Heat Treatment

Modification of timber to improvised its durability and equips the timber with new properties by using high level of temperature in certain duration is known as heat treatment [11]. Heat treatment is using only temperature without any added preservative that make it known as one of environmental friendly way application to alter the properties of timber [12]. The timber treated by heat will be exposed to temperature ranging from 150°C to 260°C as at 150°C, the changes occur on timber properties will be permanent [13]. Commonly, heat treatment procedure is applying different range of temperature and duration. These two parameters are selected based on the species and properties of the timber been used for the treatment. The temperature of heat treatment is usually started at 180 to 280°C within 15 minutes or more [14]. The researcher also found that heat treatment on timber will not change its properties it applying low temperature even for a longer duration of treatment. [15] found that applying heat treatment on timber with temperature level above than 150°C will help to change the properties of timber in term of physical and chemical. The dimensional stability and the durability of timber are increases after treated by high level of temperature [16]. The movement stability of timber in term of shrinkage and swelling will be reduce as the equilibrium moisture content is low after the exposure of heat treatment. Previous researcher found that the heat treatment will lead to slow water absorption [17]. The high temperature level during heat treatment also will lead to reduction on ability of bound water migration through the treated timber as the chemical composition of the timber also had been change. The heat treatment had lead to cell wall modification [18].

3. Experimental Works

This study consists of few phases in its experimental works. The phases involved are samples preparation, heat treatment process, and bending strength measurement in order to gain the MOE and MOR values of the samples of timbers.

3.1 Sample Preparation

There are two (2) species of Malaysian timbers in range of hardwood timbers had been utilized in this study. All of these species selected are the species that need to be treated before it can be used as stated in MS544: Part 2. The species are Keruing and Light Red Meranti. Both of these species of timber is in green state, means that the timber is wet and the moisture content level higher than 19%. The preparation of samples in term of size and number of control and heat treated samples is summarized in table 1 below.

Table 1. Samples Preparation

Species	Number of Sample			Size (mm)	Strength Group (SG)
	Control	Heat Treatment Temperature (°C)	Sample		
Keruing	15	150	15	50 x	5
		170	15	90 x	
		190	15	1800	
		210	15		
Light Red Meranti	15	150	15	50 x	6
		170	15	90 x	
		190	15	1800	
		210	15		

Before the heat treatment, all of the samples of timber were placed in the conditioning room with a proper stack to let the samples conditioned properly. The relative humidity of that room and the temperature level will be adjusted to 65% and 24°C respectively.

After two (2) weeks, part of samples prepared went for the heat treatment while the others were treated as control samples. The timber samples were treated by heat at four ranges of temperature level; 150°C, 170°C, 190°C and 210°C, within one hour duration. Only ten numbers of samples were treated for each cycle of heat treatment to ensure that the heat applied on the timber is distributed uniformly among samples. Three wires were installed to each sample; one was in the middle part of the sample and the other two were each end of the sample. Those wires are connected to the temperature controller which can be monitored to ensure that the heat is uniformly supplied. The furnace was then closed properly before the treatment can be run.

**Figure 1.** Special Design Electrical Furnace**Figure 2.** The samples arrangement in the heat treatment electrical furnace

4. Data Analysis and Discussion

A four (4) point bending test was conducted to measure the mechanical properties in term of bending strength for the selected timber species in this study, in accordance to ASTM D198. The sample size of timber beam used to conduct this test is 1800mm of length x 50mm of width x 90mm of depth. This test was run after moisture content and density of the timber beams was determined. All of the samples prepared (control, heat treated and kiln dried) have been tested with this bending test. According to the clause in the standard, the half shear span to depth ratio (a/h) of the timber beams tested on four points loading must be in the range of five to twelve. The timber beams were arranged horizontally during the setup, to receive load at crosshead rate of 0.06mm/min, as shown in figure 3. In order to monitor the deflection occurred on the beam, there were four (4) linear variable differential transducers (LVDT) moving loading crosshead attached vertically during the test, shown in figure 4.



