Dielectric properties of heat treated teak wood (*Tectona grandis* Linn. F)

L Karlinasari\(^1\)*, U Adzkia\(^1\), R A Tang\(^1\), and Irzaman\(^2\)

\(^1\)Department of Forest Product, Faculty of Forestry and Environment, IPB University, Bogor, 16680
\(^2\)Department of Physic, Faculty of Mathematics and Natural Science, IPB University, Bogor, 16680

*Email: karlinasari@apps.ipb.ac.id*

**Abstract.** Heat treatment is a modification method that uses modification of drying temperature or other heat treatment to improve wood quality. Heat treatment with a temperature of 150ºC and 180ºC for 0, 2, and 6 hours carried out on 8 years old teak wood can improve its quality. The purpose of this study was to evaluate the effect of heat treatment on the dielectric properties of teak wood. The parameters in this study are the capacitance and dielectric constant or relative permittivity. The results showed that heat treatment affected the physical and dielectric properties of wood. Moisture content and wood density decrease after heat treatment. The changes on those physical properties influenced dielectric properties. Heat treated wood have decreased the dielectric wood properties significantly. The capacitance and the dielectric constant decrease on the sample which applied in higher temperature and time. Frequencies below 10 kHz have affected on dielectric properties or both capacitance and dielectric constant. Based on the study, the heat treatment was decreasing the ability of electrical insulator properties of wood.

1. **Introduction**

Fast growing teak is a teak species that has a shorter cutting age (20-30 years) [1,2]. The availability of fast growing teak is currently increasing along with the increasing demand for wood. Teak wood is commonly used by the community as raw material for furniture, handicrafts, and construction. However, fast growing teak wood has several disadvantages, such as low dimensional stability, strength, and durability [2]. In addition to these characteristics, [3] stated that 8 years old teak had low machining quality. Therefore, in utilizing teak wood with a short cutting age, modifications need to be made to improve the wood quality. One of the modification methods used is the heat treatment method.

The heat treatment method is an modification method used to improve wood quality through drying or other heat treatments. Hill [4] stated that heat treatment is an environmentally friendly technique because it does not involve chemicals during the process. Heat treatment methods have been carried out on several types of wood such as mahogany (*Swietenia macrophylla*) [5,6] rubberwood (*Hevea brasiliensis*) [7,8], *Eucalyptus urophylla* [9] and some fast-growing wood species such as teak (*Tectona grandis*), mangium (*Acacia mangium*), sengon (*Falcataria moluccana*) and jabon (*Neolamarckia cadamba*) [3]. Based on these results, heat treatment can improve wood quality as it
increases the dimensional stability by reducing the hygroscopicity of wood, and increase the durability of wood against fungi and wood-destroying insects, while also influence on the change of surface roughness, as well as wood machining properties [3,9-11]. Changes in these properties occur due to degradation of chemical components such as cellulose, hemicellulose, and lignin in the wood [4,11]. These changes also affect the electrical properties of wood. The electrical properties of wood undergo large changes with a relatively small change in moisture content below the fiber saturation point [12]. The electrical properties of wood comprise impedance, inductance, dielectric constant, and electrical conductivity [12,13].

The electrical properties can be used to evaluate the material quality both quickly and nondestructively [14]. One of the electrical properties is dielectric properties. The dielectric properties also known as electrical insulator is concerned with the storage and dissipation of electric and magnetic energy in materials. Capacitance and dielectric constant are two variables that illustrate dielectric properties. Capacitance is the amount of charge per unit voltage that two parallel plates can store. Meanwhile, the dielectric constant (often called the relative permittivity) is a measure of the amount of electric potential energy, in the form of induced polarization that is stored in a given volume of material under the action of an electric field. The dielectric properties of material are affected by some parameter of wood such as moisture content, density, and characteristics wood pore as well as fiber direction [12,14-16]. This properties was also influenced by temperature, frequency, and orientation of electric field with respect to measurements conditions [17]. Changes in wood properties due to heat treatment may affect the dielectric properties of the wood. Therefore, this study was conducted to determine the effect of heat treatment on the capacitance value and the wood dielectric constant. The purpose of this study was to evaluate the effect of heat treatment on the dielectric properties of teak wood.

