Article

Selected Physical and Mechanical Properties of Microwave Heat Treated Rubberwood (Hevea brasiliensis)

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Abstract: The objectives of this study were to evaluate some of physical and mechanical properties of rubberwood (Hevea brasiliensis) as function of microwave heat treatment process. The specimens were heat treated at three temperature levels of 150 °C, 180 °C, and 220 °C for 20 min in a small microwave oven connected to a computer. Bending characteristics, namely modulus of elasticity (MOE), modulus of rupture (MOR) as well as hardness of the samples were tested. Dimensional stability in the form of swelling and water absorption of the specimens were also determined. Based on the findings in this work it appears that microwave can be used successfully for heat treatment of rubberwood. Overall mechanical properties of the samples were adversely influenced by the treatment. MOE, MOR and hardness values of the samples treated at a temperature of 220 °C had 2.37, 3.69, and 2.12 times reduced than those of control samples, respectively. Dimensional stability of the heat treated samples as a result of 2-h and 24-h water soaking improved. Micrographs take from scanning electron microscope (SEM) and transmission electron microscope (TEM) revealed that certain amount of damage took place in the cellwall of the treated specimens. Overall discoloration on the samples due to microwave heat treatment was found insignificant.

Keywords: heat treatment; microwave; dimensional stability; rubberwood

1. Introduction

Heat treatment or thermal modification of wood is one of the most widely used methods to improve overall properties of the unit so that it can be used more efficiently during its service life. Heat treatment of wood at commercial scale was developed in Europe in 1990 and became an accepted technique for various applications [1–3]. The fundamental of heat treatment of wood and wood products is simply modification of chemical decomposition of the member using a scheduled pyrolysis to enhance its properties. Some of the major advantages of heat treatment include improvement of dimensional stability, resistance to biological deterioration and imitate more expensive wood species by changing overall color of the processed unit. Wood is a hygroscopic material which absorbs and desorbs moisture from the surrounding environment resulting in its dimensional movement. There has been approaches to treat wood with different types of resin to enhance its dimensional stability but such techniques were found to be not cost effective. Heat treatment is one of the most practical techniques to improve hygroscopicity of wood and wood products with an acceptable cost.

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During heat treatment process water is removed from the wood causing transformation of its chemical composition [4–6]. Such modification takes place in the form of hydrolysis, decarboxylation and oxidation reducing hygroscopicity of the wood [4]. Heat treated wood is generally dimensionally more stable having reduced shrinkage and swelling characteristics due to fluctuation in moisture content within the surrounding environment. Hemicelluloses is the most reactive element in the cellwall having a low molecular weight among the other three main components of any lignocellulosic materials and degrades at lower temperature levels than cellulose and lignin during the heat treatment [4,6,7]. It is also a well-known fact that breakage of the lignin polysaccharide compounds by organic acids from hemicelluloses in the cellwall is inevitable during the heat treatment [4,8].

One of the most important disadvantages of heat treatment is its adverse influence on mechanical properties of wood. Various studies clearly revealed that heat exposure adversely influences most of the mechanical properties of wood [9–12]. Probably the first investigation related to effect of heat on mechanical properties of wood was carried out by Stamm et al., in 1944 and determined that modulus of rupture of different wood species decreased 20% as a result of heat exposure between 160 °C and 280 °C [13]. Another study found that there is decreasing linear relationship between bending characteristics including modulus of elasticity, modulus of rupture and heat treatment processing parameters [14]. Based on the findings of previous studies it was determined that the main reason of adverse effect of heat treatment on mechanical properties of wood could be related to the degradation of hemicelluloses in the cellwall [4,15]. The crystallization of cellulose, specifically on the amorphous zone would be also one of the main elements playing a major role on this issue [15–17]. Heat treatment also modifies molecular structure of wood as a result of decomposition of the polymers causing reduction of elasticity. Therefore any wood products exposed to heat treatment will have lower mechanical properties including modulus of elasticity and modulus of rupture. Negative effect of heat treatment on mechanical properties of wood has been studies in past investigations and the decrease of hemicelluloses was determined as the major reason for such reduction [4,16,18,19]. When flexible bonding between cellulose and hemicelluloses is replaced and left only rigid cellulose bonds, flexibility of the products is simply decreases [4,20].

