Effect of Oil Heat Treatment on Tensile and Bending Properties of Ethiopian Lowland Bamboo

Berhanu Abnet Mengstie[1(✉)] and Eden Aragaw Addisu[2]

[1] Department of Mechanical Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
[2] Department of Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia

Abstract. The main purpose of this study was analysis the effect of oil treatment of Ethiopian lowland bamboo on tensile and bending strength of bamboo. In this study Ethiopian lowland bamboo treated by oil in different treatment condition with hot oil and without hot oil. The treatment temperatures were 100, 130 and 160 °C with sun flower oil and treatment duration of 30, 60 and 90 min and bamboo immersed in oil for 2, 4 and 6 days without heat. After oil treatment of bamboo tensile and three point bending experimental test were investigated for treated and untreated bamboo samples. The experimental result showed that from all condition of oil heat treatment best tensile results were bamboo treated at 100 °C with sun flower oil for a duration of 60 min and for bending bamboos treated at 160 °C for a duration of 30 min. In addition to this bamboo treated without hot oil for a duration of 2, 4 and 6 days had good tensile and bending strength at long treatment duration.

Keywords: Bending strength · Ethiopian lowland bamboo · Oil treatment · Tensile strength

1 Introduction

Bamboo is a sustainable renewable material that is found globally. It is a cheap fast-growing plant and possesses high mechanical properties to compare with other woody materials. Bamboo is one of the resources which are highly distributed in Ethiopia.

Heat treatment, also known as thermal modification, is an effective way to improve the performance of materials (Li et al. 2015). Oil and heat treatment fluids are designed for rapid or controlled cooling of steel or other materials as part of hardening, tempering, or another heat-treating process. Oil has a major advantage over water due to its higher boiling range. The investigation of the thermal treatment of bamboo has led to the improvement of heat treatment with vegetable oils (Sukhairi et al. 2016).

There are studies on improving mechanical, chemical properties of bamboo through oil heat treatment in Moso bamboo, three species of Philippine bamboo (mechanical properties), and Semantan bamboo (chemical properties).

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Effects of different thermal modification media on the physical and mechanical properties of Moso bamboo (Yang et al. 2016). Yang, Lee, Lee, & Cheng study the employed thermal modification technology to modify Moso bamboo (Phyllostachys edulis) and explore its future development as a sustainable green material. The Moso bamboo exposure to linseed oil at 150, 170, 190, and 210 °C for a treatment duration of 1, 2, and 4 h. After treatment, the researchers were performing experimental for the case samples and finding of the author's shows both the modulus of rupture and modulus of elasticity values of the bamboo decreased as the treatment temperature increased.

Effects of hot oil treatment on the physical and mechanical properties of three species of Philippine bamboo (RD Manalo and MN Acda 2017). RD Manalo and MN Acda study the effects of hot oil treatment on physical and mechanical properties on three species of Philippine bamboo, viz. Bambusa blumeana, B. vulgaris, and Dendrocalamus asper were investigated after exposure to virgin coconut oil at 160 to 200 °C for 30 to 120 min. The results showed that there was a reduction strength property as indicated by the modulus of elasticity, modulus of rupture.

Properties of oil heat-treated four-year-old tropical bamboo Gigantochloa Levis (Sukhairi et al. 2016). The researchers treated Malesia bamboo by Palm oil at 140 °C, 180 °C, and 220 °C for the treatment durations of 30, 60, and 90 min. After treatment and experimental investigation, the result shows that heat-treated at 180°C for 60 min shows an overall quality in mechanical properties.

Previous research shows that bamboo mechanical properties are species-dependent. The objective of the study is how to improve Ethiopian low land bamboo mechanical properties and study the effect of treatment temperature and duration on bamboo tensile and bending strength.

This research aims to study the effect of oil heat treatment on the mechanical properties of Ethiopia lowland bamboo, which is one of the critical issues for the property improvement of bamboo and using bamboo in different bio structural engineering applications.

In addition, the research also studies the effect of oil on tensile and bending strength when the bamboo samples soaked in oil for a day without heat supply.