2. Materials and Methods

2.1. Materials

The material used in this study was an 8 years old teak wood (Tectona grandis) with diameter about 40 cm from Dramaga Sub District, Bogor. The electrical properties testing was carried out with the 3532-50 LCR Hi-tester (Hioki). The research was conducted from April until October 2018 at some Laboratories in Department of Forest Product, Faculty of Forestry and Environment, IPB University for preparing and treatment of wood samples. The measuring of electrical properties was done in the Spectroscopy Laboratory, Department of Physics, Faculty of Mathematic and Natural Science, IPB University.

2.2. Methods

2.2.1. Heat treatment

The heat treatment was carried out on tangential and radial boards using an oven at a temperature of 150 and 180°C at 0 (control), 2, and 6 hours. After the boards have been treated, they were then conditioned for ± 7 days to release residual stress and stabilize the moisture content of the boards. The boards were then cuts to have sample dimensions of width, length, and thickness 2 x 1 x 0.5 cm and it would have three sections plane of wood namely cross-section, radial, and tangential. The samples number used in this study are summarized in Table 1. The specimens with similar treatment were chosen for the measurement of wood moisture content and density.
Table 1. The number of samples electrical properties of heat modified teak wood test

| Temperature | Time variation (jam) | Type and number of sample planes | Cross-section | Radial | Tangential |
|-------------|----------------------|----------------------------------|---------------|--------|------------|
| Control     | 0                    |                                  | 3             | 3      | 3          |
| 150°C       | 2                    |                                  | 3             | 3      | 3          |
| 150°C       | 6                    |                                  | 3             | 3      | 3          |
| 180°C       | 2                    |                                  | 3             | 3      | 3          |
| 180°C       | 6                    |                                  | 3             | 3      | 3          |
| Total       | 15                   |                                  | 15            | 15     | 15         |

2.2.2 Physical properties

Testing of the physical properties included the Moisture Content (MC) and wood density (ρ). It was obtained by weighing the sample (M_m) before putting it in the oven at a temperature of 103 ± 2°C for 24 hours and followed by measuring the sample using a digital caliper to gain an air-dry volume (V_m). Subsequent test samples were removed from the oven and put into the desiccator for ± 15 minutes, then proceeded with weighing the sample after it was in the oven (M_0) and measuring the dimensions. The value of moisture content and density were calculated using the following equation.

\[
\text{Moisture content (\%) } = \frac{M_m - M_0}{M_0} \times 100 \tag{1}
\]

\[
\text{Density (g/cm}^3\text{) } = \frac{M_m}{V_m} \tag{2}
\]

where, \(M_m\): initial weight (g), \(M_0\): oven-dry weight (g), \(V_m\): volume of specimen (cm³)

2.2.3 Dielectrical properties

The dielectric properties consisted of the unheated (control) and heated samples. The sample dimension as well as the plate dimension for testing of the electrical properties was 2 x 1 x 0.5 cm. They were attached to a cable connected to the LCR Hi-tester (Hioki) device (Figure 1) with the measurement results on the monitor. The variable which differentiated was the frequency from \(10^3\) to \(10^6\) Hz. The electrical properties were tested for three sections of wood i.e. cross-section, radial, and tangential with three replications of each. The parameters used in this study consisted of capacitance and dielectric constant. The capacitance and dielectric constant value was calculated with the following equation [12].

\[C_s = \frac{\varepsilon \varepsilon_0 A}{d} \tag{3}\]

\[\varepsilon_r = \frac{C_s d}{\varepsilon_0 A} \tag{4}\]

where, \(C_s\): capacitance (F), \(\varepsilon\): dielectric constant or relative permittivity, \(\varepsilon_0\): unitless material parameter, \(\varepsilon_0\): permittivity of a vacuum or free space (8.854 x 10⁻¹² F/m), \(A\): sectional area (m²), \(d\): distance between plate (m)

