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DURABILITY AND PHYSICAL PROPERTIES OF MODIFIED *PINUS MASSONIANA* (L) WOOD BY TIN-BASED THERMAL TREATMENT

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Abstract:

Eco-friendly approaches to wood treatment have gained increasing attention due to the adverse impact chemical preservatives have on the environment. In this study, tin-based alloy was used as a heating media in the tin-based thermal treatment (TTT) of Pinus massoniana wood to improve the durability and other properties of the wood. The tin alloy was used for the treatment of the wood samples at 150, 180 and 210^{o}C for 2, 6 and 8h. To evaluate the effect of TTT, wood durability, shrinkage and swelling, anti-swelling efficiency, weight loss and water absorption were examined. The results showed that all the tested properties were improved at high temperatures respectively, indicating that tin alloy was effective in the modification of P. massoniana wood.

Key words: *anti-swelling efficiency; brown fungus; durability; Pinus massoniana; shrinkage; tin-based thermal treatment; white fungus.*

INTRODUCTION

Wood is a multi-purpose material due to its superior properties compared to other materials such as iron and plastic, the advantages of wood as a material include: it is a natural renewable resource, it is a versatile material used in furniture, decoration and construction of buildings, it is a good thermal insulation; it provides high strength and elasticity, it is environmentally friendly and it has a special aesthetic feature such as colour and grains (Liu *et al*. 2022), easy manufacture etc. However, despite its numerous merits, wood has some disadvantages including its dimensional instability with its moisture variation below the fibre saturated point (FSP), its susceptibility to attack by biodegrading organisms like insects and fungi, its high hygroscopicity etc. The presence of moisture in the wood affects its behaviour for instance when the quantity of moisture in the wood decreases, the wood shrinks, and when it increases, the wood swells (Park *et al*. 2020). These deficiencies have limited the utilization of wood to some extent and therefore require appropriate improvement methods to extend its service life.

On the other hand, some wood species are naturally not durable, therefore require treatments to improve their performance and lifespan (Brocco *et al*. 2017). Some of the common wood treatment methods are not eco-friendly due to their content, making them toxic to the environment at the end of the service life of the wood (Ruwoldt and Toven 2022). Thermal modification, chemical modification and preservative treatment are some of the wood treatment technologies (Kamdem *et al*. 2022) developed to improve the properties of wood. In thermal modification, the wood is heated using different heating media such as oil, steam, water or inert atmosphere at temperatures ranging from 150 to 280°C (Cao *et al*. 2011). The intensity of thermal modification depends on the thermal modification temperature and time and treatment of wood above 150°C can significantly affect the physical, chemical and biological properties of wood by causing changes (Metsä-Kortelainen *et al*. 2011, Metsä-Kortelainen and Viitanen 2017, Minkah *et al*. 2021). Swelling and shrinkage in wood are reported to be significantly reduced and the moisture content improved (Korkut *et al*. 2008) and higher modification temperatures result in better durability of wood (Syrjanen 2001). The degree of changes in wood properties increases with higher modification temperature and longer treatment time. According to Akyildiz and Ates (2008), noticeable differences occur between thermally modified wood at lower temperatures that last for a longer time and the treatment that takes place at higher temperatures lasting for a shorter time.

Previous studies reported other factors which affect wood property change during thermal modification to depend mainly on the wood species (i.e., their properties, moisture content, sample dimensions, sapwood/heartwood proportion, quality) and method of thermal modification used (Hill 2007, Korkut *et al.* 2008). Thermal modification causes the wood's components to degrade, reducing their hygroscopicity and

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limiting swelling and shrinkage as well as fungi growth and water absorption (Metsä-Kortelainen and Viitanen 2012).

This latest study is focused on finding a non-toxic eco-friendly heating medium for the thermal modification of wood. Recently, researchers have shown interest in using tin-based alloy in both heating and treatment mediums for the modification of wood. Tin-based alloy has high moisture repellence, excellent electrical insulation and good heat conduction. It is non-flammable, odourless, non-flavoured and toxic-free, which makes it a unique substance for safe, quick and uniform heat transfer medium to improve wood properties. The alloy has a low melting point (97^0C) and two main components: bismuth (0.69%) and tin (0.26%). They present much higher thermal conductivities than most other heating media by excluding oxygen from the treated samples and minimizing the thermal degradation of some wood constituents (Okon *et al*. 2018a).

On the other hand, not much data is available regarding the effectiveness of tin-based alloy as a heating medium compared to other media (vegetable oils, steam). The main objective of this research is to enhance the durability, shrinkage and swelling, anti-swelling efficiency, weight loss and water absorption of *P. massoniana* wood to broaden the application of the wood using tin-based alloy as a heating medium. As an eco-friendly wood modification approach, it could be considered by far one of the most effective approaches to modifying wood properties. Understanding the effects of tin-based thermal modification on the properties of wood can help inform decisions about the use of modified wood in numerous applications and can guide the further development of new wood modification techniques.

MATERIALS AND METHODS

Materials

30-year-old pine wood (*Pinus massoniana* L) was purchased from wood merchants in Fuzhou and tin-based alloy was purchased from Beijing, Peoples Republic of China (26^o 04'34''N119^o 18'23''E). The moisture content of the wood samples ranged between 20 to 25% before treatment.