2 Methodology

To study the effect of oil heat treatment on mechanical properties Ethiopia lowland bamboo, 3 years old Ethiopian lowland bamboo harvested from Awi, Enjibra, Ethiopia. Ethiopian lowland bamboo is fast-growing and mature at age 3 years. also research showed that bamboo grows very rapidly usually takes 3–6 years to harvest (Xu et al. 2017). The bamboo samples were taken from the middle part and only internodes for practical and uniformity of samples.

After collecting bamboo culm, cut the middle part, and required internodes using wood workshop and ready for the oil treatment process. Bamboos were oil-treated in two cases. The first set bamboo treated with hot oil and second set bamboo treated without heat oil (simply soak bamboo in oil).

The oil treatment process uses a deep fryer electric (Nima, Japan) oil bath with sunflower oil as a heating medium. The sunflower oil selected because of readily available in the market, organic, and have a high flash point (217 °C).

2.1 Oil Treatment of Bamboo

In this study oil treatment of bamboo done in two ways firstly bamboo treated by heated oil and secondly bamboo treated without heat.

The first treatment with hot oil, the sunflower oil poured into the deep fryer electric (Nima, Japan) oil bath and heated up to a temperature of 100, 130 and 160 °C, and keep constant the temperature for a duration of 30, 60 and 90 min respectively. The treatment temperature and durations were selected based on kinds of literature results and by a preliminary test. In addition to this, the oil heat treatment technique was adopted from literature with some modifications.

To get a target and constant temperature a thermocouple was placed in the oil. The bamboo specimens then soaked in the heated oil. The bamboo samples get out of the oil bath after a treatment duration of 30, 60 and 90 min. Next to followed by the treatment temperature of 130 and 160 °C for a treatment duration of 30, 60 and 90 min. The oil treatment procedure developed by Berhanu et al. (Manalo 2017), (Salim et al. 2009), (Sukhairi et al. 2016), (Yang et al. 2016) used with some modifications.

Optimum temperature controlling method of oil heat treatment of bamboo procedure:

- For the oil heat-treatment of bamboo, the oil was firstly heated to the target temperature (100, 130 and 160 °C).
- Once the temperature was achieved, the bamboo specimens were soaked in the oil and treated for 30, 60 and 90 min of duration.
- To get a uniform target temperature a thermocouple was placed in the oil (Fig. 1).

The second oil treatment of bamboo is without heat, the sunflower oil poured into the steel tank and no heat supply. The bamboo samples were simply soaked in the oil. After a duration of 2, 4- and 6-days bamboo gets out from the tank.

After treatment of bamboo, all treated bamboo placed for one week in the same humidity. Next, prepared test samples based on test standards. For one test 3 samples were made. Among different standards for composites based materials, the tensile test of treated and untreated bamboo was carried out according to ASTM-D3039 (Intertek expert 2018.) and bending test was done based on ISO/TR22157–2: 2004 (E) (ISO/TR 2004) (Manak 1983).

All the mechanical tests were investigated using Computer Controlled Electro-Hydraulic Servo Universal Testing Machine which has a capacity of up to 100 KN, with 0.01 - 500 mm /min test speed. During the test, the following initial parameters were feed to the computer, displacement 0.2 mm/min, load speed 0.1 KN/s, and extension 0.01 mm/s.

3 Results

3.1 Tensile Test Result

The tensile strength of bamboo along the grain direction was tested. After a series of tests of bamboo for oil-treated and untreated bamboo for tensile load. Below table shows the average value of the three test results for each treatment temperature and duration (Tables 1 and 2).