Regarding adverse effect of heat treatment on mechanical properties of wood, eastern redcedar samples were exposed to temperature levels of 120 °C, 160 °C and 190 °C for 6-h and it was found that their shear strength reduced from 44.4% to 64.1% [10]. It appears that it can clearly be concluded that heat treated wood products are not ideal for structural applications where high strength requirements from the unit are priority [20,21].

In addition to bending properties of heat treated wood, its hardness is also adversely influenced due to degradation of hemicelluloses. Heat treated eastern redcedar, yellow poplar and southern pine samples had an average of 50% reduction in their Janka hardness [10]. Changes in structure of lignin also reduce overall of hardness of heat treated wood [4,17].

In general heat treatment process of wood consists of several major levels, namely drying, application of heat treatment schedule, cooling and finally conditioning [9,10]. A previous study found that the swelling values of poplar, pine, and spruce samples decreased ranging from 50% to 80% as a result of exposure them to heat treatment process having a temperature ranging from 180 to 200 °C [11]. Heat treated pine samples at a temperature of 220 °C also had 2.7% and 1.95% reduction in their tangential and radial grain orientation swelling, respectively [11]. Discoloration in the form of being darker is also one of the results of heat treatment of wood. Naturally, this characteristic is more prominent in the case of light color species such as pine or yellow poplar [18]. Degradation of hemicelluloses and extractive content in wood are main parameters influencing discoloration of the member during heat treatment process [21,22]. In a past study yellow poplar, eastern redcedar and southern pine samples exposed to temperature levels of 130 °C, 160 °C, and 190 °C had average lightness values ranging from 32.82 to 68.75 [18].

Most of the experimental heat treatment processes of wood and wood products are carried out using a laboratory type oven. Although dry-kiln type compartments are effectively used for a
commercial scale operation but heat treatment process is quite time consuming in both approaches. Microwave heat treatment is relatively new approach and has been getting a certain attention in heat treatment of wood products. Better temperature control and more homogeneous distribution of heat within the sample in a short time would be considered some of the main advantages of this technique. This technology provides substantial energy, material and time saving as compared to traditional heat treatment methods [23–25]. It is expected that microwave heat treatment of wood products will be getting more popular for lumber and other products including particles and biomass.

Rubberwood (Hevea brasiliensis) is an indigenous species to Amazon forestland in Brazil. Around 1840 this species was introduced to South East Asian countries including Malaysia, Thailand, and Vietnam [26]. Rubber tree is tapped to produce natural latex until age of 20–25 years old during its productive life span. Until several decades ago majority of rubber trees were wasted by burning or land filling once tree reached its unproductive life. However, rubberwood is highly demanded and used for mainly furniture production, plywood and veneer manufacture as well as a raw material for value-added composite panels such as particleboard or fiberboard production [26,27].

Thailand is a major exporter of rubberwood in South East Asia. An approximate rate of 65% rubberwood products of the country is shipped aboard. It is expected that such value will be increasing linearly within next two decades. Both mechanical properties of rubberwood are slightly lower than those of typical oak with an exception of dimensional stability. During the heat treatment of wood, density, anatomical structure and units size are some of the parameters influencing overall quality of the process. Application of microwave heat treatment would be ideal for species having less permeability such as oak or maple. It is clear that low permeable species will simply resist heat transfer during the treatment resulting in longer processing time. This would also create certain amount of excessive discoloration on the samples especially when higher temperature levels are used. In the case of rubberwood being as relatively porous hardwood species used in this work, reducing heat exposure time in a microwave would be considered as a main advantage. Such advantage will not only create overall lower energy consumption but also complete the process within a short period of time without having any possible defects.

Most of the properties of the rubberwood have been evaluated and tested in previous investigations [26,27]. However, there is very limited information on behavior of microwave heat treated rubberwood. Therefore, the main objective of this study was to evaluate both physical and mechanical properties of heat treated rubberwood samples in a microwave oven. Bending properties, hardness, anatomical change, and dimensional stability of such samples were also determined within the scope of the study. It is expected that data from this work would be helpful to understand better of such properties of rubberwood, so that microwave heat treatment process of this species having a potential can be used effectively and efficiency from the point of sustainability.