Figure 1. Setting sample for dielectric wood properties testing
2.3. Data analysis
Statistical analysis was conducted with a Completely Randomized Factorial Design analysis with two factors used in this study. Factor A is the heating temperature which consists of three levels (control, 2 and 6 hours) and factor B is the heating time which consists of 2 level (150 and 180°C). The test was carried out with three replications. Data was analyzed using Microsoft Excel 2013 application and IBM SPSS ver. 22.0. Duncan’s Multi Range Test was used for further analysis if the significance value in the 95% confidence levels.

3. Results and Discussion
3.1. Physical properties
3.1.1. Moisture content
Moisture content is the amount of water contained in the wood. The average moisture content decrease with the increase of the temperature and time of heat treatment as shown in Figure 2. The average moisture content of teak without heat treatment was 16%. In treated wood, at 150°C for 2 hours the average moisture content was 10%, while at the same temperature for 6 hours, the average decreased to 9%. Meanwhile, the moisture content at 180°C for 2 and 6 hours were 8% and 7%, respectively. Decreased moisture content due to heat treatment was also conveyed by [3,6,18] who studied on teak (Tectona grandis), mangium (Acacia mangium), jabon (Neolamarckia cadamba), and sengon (Falcataia moluccana). The high temperature and longer heating time caused the moisture content to decrease.

![Figure 2. Average of moisture content from teak wood with heat modification treatment on the three planes of wood](image)

Statistical analysis at a 95% confidence interval shows that the moisture content in each of the wood was affected by the interaction of temperature factors and heating time (Table 2). Duncan test showed that the high temperature and longer heating time caused the moisture content to decrease. It was due to heat treatment mostly caused degradation in hemicellulose and lead to decrease the ability cell wall to absorb the water [10] and [18]. Degradation of hemicellulose caused a decrease in hydroxyl groups, resulting in a decrease in the moisture content of wood. [19] stated that a significant decrease in the moisture content occurred at 150°C and would continue to do so with additional temperature in the heat treatment.
Table 2. Resume of variance analysis (ANOVA) the effect of temperature and heating time on the moisture content of teak wood

| Wood plane | Significant of ANOVA | Temperature | Time | Temperature vs Time |
|------------|----------------------|-------------|------|---------------------|
| Cross-section | 0.382tn | 0.000** | 0.000** |
| Radial | 0.528tn | 0.000** | 0.000** |
| Tangential | 0.360tn | 0.000** | 0.000** |

Note: tn= no significant difference at the confidence level 95%, **= significant difference at the confidence level 95%

3.1.2. Density
The average density of teak before heat treatment was 0.75 g/cm$^3$, whereas after treatment is 0.69 g/cm$^3$, meaning it was reduced about 8% (Figure 2). Study conducted by [20] reported the heat treatment on teak wood lead to a slightly decrease wood density was about 3.58% . While, the study by [21] on alder hardwood species applied heat treatment with temperature at 220°C for 6 hours has led decreasing density wood until was 19.7%. For that reason, wood species and characteristics of heat treatment were factors the decreasing of wood density.

![Figure 2. The average density of teak wood on the three planes of wood](image)

Statistical analysis at a 95% confidence interval in Table 3 shows that the density of teak in the cross-section and tangential direction is not affected by interaction between temperature and heating time. Meanwhile, the radial plane was influenced by those interaction. The results of the Duncan test analysis showed that the density of teak without heat treatment was significantly higher than that with the treatment. Heat treatment resulted in changes in extractive substances and degradation of hemicellulose, causing the wood density to decrease. Hill [4] and Yildiz [21] mentioned that on alder wood species, the higher heating temperature affected the increase in hemicellulose degradation. Hemicellulose was a component that is more susceptible to heat compared to other wood components.
Table 3. Resume of variance analysis (ANOVA) the effect of the temperature and heating time on the density of teak wood

| Wood plane      | Significance of ANOVA |  |  |
|-----------------|-----------------------|---|---|
|                 | Temperature | Time | Temperature | Time |
| Cross-section   | 0.605<sup>n</sup> | 0.018<sup>**</sup> | 0.169<sup>n</sup> |  |
| Radial          | 0.798<sup>**</sup> | 0.001<sup>**</sup> | 0.031<sup>**</sup> |  |
| Tangential      | 0.289<sup>n</sup> | 0.020<sup>**</sup> | 0.090<sup>n</sup> |  |