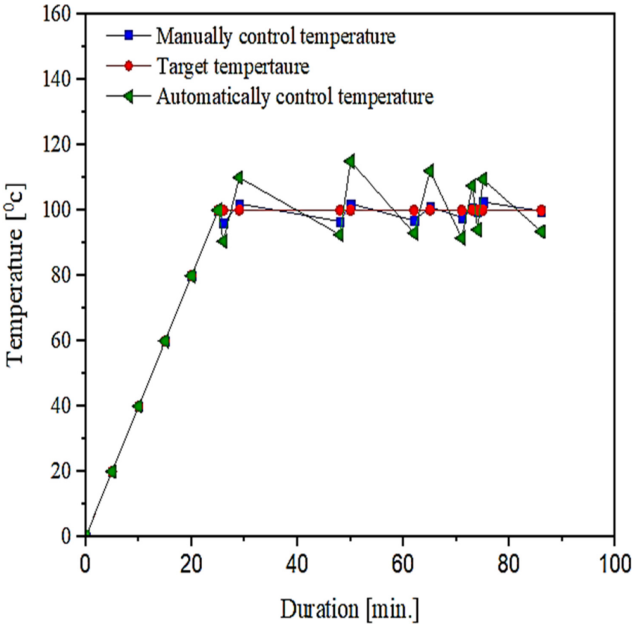

Fig. 1. Optimum temperature controlling method of oil heat treatment of bamboo.

Table 1. Result of tensile test of oil heat-treated bamboo at the temperature of 100, 130 and 160 °C for a duration of 30, 60 and 90 min and untreated bamboo.

Temperature [°C]	Duration [Min.]	Maximum load [KN]	Tensile strength [MPa]
Untreated	–	15.8	211.0
100	30	16.0	212.7
	60	19.7	262.2
	90	26.2	256.4
130	30	18.6	248.0
	60	18.3	243.9
	90	17.3	230.5
160	30	17.0	226.4
	60	15.9	211.9
	90	15.2	203.1

Table 2. Result of the tensile test of oil-treated bamboo at room temperature for a duration of 2, 4 and 6 days.

Temperature [°C]	Duration [Days]	Maximum load [KN]	Tensile strength [MPa]
Untreated	–	15.8	211.0
Room temperature (27.5 °C)	2	18.1	241.8
	4	19.7	262.4
	6	21.6	287.4

3.2 Bending Test Result

The loading condition of the bending test is in the lateral direction which is perpendicular to the grain direction (Tables 3 and 4).

Table 3. Result of bending test of oil heat-treated bamboo at the temperature of 100, 130 and 160 °C for a duration of 30, 60 and 90 min and untreated bamboo.

Temperature [°C]	Duration [Min.]	Maximum load [N]	Bending strength [MPa]
Untreated	–	1885.0	12.2
100	30	2016.0	22.1
	60	2865.2	28.0
	90	1382.3	14.9
130	30	2516.9	24.9
	60	2132.7	17.6
	90	1770.1	16.0
160	30	3615.0	29.1
	60	2340.9	15.0
	90	2075.3	14.9

Table 4. Result of the tensile test of oil-treated bamboo at room temperature for a duration of 2, 4 and 6 days.

Temperature [°C]	Duration [Days]	Maximum load [N]	Bending strength [MPa]
Untreated	–	1885.0	12.2
Room temperature (27.5 °C)	2	2725.1	17.2
	4	2976.4	19.6
	6	3098.0	20.6

4 Discussion

4.1 Effect of Oil Heat Treatment Temperature and Duration on Tensile and Bending Strength of Bamboo

The experimental result showed that the tensile strength of bamboo treated for 30 min at 100 °C oil less, maximum at 130 °C oil and drop at 160 °C oil. Also, bamboo treated for a duration of 60 and 90 min in 100 °C hot oil the tensile strength is higher than remaining treatment temperature (130 °C & 160 °C). For the remaining treatment temperature after 30 min treatment duration the tensile strength shows almost a linear drop. This shows bamboo oil heat-treated in short treatment duration and at low treatment temperature tensile strength is less, at high treatment temperature, and in short treatment duration tensile strength is good. Also, at high treatment temperature and long treatment duration tensile strength is poor.

Bamboo treated at a temperature of 100 °C oil with a treatment duration of 30, 60- and the 90-min experimental result showed a significant effect on the tensile strength of Ethiopian bamboo. In this treatment temperature, the bamboo was improved its tensile strength from 0.8% up to 24.26%. Bamboo treated at 100 °C oil had a maximum tensile strength at treatment duration of 60 min with 262.2 MPa. At this treatment temperature, the result showed that less improvement at 30 min, reached a peak at 60 min, and drop at 90 min in tensile strength (Fig. 2).

Next selected bamboo samples were oil treated in a temperature of 130 and 160 °C hot oil with a duration of 30, 60 and 90 min. Bamboos treated 130 and 160 °C hot oil the experimental result showed that high tensile strength at a treatment duration of 30 min as compared to other treatment durations.