2. Materials and Methods

Rubberwood lumbers were supplied by a local sawmill in Surat Thani, Thailand. Lumber were sprayed with boron compound to preserve against any biological deterioration before they were kiln dried to 20% moisture content. Dried lumber were sanded with 220 grit size sandpaper by applying several light strokes. Forty defect free samples with dimensions of 40 mm by 20 mm by 55 mm and twenty specimens with dimensions of 40 mm by 20 mm by 270 mm in tangential, radial and longitudinal grain orientations were cut from flat sawn lumber. A total of sixty samples were conditioned in the laboratory oven at a temperature of 103 ± 2 °C until they had a constant weight to find their oven-dry density.

A computer controlled microwave oven with a capacity of 20 L and 800 watt power supply having frequency of 2.45 MHz was employed for heat treatment process. Experimental set-up used in this work is illustrated in Figure 1. The samples of rubberwood were treated in the microwave system at the temperature levels of 150 °C, 180 °C, and 220 °C for 20 min. by using a software Arduino 1.8.7. which controlled temperatures in the microwave oven at an accuracy level of 4 °C.
Thermocouples were also used to measure the actual temperature in the microwave reactor. Following the treatment, samples were kept in the conditioning room having a temperature of 25 °C and relative humidity of 65% for two weeks before any tests were carried out.

Figure 1. Microwave heat treatment set-up.

Mechanical properties, namely modulus of elasticity (MOE), modulus of rupture (MOR) and Janka hardness of the samples were carried out on an Instron Universal Testing system equipped with a loadcell having a capacity of 10,000 kg based on ASTM D143-14 Standard Test Methods for Small Clear Specimens of Timber (2014) [28].

Dimensional stability of the specimens in the form of swelling and water absorption was also tested by soaking them in distilled water for 2-h and 24-h. Dimensions of the samples were measured and weighed at an accuracy of 0.01 cm and 0.01 g, respectively at each water exposure level to calculate their dimensional and weight changes. Additional twenty specimens were also examined for oven-dry density and weight loss.

Bending samples were also used to determine discoloration of the samples due to the heat treatment by taking three random measurements using a spectrophotometer, MiniScan EZ 4500, HunterLab.

Small cubes in dimensions of 5 mm by 5 mm by 5 mm were cut from heat treated samples for microscopic evaluation. A scanning electron microscope (SEM), FEI Quanta 250, and transmission electron microscope (TEM), Talos L120C at 120 kV with BF-TEM mode were employed to determine effect of heat treatment on the samples at microscopic level.

3. Results and Discussion

Mechanical properties of the samples including MOE, MOR and hardness values of four different temperature levels are listed in Table 1. MOE and MOR values of control samples were 6280 N/mm² and 107.11 N/mm², respectively being the highest among the other specimens. Both properties of the samples decreased 1.05, 1.17, 1.64, 1.44, 2.37, and 3.70 times than those of control samples as a result of heat treatment at temperatures of 150, 180 and 220 °C. Previous studies also showed that negative effect of heat treatment on mechanical properties of wood [4,10,16]. In a past work bending properties of heat treated North American Jack pine also showed reduced values similar to those determined in this work [21].
Table 1. Mechanical properties of the samples. (The numbers in parentheses are the standard deviation values).

| Temperature (°C) | Swelling in Water Soaking (%) | 2-h | 24-h |
|------------------|--------------------------------|-----|------|
|                  | Radial | Tangential | Longitudinal | Radial | Tangential | Longitudinal |
| 0                | 1.60 (0.38) | 1.86 (0.47) | 0.24 (0.07) | 2.67 (0.49) | 2.96 (0.56) | 0.44 (0.05) |
| 150              | 0.562 (0.23) | 0.988 (0.17) | 0.23 (0.05) | 2.25 (0.47) | 2.63 (0.48) | 0.43 (0.14) |
| 180              | 0.474 (0.16) | 0.878 (0.10) | 0.21 (0.02) | 1.62 (0.43) | 2.56 (0.32) | 0.43 (0.06) |
| 220              | 0.243 (0.21) | 0.472 (0.37) | 0.20 (0.03) | 1.49 (0.22) | 2.34 (0.60) | 0.42 (0.09) |

Overall hardness of the samples also followed the similar trend as a result of heat treatment. It was found that heat treated eastern redcedar samples exposed to a temperature of 190 °C for 6-h had 50% reduction in their Janka hardness values and had a certain amount of brittles and crushed during the hardness test [17]. Although the samples also had reduced hardness values as function of heat treatment but no crushing or any other deformation on them was observed. This could be related to only twenty minutes heat exposure time used in this work which could be considered as main advantage of microwave heat treatment approach.