Note: <sup>n</sup>= no significant difference at the confidence level 95%, <sup>**</sup>= significant difference at the confidence level 95%

3.2. Dielectrical Properties

3.2.1. Capacitance

Capacitance is the ability of a material to maintain an electric charge in Farad unit (F) [22]. The value of teak wood capacitance decreases with increasing frequency (Figure 3). The maximum value of capacitance was at a frequency of 10<sup>3</sup> Hz. A significant reduction in capacitance occurred at a frequency of 10<sup>3</sup> to 10<sup>4</sup> Hz. Meanwhile, the capacitance with frequencies at 10<sup>4</sup> to 10<sup>6</sup> Hz tended to be constant. The capacitance value of cross-section differed from the radial and tangential. Below the frequency of 10<sup>4</sup> Hz, the difference value of capacitance was significant where the cross-section was the highest followed by radial and tangential section in untreated wood (Figure 3a, 3b, 3c). However, the almost similar values in a range 2 to 7 F was found at all section in treated wood in which the lower temperature and shorter time treatment had higher capacitance values. Untreated wood had significantly higher value of capacitance compared with treated wood. It was presumably related to wood porosity characteristics in term of correlated to wood density as mentioned by [23] In further, they reported wood species differentiation can be determined based on its dielectric properties.
Figure 3. The capacitance of teak wood heat-modification on the three plane (a) cross-section (b) radial (c) tangential.

Statistical analysis at a 95% confidence interval shows that the capacitance was influenced by the interaction between the temperature and heating time (Table 4). The higher the temperature and the longer of heating time, the lower the capacitance. The results of Duncan’s test showed that the wood capacitance without heat treatment was significantly higher than with heat treatment. Wood capacitance was affected by density, specific gravity, and moisture content [24]. Higher temperature and longer time in heat treatment caused a decreasing of wood moisture content. Higher moisture content made the capacitance lower [14,15,22].

Table 4. Resume analysis of variance (ANOVA) the effect of temperature and heating time to the capacitance on the three plane

| Wood plane    | Significance ANOVA | Temperature | Time   | Temperature vs Time |
|---------------|--------------------|-------------|--------|---------------------|
| Cross-section | 0.929**            | 0.000**     | 0.000**|
| Radial        | 0.949**            | 0.000**     | 0.003**|
| Tangential    | 0.617**            | 0.000**     | 0.004**|

Note: *n* = no significant difference at the confidence level 95%, ** = significant difference at the confidence level 95%
The dielectric constant is an important parameter in the absorption of electromagnetic energy. This value was generated from capacitance. The knowledge of this properties is crucial for a process design, control, and optimazation, as well as simulation of some heating drying technique such as high frequency and microwave drying technique [23].

Figures 4a, 4b, and 4c show the dielectric constant values from three different section of heat-modified teak wood. The highest dielectric constant value of teak was at a cross-section, followed by radial and tangential section. This phenomena was in line with study by [24-26]. It could be explained that cross-sectional plane could store the electrical energy greater than the radial and tangential. The dielectric constant value was strongly influenced by moisture content, wood density, fiber direction, anatomical structure [27]. Wood porosity have significant affected on dielectric constant value. Higher porosity resulted a lower dielectric contant or relative permittivity [23]. In term of this study, small changes of wood density caused by heat treatment compared with untreated wood have led relatively large changes in dielectric constant values. The most significant differences appear for lower frequencies. In specific, it was happened on dielectric wood properties below 5 kHz [23,24,28].