The experimental result showed that bamboo treated at 130 °C hot oil with a duration of 30, 60 and 90 min the tensile strength increased to 9.24% up to 17.53% than untreated bamboo. Also, bamboo treated 160 °C oil for 30, 60 and 90 min the tensile strength increased up to 7.29% in a treatment duration between 30 min and 60 min. But bamboo treated for a duration of 90 min decrease to 3.75% than untreated bamboo (Fig. 3).

Bamboo simply soaked in oil for a duration of 2, 4- and 6-days, in this treatment condition the experimental result showed that a significant change in tensile strength as compared to oil heat-treated specimens and untreated bamboo. The improvement of tensile strength up to 36.21%.

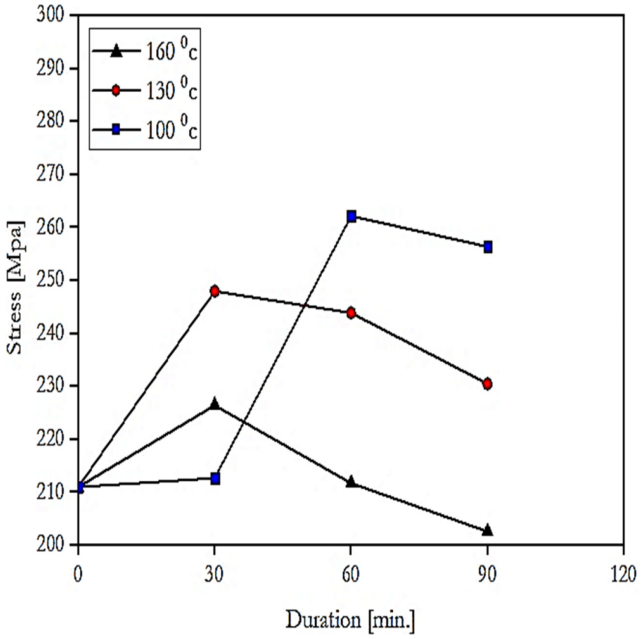

Fig. 2. Effect of oil heat treatment on tensile strength of Ethiopian bamboo.

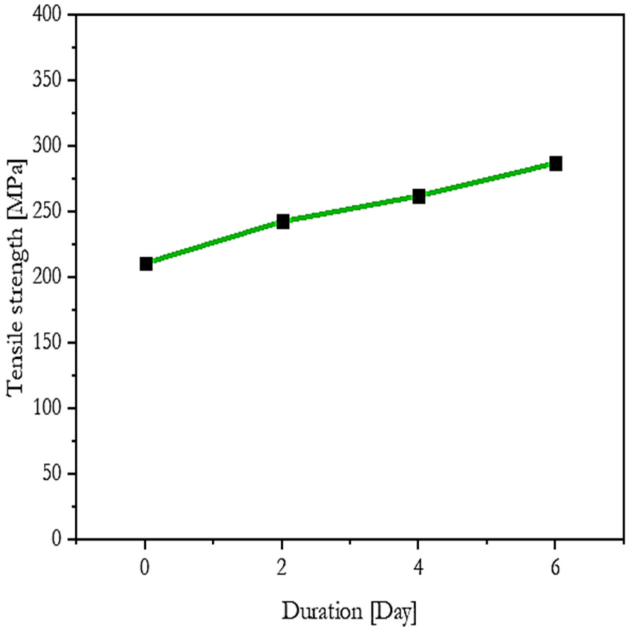

Fig. 3. Effect of oil treated without heat on tensile strength of bamboo.

The disadvantage of this treatment condition takes longer treatment duration as compared to oil heat-treated bamboo in the same tensile strength. This shows temperature (heat) is used to speed up the penetration of oil inside the bamboo culm.

When we compare the experimental result of bamboo treated with hot oil and without hot oil, the tensile strength of bamboo treated for a duration of 30, 60 and 90 min at a treatment temperature of 100, 130, and 160 °C the result showed that maximum improvement at one optimum treatment temperature and become drop at longer treatment duration. But bamboo treated by oil without heat or at room temperature for 2, 4 and 6 days the experimental result showed that almost linearly increased its tensile strength up to the end of a longer duration of 6 days (Fig. 4).