Figure 3. Timber Beam for Bending Test Set up



Figure 4. Arrangement of LVDT and Loading Crosshead



Figure 5. The Data Logger Connected to each LVDT

The data logger used to receive and record the reading of the data was connected to each of the LVDT attached on the timber beam, as shown in figure 5. The test had been conducted in Heavy Structure Laboratory, Faculty of Civil Engineering UiTM Malaysia using 250kN Universal Testing Machine (UTM). The value of MOE and MOR for each beam was then calculated based on the data from this bending test, using the equation shown in Equation 1 and Equation 2. The unit for both data is expressed in MPa.

$$MOR = \frac{pl}{bh^2} \quad (1)$$

$$MOE = \frac{23PL^3}{108bh^3\Delta} \quad (2)$$

where,

b= width of the timber beam (mm), h= depth of the timber beam (mm), P= load at the proportional limit (N), Δ = deflection at the proportional limit (mm), L= length of the span (mm), a= half shear span (mm)

Figure 6 shows the load versus deflection curve of structural size samples for Keruing. The curve shows different behavior of the slope between control samples and heat treated samples in four ranges of temperature. In elastic region of the curve, it can be seen that the linear slope of samples treated at temperature of 150°C, 170°C and 190°C are higher compared to the control samples. Treating Keruing at these three temperature level had improved the stiffness of the samples. According to the degree of slope in this figure, there is improvement on the ability of the heat treated samples to sustain load compared to the control sample. These three samples take the longest time to fail compared to control samples and the slope is drop abruptly after achieved the maximum load. The samples are samples treated at 150°C, 170°C and 190°C where the highest maximum load is performed by the sample treated at 190°C. Treated Keruing at temperature level of 210°C still improvised its bending capacity as both of the ability to sustain load and stiffness is is still higher than the control samples but low than other samples of temperature. It can be said that Keruing sample treated by heat at 190°C shows the highest improvement in bending behavior as it achieved highest load and take the longest time to fail compared to the other samples.

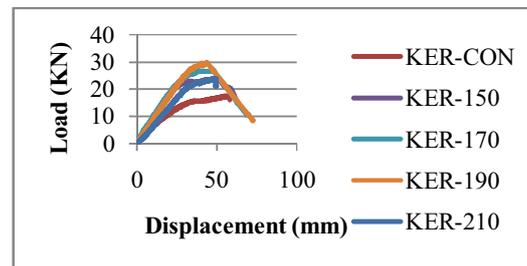


Figure 6. Load Deflection Curve for Keruing

Table 2 shows the MOE and MOR value of each sample for Keruing including control and heat treated samples at four different levels of temperatures. The MOE value indicated in the figure for control sample is 10.06GPa. The value then increasing to 17.24GPa for sample treated at temperature of 150°C. The figure shows that the MOE value is keep increasing with the increment of heat treatment temperature which is 19.55GPa at 170°C and 22.42GPa at 190°C. However, the value shows a slight reduction at temperature of 210°C which is 16.90GPa. It is learned that even there is reduction of value of MOE at the highest temperature of heat treatment on Keruing, the value is still higher compared to the control sample. The MOR value for control and heat treated samples for Keruing. The result shows that the value of MOR for this timber increase compared to the control sample when treated by heat. The MOR value for PAU-CON is 80.24MPa. The MOR value for sample treated at temperature of 150°C is 104.65MPa, 117.36MPa at 170°C and 135.0MPa at 190°C. The value decreased once the timber been treated by temperature of 210°C where the MOR value dropped to 104.87MPa.

Table 2. MOE and MOR Value for Keruing

SAMPLE	MOE				MOR			
	Mean (GPa)	S.D	COV (%)	Δ (%)	Mean (MPa)	S.D	COV (%)	Δ (%)
KER-CON	10.06	0.62	6.20		80.24	6.64	8.28	
KER-150	17.24	1.11	6.43	-71.37	104.65	7.94	7.59	-30.42
KER-170	19.55	1.39	7.11	-94.38	117.36	7.92	6.75	-46.26
KER-190	22.42	1.09	4.86	-122.84	135.00	6.58	4.88	-68.24
KER-210	16.90	1.40	8.29	-68.04	104.87	7.57	7.22	-30.69

During the bending test parallel to the grain, the load versus displacement had been monitored and recorded continuously for each of heat treated samples of Keruing. It was tested until the samples gained the maximum load and completely failed. The mode of failure shown by each samples tested was recorded. The samples failed at the tension zone with the different degree of tare on the samples beam. Figure 7 shows the pattern of failure occurred on the beam after been tested.