Table 2 displays swelling values of the samples soaked in distilled water for 2-h and 24-h. Control specimens had swelling values of 1.60%, 1.86%, and 0.24% for 2-h and 2.67%, 2.96%, and 0.44% for 24-h for radial, tangential, and longitudinal grain orientation, respectively. Heat treated specimens at a temperature of 150 °C had reduced corresponding values of 64.90%, 46.97%, and 4.90% of 2-h and 15.64%, 11.10%, and 2.01% of 24-h compared to those of control specimens. As temperature level was increased to degrees of 180 and 220 higher positive influence of heat treatment on dimensional stability of the samples can clearly be seen from Table 2.

Table 2. Swelling values of the heat treated samples. (The numbers in parentheses are the standard deviation values).

| Temperature (°C) | Bending (N/mm²) | Hardness (N) |
|------------------|----------------|--------------|
|                  | MOE | MOR |               |
| 0                | 6280 (256.98) | 107.11 (24.21) | 5934 (583.12) |
| 150              | 5946 (517.33) | 91.26 (26.63) | 5320 (827.11) |
| 180              | 3820 (383.54) | 74.33 (21.55) | 3513 (889.13) |
| 220              | 2646 (854.24) | 28.93 (11.42) | 2506 (388.42) |

The values of oven dry density, weight loss of treated samples gradually decreased as presented in Table 3. The density of heated specimens had values of 648 kg/m³, 613 kg/m³, 611 kg/m³, and 556 kg/m³ for control samples and those exposed to temperatures of 150 °C, 180 °C and 220 °C, respectively. Wood being a hygroscopic material absorbs moisture from the surrounding environment resulting in dimensional changes [29,30]. Therefore how much moisture is absorbed plays a significant role on the member during its service life [31,32]. Samples treated at a temperature of 220 °C and soaked in the water for 24-h had 19.39% water absorption which was 1.38 times lower than that of the control sample. It is clear that water absorption values of the samples were improved as a result of heat treatment as can be seen in Table 3 [26–28].
Table 3. Density, weight loss and water absorption of the samples. (The numbers in parentheses are the standard deviation values.

| Temperature (°C) | Oven-Dry Density (kg/m³) | Weight Loss (%) | Water Absorption (%) |
|------------------|--------------------------|----------------|----------------------|
| 0                | 648 (43)                 | -              | 9.31 (1.22)          |
| 150              | 613 (83)                 | 5.61 (3.42)    | 8.89 (1.94)          |
| 180              | 611 (31)                 | 8.32 (2.78)    | 3.96 (1.89)          |
| 220              | 556 (49)                 | 12.17 (4.91)   | 3.73 (1.31)          |

Discoloration of heat treated samples in the form of values of L*, a*, and b* is displayed in Table 4. Lower L*, value of parameters is related to darker color of the samples. Values of 48.88 for L*, 9.69 for a*, and 20.80 for b* were determined for the darkest samples exposed to 220 °C for 20 min. It appears that temperatures of 150 and 180 °C did not create substantial darkening of the samples. In a past study carried out heat treatment of teak wood found L* value of 65 for 2-h exposure of samples [29].