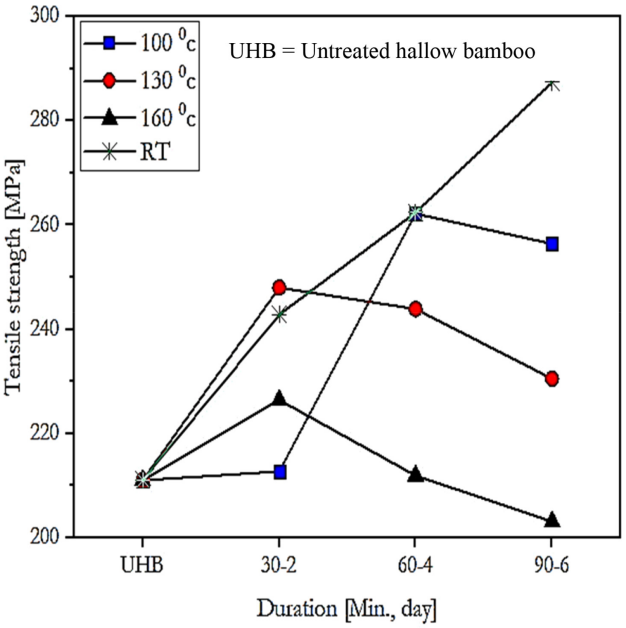

Fig. 4. Effect of oil treated with and without heated oil on tensile strength of bamboo

The bending experimental result showed that all treated bamboo had an improved strength. A similar tendency was observed with the tensile strength, indicating that the treatment temperature and duration affecting the bending strength of Ethiopian bamboo.

Bamboo treated at 100 °C oil had a maximum tensile strength at treatment duration of 60 min with 28.01 MPa. Bamboo treated at a temperature of 100 °C oil with a treatment duration of 30, 60- and the 90-min experimental result showed a significant effect on the bending strength of Ethiopian bamboo. In this treatment temperature, the bamboo was improved its bending strength 21.81% up to 128.83%.

Oil heat-treated bamboo at a temperature of 130 and 160 °C for a treatment duration 30 min had high bending strength as compared to other treatment temperatures and durations. The experimental result showed that oil heat-treated bamboo at 130 and 160 °C

were 30.88% up to 62.33% and 22.39% up to 137.42% respectively increment in bending strength for a treatment duration of 30, 60 and 90 min.

The bending strength of bamboo treated at 100 °C for 60 min duration and 160 °C for 30 min duration almost the same. This shows that bamboo treated at a lower temperature for the long optimum duration and treated bamboo at high temperature for an optimum short duration the bending strength almost the same. But treat bamboo at a very high temperature for long-duration affects the microstructure of bamboo due to this experimental result showed that the bending strength bamboo treated for 90 min dropped (Fig. 5).

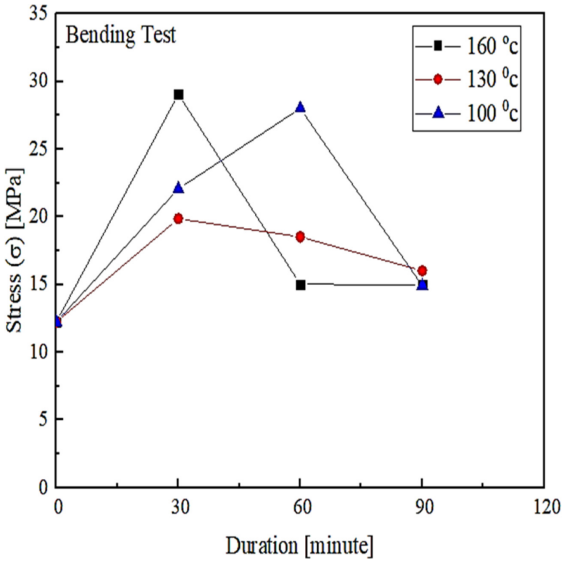

Fig. 5. Effect of oil heat treatment on bending strength of Ethiopian bamboo.

Bamboo treated in oil without heat for 2, 4, and 6 days at room temperature experimental result showed that almost a linear change increment in bending strength as the shown figure below (Fig. 6).