![Cross-section](image1)

![Radial](image2)
Figure 4. The dielectric constant of teak wood heat modification on the three plane (a) cross-section, (b) radial, (c) tangential

Statistical analysis of variance at a 95% confidence interval shows that the dielectric constant is influenced by the interaction of the temperature and the heating time (Table 5). The higher the temperature and the longer the heating duration, the lower the dielectric constant value. The results of Duncan's analysis showed that the dielectric constant of teak without heat treatment was significantly higher than the heat treated teak wood. This was also conveyed by [17, 29, 30] that the electrical properties of wood were strongly influenced by moisture content, wood porosity, fiber direction, as well as temperature and frequency during testing. Dielectric constant value without heat treatment were higher than with heat treatment. A decrease in the dielectric constant value showed a decrease in the wood's ability to deviate electrical energy. Therefore, wood, which was originally an insulator, it can be modified becoming a semiconductor material.

Table 5. Resume of variance analysis (ANOVA) the effect of the temperature and heating time to the dielectric constant on the three planes of wood

| Wood plane    | Significance of ANOVA |
|---------------|------------------------|
|               | Temperature | Time | Temperature#Time |
| Cross-section | 0.825m^    | 0.000** | 0.000**         |
| Radial        | 0.447m^    | 0.000** | 0.001**         |
| Tangential    | 0.207m^    | 0.000** | 0.004**         |

Remarks: m: not significant at 95% confidence intervals; **: significant difference at 95% confidence intervals

4. Conclusion

Wood modification of heat treatment affected on the dielectric properties of teak wood where applied to cross-section, radial and tangential plane. Untreated teak wood possessed had higher dielectric properties of capacitance and dielectric constant compared with the heat treated wood. The higher temperature and the longer time treatment led to decrease dielectric properties. The changes of dielectric properties in term of wood section i.e cross-section, radial, and tangential was lower in treated wood than untreated wood. The most significant decreasing of dielectric properties was at frequency below 10 kHz. Based on this study, the heat treatment decreased the ability of electrical insulator properties of wood.
References

[1] Bhat KM and Priya PB 2004 Influence of provenance variation on wood properties of teak from the Western Ghat region in India IAWA J. 25(3) 273-82

[2] Wahyudi I, Priadi T, and Rahayu IS 2014 Characteristics and basic properties of 4 and 5 year-old of superior teakwoods from west java Indones. J. of Agricultural Sci. 19(1) 50-6

[3] Adzkia U, Priadi T, and Karlinasari I. 2019 Evaluation of drying and machining defects of four thermo modified wood of tropical fast growing species JPHH 37(3) 209-22

[4] Hill CA 2007 Wood Modification: Chemical, Thermal and Other Processes (John Wiley & Sons) 5

[5] Lukmandaru G, Susanti D, and Widyorini R 2018 Chemical properties of modified mahagony wood by heat treatment Wallacea J. of Forest Research 7(1) 37-46

[6] Widyorini R, Khotimah K, and Prayitno TA 2014 The effect temperature and heat-treated method to the physical and finishing of mahoni wood JIK 8(2) 65-74

[7] Taylor P, Srinivas K, and Pandey KK 2013 Effect of heat treatment on color changes, dimensional stability, and mechanical properties of wood J. of Wood Chem. 37-41

[8] Bakar BFA, Hiziroglu S, and Tahir P 2013 Properties of some thermally modified wood species J. Mater. 43 348-55

[9] Tu D, Liao L, Yun H, Zhou Q, Cao X, and Huang J 2014 Effects of heat treatment on the machining properties of Eucalyptus utoephylla\(E.\) camaldulensis BioResources 9(2) 2847-55

[10] Korkut DS, Korkut S, Bekar I, Budakç M, and Dilik T 2008 The effects of heat treatment on the physical properties and surface roughness of turkish hazel (Corylus colurna L.) wood Int. J. of Molecular Sci. 9(9) 1772-83

[11] Piao C, Winandy JE, and Shupe TF 2010 From hydrophilicity to hydrophobicity: a critical review - Part I: wettability and surface behavior Wood Fiber Science 42(4) 490-510