Table 4. Discoloration values of treated samples. (The numbers in parentheses are the standard deviation values.)

| Temperature (°C) | Color Parameters |
|------------------|-----------------|
|                  | L*              |
| 0                | 72.07 (1.28)    |
| 150              | 75.29 (0.83)    |
| 180              | 54.41 (1.23)    |
| 220              | 48.88 (1.31)    |
|                  | a*              |
| 0                | 5.65 (0.70)     |
| 150              | 5.56 (1.01)     |
| 180              | 8.32 (0.39)     |
| 220              | 9.69 (0.51)     |
|                  | b*              |
| 0                | 20.57 (1.10)    |
| 150              | 20.53 (0.73)    |
| 180              | 20.26 (0.40)    |
| 220              | 20.80 (0.62)    |

Micrographs taken from the surface of heat treated samples using SEM and TEM are depicted in Figures 2 and 3. It looks like samples exposed to a temperature of 220 °C had damaged vessels in the form of some cracks and separation between the vessels while control sample is well preserved as can be seen Figure 2a,b, respectively. It is an accepted fact that high temperature exposure adversely influences the overall structure of cellwall consisting of cellulose, lignin and hemicelluloses by the process of thermo-plasticization [21]. This was also confirmed by the micrograph taken using TEM as can be seen partially broken and cracked cell walls due to exposure to a temperature of 220 °C.

Figure 2. SEM micrographs of control sample (a) and the one exposed to 220 °C (b).
4. Conclusions

Based on the findings in this work, it appears that rubberwood can be heat treated employing the microwave technique. Mechanical properties of the samples were also adversely influenced similar to those different species heat treated with the traditional heat treatment techniques. Overall it was determined that dimensional stability of the samples had some enhancement. Microscopic evaluation of the specimens revealed that certain amount of damage took place at cell wall level reflected in reduced mechanical characteristics of the samples. Considering only twenty minutes processing time which is the main advantage of the microwave method as compared to other traditional ones would create significant energy saving. Heat exposure of the samples for a short time also did not result in noticeable discoloration. In further studies, economical feasibility of the microwave heat treatment of rubberwood would be desirable to investigate to have a better understanding of such application. Also it is planned to evaluate chemical modification of the rubberwood due to microwave heat treatment by using Fourier-transform infrared spectroscopy (FTIR) in addition to other chemical analyses in the second phase of this study.

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References
1. Tumen, I.; Aydemir, D.; Gündüz, G.; Uner, B.; Cetin, H. Changes in the chemical structure of thermally treated wood. Bioresources 2010, 5, 1936–1944.
2. Pétrissans, M.; Pétrissans, A.; Gérardin, P. Pore size diameter, shrinkage and specific gravity evolution during the heat treatment of wood. Innov. Woodwork. Ind. Eng. Des. 2013, 3, 18–24.
3. Taghiyari, H.R.; Esmailpour, A.; Adamopoulos, S.; Zereshki, K.; Hosseinpouria, R. Shear strength of heat-treated solid wood bonded with polyvinyl-acetate reinforced by nanowollastonite. Wood Res. 2020, 65, 183–194. [CrossRef]
4. Kocaefe, D.; Poncsak, S.; Boluk, Y. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. Bioresources 2008, 3, 517–537.
5. Candelier, K.; Thevenon, M.F.; Petriassans, A.; Dumarcay, S.; Gerardin, P.; Petriassans, A. Control of wood thermal and its effects on decay resistance: A review. Ann. For. Sci. 2016, 73, 571–583. [CrossRef]
6. Yildiz, S.; Gezer, D.; Yildiz, U.C. Mechanical and chemical behavior of spruce wood modified by heat. Build. Environ. 2006, 41, 1762–1766. [CrossRef]

7. Poncsak, S.; Kocae, D.; Bouazara, M.; Pichette, A. Effect of high temperature treatment on the mechanical properties of birch. Wood Sci. Technol. 2006, 40, 467–668. [CrossRef]

8. Boonstra, M.J.; Tjeerdsma, B. Chemical analysis of heat treated softwoods. Holz Roh Werkst. 2006, 64, 204–211. [CrossRef]

9. Hiziroglu, S. Fundamental aspects of heat treated wood. Fact Sheet 2019, 2. Available online: www.fapc.biz (accessed on 3 August 2020).