Bamboo specimens treated for 30 min with hot oil and 2 days without hot oil the bending strength test result showed greater for 30 min. This shows that the penetration of oil in the bamboo internode is less at a treatment duration of 2 days without hot oil. In another way, samples treated for 30 min with hot oil the temperature speeds up the penetration of oil (Fig. 7).

When we compare the result of oil heat-treated for 60 min and without heat oil-treated for 4 days the experimental result showed that bamboo treated 100 °C oil for 60 min had good bending strength. Bamboo treated at 130 and 160 °C oil for 60 min treatments the test result showed that the bending strength is less than bamboo treated at 100 °C oil with 60 min these shows to the effect of temperature. But without heat oil-treated bamboo for a day the bending strength increased.

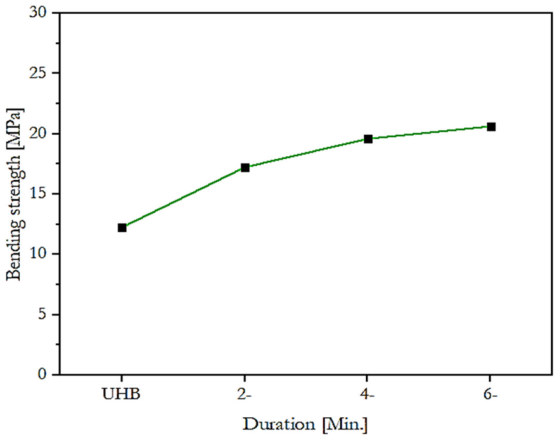

Fig. 6. Effect of oil treatment without heat on bending strength of bamboo.

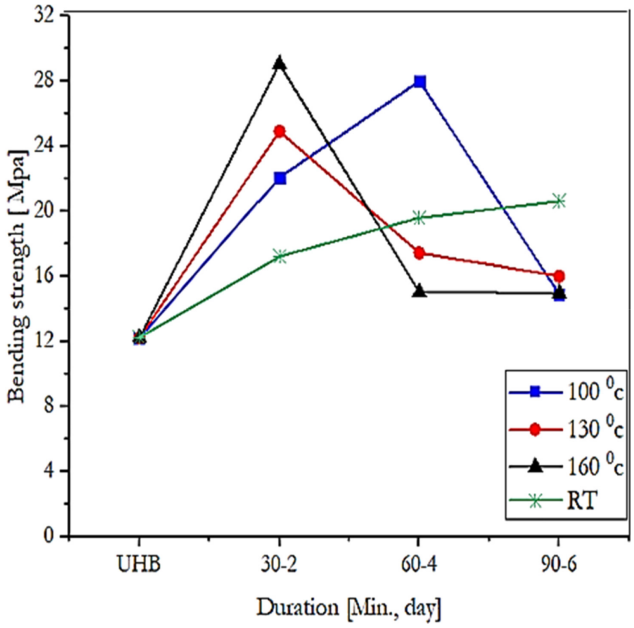

Fig. 7. Effect of oil treated with and without heated oil on bending strength

When we compare bamboo treated for 90 min oil heat and 6 days without heated oil the result the bending strength of 90 min bamboo in all treatment temperatures was dropped. Treatment for 90 min with hot oil, the temperature highly affects the microstructure of bamboo. The test result showed that oil heat-treated and without heat-treated bamboo had a significant difference in bending strength at longer treatment duration.

5 Conclusions

Results indicate that the uptake of oil by the Ethiopian low land bamboo is different from heated oil at different temperatures and soaking in oil at room temperature. The temperature of oil has a significant influence on the tensile and bending strengths of the bamboo. The effect of treatment in heated oil has minimized the duration to achieve the same value of the required properties. For example, the same value of tensile strength can be obtained by treatment in oil at 100 °C for 60 min. will take 4 days duration for treating in oil at room temperature.

Tensile and bending properties of oil-treated bamboo at 100 °C for 60-min duration have given maximum tensile and bending strengths of 262.2 MPa and 28.01 MPa respectively. It has produced an increase in tensile strength by 24.26% and 56.3% for bending strength relative to the untreated bamboo.