Figure 7. Mode of failure for Keruing

Figure 8 shows the behavior of load versus displacement curve under bending parallel to grain for structural size samples of Light Red Meranti. There are five numbers of slopes and each of the slopes represents the control and heat treated samples at four ranges of temperature. In this figure, it can be seen that the linear slopes are almost similar between all heat treated samples treated at different temperature level. Meanwhile, samples treated by heat at 150°C, 170°C and 190°C shown high improvement of linear slope which means these samples are stiffer compared to the control sample. The improvement of bending behavior on heat treated Light Red Meranti as the degree of slope had increasing from the lowest range of temperature to the highest range. It shows that the ability of Light Red Meranti to sustain the applied load is improving compared to control sample as the maximum load obtained keep increasing for heat treated samples from 150°C, 170°C to 190°C except for beam treated at 210°C. The maximum load achieved by LRM-210 is higher compared to the control beam, but it is low compared to maximum load achieved by LRM-190. It is an indicator that at temperature level above of 190°C, the bending behavior of Light Red Meranti started to decrease. In overall, heat treating Light Red Meranti had improved the bending behavior of the samples of each temperature applied but the best improvement occurred at 190°C temperature level where the beam is stiffer, sustain higher maximum load and take the longest time before completely fail.

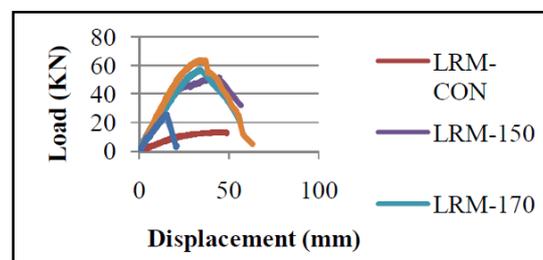


Figure 8. Load Deflection Curve for Kapur

Table 3 show the MOE and MOR value for all the samples of Light Red Meranti respectively. For MOE value, the result clearly indicates that the value increase for the heat treated timber of each level of temperature applied, compared to the control sample, except at 210°C. At 210°C, the MOE value started to decrease yet is still higher compared to the control and heat treated sample at 150°C. The MOE value of LRM-CON is 9.16GPa, then increased to 58.62Gpa at 190°C. At 210°C, MOE value had dropped to 55.60GPa. The value of MOE for Light Red Meranti for each sample; Table 3 shows the MOR value of Light Red Meranti before and after been treated by heat. The MOR value for LRM-CON is 56.87MPa. This value is then increasing once this timber been treated by heat as MOR value for LRM-150 is 227.92MPa, followed by LRM-170 with 251.30MPa. The value is keep increasing once the timber been treated by heat at temperature level of 190°C with 270.21MPa. The value is then dropped to 117.43MPa once temperature of heat treatment had been increased to 210°C. Even though the value at this temperature seems to be dropped compared to other three level of heat treatment temperature but if compared to the control samples, the value of MOR for LRM-210 is still shows improvement and better than the MOR value for control samples.

Table 3. MOE and MOR Value for Light Red Meranti

SAMPLE	MOE				MOR			
	Mean (GPa)	S.D	COV (%)	Δ (%)	Mean (MPa)	S.D	COV (%)	Δ (%)
LRM-CON	9.16	1.55	16.97		56.87	6.93	12.18	
LRM-150	37.67	2.08	5.51	-311.25	227.92	7.96	3.49	-300.81
LRM-170	55.55	3.56	6.41	-506.42	251.30	9.97	3.97	-341.93
LRM-190	58.62	3.00	5.12	-540.02	270.21	8.09	2.99	-375.18
LRM-210	55.60	1.67	3.01	-507.04	117.43	5.91	5.03	-106.51

Figure 9 shows the failure modes on Light Red Meranti's heat treated beam tested by bending parallel to the grain. Overall observation shows that all of the heat treated Kapur beams have same modes of failure. The beams failed at the tension zone except for the degree of tear shown by each species of sample beam tested. Light Red Meranti beam treated at heat of 210°C shows the highest degree of tear failure at tension zone compared to the other three beams treated at lower temperature.

**Figure 9.** Mode of failure for Light Red Meranti

Heat treatment had increased the bending strength properties of beech wood [19]. The increment of temperature level applied during heat treatment process had positively affected the bending strength properties of black pine [20].

5. Conclusion

According to the findings of this study, the value of MOE and MOR of heat treated Keruing and Light Red Meranti had been improvised and increased. It shows that, heat treatment is an alternative way in order to modify the properties and characterization of timber, which is better and environmental friendly compared to the chemical preservative. The heat treatment might give an acceptable effect on the properties of timber in term of physical, chemical or mechanical composition that will lead to the timber application in construction industry as structural materials without using chemical preservatives. To be concluded, bending strength properties of Keruing and Light Red Meranti had been improved by applying heat treatment. It can be said that, the timber with low strength properties can be modified and improvised by high level of temperature.

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