10. Dilik, T.; Hiziroglu, S. Bonding strength of heat treated compressed Eastern redcedar wood. Mater. Des. 2012, 42, 317–320. [CrossRef]

11. Shi, J.L.; Kocaefe, D.; Zhang, J. Mechanical behaviour of Quèbec wood species heat-treated using ThermoWood process. Holz Roh Werkst. 2007, 65, 255–259. [CrossRef]

12. Ozcan, S.; Ozcifci, A.; Hiziroglu, S.; Toker, H. Effects of heat treatment and surface roughness on bonding strength. Constr. Build. Mater. 2012, 33, 7–13. [CrossRef]

13. Esteves, B.M.; Pereira, H.M. Wood modification by heat treatment: A review. BioResources 2009, 4, 370–404.

14. Korkut, S.; Kök, M.S.; Korkut, D.S.; Gürleyen, T. The effects of heat treatment on technological properties in red-bud maple (Acer trautvetteri Medw.) wood. BioResources Technol. 2008, 99, 1538–1543. [CrossRef] [PubMed]

15. Santos, J.A. Mechanical behaviour of Eucalyptus wood modified by heat. Wood Sci. Technol. 2000, 34, 39–43. [CrossRef]

16. Hill, C. Wood Modification: Chemical, Thermal and Other Processes; John Wiley & Sons, Ltd.: Hoboken, NY, USA, 2006.

17. Bakar, B.; Hiziroglu, S.; Tahir, P.M. Properties of some thermally modified wood species. Mater. Des. 2013, 43, 348–355. [CrossRef]

18. Ulker, O.; Aslanova, F.; Hiziroglu, S. Properties of thermally treated yellow poplar, Southern pine, and Eastern redcedar. BioResources 2018, 13, 7726–7737. [CrossRef]

19. Bekhta, P.; Niemz, P. Effect of high temperature on the change in dimensional stability and mechanical properties of spruce wood. Holzforschung 2003, 57, 539–546. [CrossRef]

20. Boonstra, M.J.; van Acker, J.; Tjeerdsma, B.; Kegal, E. Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. Ann. For. Sci. 2007, 64, 679–690. [CrossRef]

21. Kocae, D.; Poncsak, S.; Tang, J.; Bouazara, M. Effect of heat treatment on the mechanical properties of North American Jack pine: Thermogravimetric study. J. Mater. Sci. 2009, 45, 681–687. [CrossRef]

22. González-Peña, M.; Breese, M.; Hill, C. Hygroscopicity in heat-treated wood: Effect of extractives. In Proceedings of the International Conference on Environmentally Compatible Forest Products (ICECFOP), Oporto, Portugal, 22–24 September 2004; pp. 105–119.

23. Torgovnikov, G.; Viden, P. Microwave wood modification technology and its applications. For. Prod. J. 2010, 60, 173–182.

24. Torgovnikov, G.; Viden, P. High-intensity microwave wood modification for increasing permeability. For. Prod. J. 2009, 59, 1–9.

25. Harris, G.A.; Torgovnikov, G.; Viden, P.; Brodie, G.I.; Shaginov, A. Microwave Pretreatment of Backsawn Messmate Boards to Improve Drying Quality: Part 1. Dry. Technol. 2008, 26, 579–584. [CrossRef]

26. Ratnasingam, J.; Ioras, F. Effect of heat treatment on the machining and other properties of rubberwood. European. J. Wood Prod. 2012, 70, 759–761. [CrossRef]

27. Teoh, Y.P.; Don, M.M.; Ujang, S. Assessment of the properties, utilization, and preservation of rubberwood (Hevea brasiliensis): A case study in Malaysia. J. Wood Sci. 2011, 57, 255–266. [CrossRef]

28. ASTM D 143–14. Standard Test Methods for Small Clear Specimens of Timber; Street: Washington, DC, USA, 2010.

29. Priadi, T.; Hiziroglu, S. Characterization of heat treated wood species. Mater. Des. 2013, 49, 575–582. [CrossRef]

30. Chotikhun, A.; Hiziroglu, S. Measurement of dimensional stability of heat treated southern red oak (Quercus falcata Michx.). Measurement 2016, 87, 99–103. [CrossRef]
31. Priadi, T.; Suharjo, A.C.; Karlina'sari, L. Dimensional stability and color change of heat treated young teak wood. *Int. Wood Prod. J.* 2019, 10, 119–125. [CrossRef]

32. Giebeler, E. Dimensional stability of wood through warm pressure treatment. *Holz Roh Werkst.* 1983, 41, 87–94. [CrossRef]

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