[12] Glass SV and Zelinka SL 2010 Moisture Relations and Physical Properties of Wood (Madison: Forest Product Laboratory, University of Wisconsin)

[13] K. Khamoushi 2014 Characterization and Dielectric Properties of Microwave Rare Earth Ceramics Materials for Telecommunications (Finlandia: Tampere University of Technology)

[14] Husein I, Agustina A, and Khabibi J 2014 Electrical properties of Indonesian hardwood case study: Acacia mangium, Swietenia macrophylla and Maesopsis eminii Wood Res. 59(4) 695-704

[15] Husein I, Sadiyo S, Nugroho N, Cabuy LR, Afif A, Fakhruzy, Zabed M, Indasuary N, Fajriani E, Kabe A, and Sucipto 2011 Electrical properties of Indonesian hardwood Int. J. of Basic and Applied Sci. 11(6) 161-6

[16] Olmi R, Bini M, Ignesti A, and Riminesi C 2000 Dielectric properties of wood from 2 to 3 GHz J. Microw. Power Electromagn. Energy 35(3) 135-143

[17] Daian G, Taube A, Birnboim A, Daian M, and Shramkov Y 2006 Modeling the dielectric properties of wood Wood Sci. Technol. 40(3) 237-46

[18] Karlinasari L, Lestari AT, and Priadi T 2018 Evaluation of surface roughness and wettability of heat-treated, fast-growing tropical wood species sengon (Paraserianthes falcataria (L.) I.C.Nielsen), jabon (Antheophalus cadamba (Roxb.) Miq), and acacia (Acacia mangium Willd.) Int. Wood Prod. J. 9(3) 142-8

[19] Zhang Y, Yu W, and Zhang Y 2013 Effect of steam heating on the color and chemical properties of neosinocalamus affinis bamboo J. Wood Chem. Technol. 33(4) 235-46

[20] Priadi T, Suharjo AAC, and Karlinasari L 2019 Dimensional stability and colour change of heat-treated young teak wood Int. Wood Prod. J. 10(3) 119-125

[21] Yildiz S, Yildiz UC, and Tomak ED 2011 The effects of natural weathering on the properties of heat-treated alder wood BioResources 6(3) 2504-21

[22] Voss A, Seppănen A, Siltanen S, Salokangas L, and Baroudi D 2016 Imaging of moisture content in wood using electrical capacitance tomography World Conf. Timber Eng. (Austria: Univeristy of Eastern Finland) p. 1621
[23] Pentos K, Luczycka D, and Wysockzanski T 2017 Dielectric properties of selected wood species in Poland Wood Research 62(5) 727-736
[24] Kol HS 2009 Thermal and dielectric properties of pine wood in the transverse direction BioResources 4(4) 1663-9
[25] Misato N 1976 Dielectric properties of wood Bulletin of The Wood Research Institute Kyoto University 59/60 106-52
[26] Xu C, Chai H, Cao T, Cai M, Cai Y, and Liu H 2019 Detection of dielectric constant of Pinus sylvestris Var. mongolica and its influencing factors BioResources 14(2) 4532-4542
[27] Torgovnikov GI 1993 Dielectric Properties of Wood-Based Materials (Springer-Verlag) p.135-59
[28] Kabir MF, Daud WM, Khalid KB, and Sidek HAA 2001 Temperature dependence of the dielectric properties of rubber wood Wood Fiber Sci. 33(2) 233-238
[29] Sahin H and Ay N 2004 Dielectric properties of hardwood species at microwave frequencies J. Wood Sci. 50(4) 375-80
[30] Li T, Cheng D, Avramidis S, Wålinder MEP, and Zhou D 2017 Response of hygroscopicity to heat treatment and its relation to durability of thermally modified wood Constr. Build. Mater. 144 671-76

Acknowledgment
The authors would like to thank the Directorate for Research and Community Service, Ministry of Research Technology and Higher Education of the Republic of Indonesia (RISTEKDIKTI) for research grant 2017-2018.