For a treat in oil at 130 °C for 30 min has produced a tensile strength of 248 MPa and a bending strength of 19.87 MPa. When samples are treated at the temperature of the oil at 160 °C for 30, 60, and 90 min, maximum tensile and bending strengths are obtained only for treatment at 30 min duration to the extent of 226.4 MPa and 29.06 MPa respectively.

Bending strength of bamboo treated at 160 °C oil for 30 min has produced the highest bending strength compared to all other cases of treated bamboo with an improvement of 137.42% relative to untreated bamboo.

Bamboo samples simply soaked in oil at room temperature for 6 days had a maximum tensile and bending strength of 287.4 MPa and 20.63 MPa respectively.

In general, from this study, we can conclude that better properties are achieved with minimum oil heat treatment temperature for longer duration and higher treatment temperatures for a shorter duration of treatment.

In addition to this, the result shows bamboos simply soaking in oil at room temperature for longer duration gives maximum tensile and bending strengths than oil heat-treated and untreated bamboos.

The strength values have increased linearly with the duration of soaking time in oil at room temperature. Finally, it is concluded that treating the bamboo in oil at different temperatures has reduced the time to achieve the desirable properties compared to treatment at room temperature and untreated bamboo.

References

Manalo, R.D., Acda, M.N.: Effects of hot oil treatment on physical and mechanical properties of three species of philippine bamboo. For. Res. Inst. Malaysia **21**(1), 19–24 (2017)

Armandei, M., Fathi, I., Ghavami, K.: Experimental study on variation of mechanical properties of a cantilever beam of bamboo. Constr. Build. Mater. **101**, 784–790 (2015)

Arpa, E.: Advanced composites materials and their manufacture technology. Bioresour. Technol. **10**, 1–37 (2013)

Callister, W.D.J.: Fundamentals of Materials Science and Engineering, 7th edn., pp. 200–589. Wiley, New York (2007)

Costa, M.M.E., et al.: Influence of physical and chemical treatments on the mechanical properties of bamboo fibers. Proc. Eng. **200**, 457–464 (2017)

Bansal, R.K.: Text Book of Strength of Materilas, 3rd edn., pp. 125–130. Laxmi Publisher, New Delhi (2009)

Dubey, M.K.: Improvements in stability, durability and mechanical properties of radiata pine wood after heat-treatment in a vegetable oil. For. Res. Inst. Malaysia **2**, 10–15 (2010)

Embaye, K., Christersson, L., Ledin, S., Weih, M.: Bamboo as bioresource in Ethiopia : Management strategy to improve seedling performance (oxytenanthera abyssinica). Biores. Technol. **88**(2003), 33–39 (2003)

Gottron, J., Harries, K.A., Xu, Q.: Creep behaviour of bamboo. Constr. Build. Mater. **66**, 79–88 (2014)

Intertek expert: Tensile properties grips, vol. C, p. 2 (2018). Retrieved from iptl@intertek.com

Journal, P., Science, T.A., Sarawak, T.: The effects of oil boiling treatment on physical properties of bambusa vulgaris var. Striata (buluh gading). Pertinika J. Trop. Agric. Sci. **25**, 823–832 (2012)

Li, T., Cheng, D.L., Walinder, M.E.P., Zhou, D.G.: Wettability of oil heat-treated bamboo and bonding strength of laminated bamboo board. Ind. Crops Prod. **69**, 15–20 (2015)

Mahzuz, H.M.A., Ahmed, M., Dutta, J., Rose, R.H.: Determination of several properties of a bamboo of bangladesh. J. Civ. Eng. Res. **3**(1), 16–21 (2013)

Mallick, P.K.: Fiber- Reinforced Cmposites, 3rd edn., pp. 200–225. CRC Press, New York (2008)

Obispo, S.L.: Optimizing the mechanical characteristics of bamboo, construction and building materials. Master thesis, California Polytechnic State University, San Luis Obispo, pp. 100–125 (2012)

Panda, A., Dyadyura, K., Val, J., Harniˇ, M., Zajac, J.: Manufacturing technology of composite materials principles of modification of polymer composite materials technology based on polytetrafluoroethylene. Ind. Crops Prod. **12**, 25–49 (2017)

Richard, M.J.: Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing. LSU Master Thesis **1**, 121–125 (2013)