Sample preparation

Wood samples were prepared in the wood workshop of the College of Material Engineering, Fujian Agriculture and Forestry University. Test samples with dimensions 20mmx20mmx10mm (tangential x radial x longitudinal) were prepared for durability test and 20mmx20mmx60mm were prepared for shrinkage, swelling, anti-swelling efficiency, weight loss and water absorption tests. The samples weight and dimensions were measured and were kept in a conditioning chamber at 65% relative humidity and 20^oC to attain 12% moisture content.

Tin-based thermal treatment (TTT)

The prepared wood samples were subjected to tin-based thermal treatment at 150, 180 and 210^oC for 2, 4 and 8h in a tin bath. All the wood samples were submerged in the tin to isolate oxygen. The untreated samples were used as control samples.

Durability test

A durability test was performed on tin-based thermal treated (TTT) and control samples of *P. massoniana* wood according to American Wood Protection Association (AWPA) (2016) with minor modifications. The modification is that samples were sterilized in an autoclave at 121 ± 1^oC. A 500mL bottle was filled with 160g sieves of air-dried river sand with a pH of 5 and 7 then, 16g of *P. massoniana* sawdust, plus 8.5g corn flour, and 80mL medium of potato dextrose agar composed of 2g of granulated sugar plus feeder chips were added and sterilized at 121 ± 1^oC for 1h and inoculated with fungi. The sterilized TTT and control wood samples were placed in culture bottles. 12 replicates from each treatment making a total of 240 samples were exposed to a *Poria placenta* (brown fungus) and *Coriolus versicolor* (white fungus) and were incubated for 12 weeks. At the end of the exposure period, the samples were removed and all adhering fungal hyphae were cleaned from the surfaces. The durability test against fungi was evaluated in terms of mass loss, which was calculated using Equation (1) and the classification of wood durability is shown in Table 2.

$$Mass\ loss\ (\%) = {(M_{trt} - M_{trt\ n\,\exp})}/{Mtrt}\ X\ 100 \qquad (1)$$

where: M_{trt} and $M_{trt\ n\ exp}$ is oven-dry mass before and after exposure to fungi.

Shrinkage and swelling tests

The dimensions of the wood samples used for shrinkage and swelling determination were 20mm×20mm×60mm (T × R × L) according to TS 4084 (1983) standard procedure with minor modification. 12 replicates from each treatment making a total of 120 samples were used in the determination of shrinkage and swelling tests. Shrinkage was determined on TTT and control samples soaked in deionized water for 2 days. Then, the samples were removed and measurements were taken in the tangential, radial and longitudinal directions in wet conditions using a digital vernier calliper to the nearest millimetre (i.e., ±0.1mm) sensitivity. The samples were oven-dried at 103±2°C to a constant weight and the dimensions were measured again. Percentage shrinkages in all three directions were calculated using Equation (2).

$$Sh\ (\%) = {(D_s - D_o)}/{D_s}\ X\ 100 \qquad (2)$$

where: Sh is shrinkage in percentage (i.e., Sht or Shr or Shl), D_s is the dimension of the saturated samples in (mm) and D_o is the dimension of the oven-dried samples in (mm). Sht is tangential shrinkage, Shr is radial shrinkage and Shl is longitudinal shrinkage respectively.

Swelling was determined after samples were oven-dried at 103±2°C to a constant weight based on the procedure of TS 4084 (1983) standard. Then, measurement was taken in the tangential, radial and longitudinal directions, after measurement, the samples were soaked in deionized water for two days until they were completely saturated and the dimension measured again. Swelling in tangential, radial and longitudinal directions was calculated according to Equation (3).

$$Sw\ (\%) = {(S_s - S_o)}/{S_o}\ X\ 100 \qquad (3)$$

where: Sw is Swelling in percentage (i.e., Swt or Swr or Shl), S_s is the dimension of the saturated samples in (mm) and S_o is the dimension of the oven-dried samples in (mm). Swt is tangential swelling, Swr is radial swelling and Swl is longitudinal swelling respectively.

Anti-swelling efficiency, weight loss and water absorption tests

Wood samples of TTT and control were soaked in deionized water in a water bath at a controlled temperature (20°C). The water was changed after every 24 hours until the weight change of the samples was less than 0.1 % (Okon *et al*. 2018b). The wood samples were weighed and dimensions measured and anti-swelling efficiency was determined based on the differences in the volumetric swelling coefficient of the samples before and after the TTT Equation (4 and 5).

$$Vs\ (\%) = {(V_s - V_o)}/{V_o}\ X\ 100 \qquad (4)$$

where: Vs is the volumetric swelling coefficient in percentage, V_s is the saturated volume of samples after soaking in water and S_o is the oven-dried volume of samples before soaking in water.

$$ASE\ (\%) = {(Vs_o - Vs_s)}/{Vs_o}\ X\ 100 \qquad (5)$$

where: ASE is anti-swelling efficiency in percentage, Vs_o is the volumetric swelling coefficient of control samples and Vs_s is the volumetric swelling coefficient of TTT samples. To determine water absorption, samples of TTT and control were oven-dried at 103°C to a constant weight and weight recorded before soaking in deionized water for 2 days. After this, the samples were removed from the water and the weight taken in the saturated condition and water absorption was calculated in equation (6).

$$Wa\ (\%) = {(W_2 - W_1)}/{W_1}\ X\ 100 \qquad (6)$$

where: Wa is water absorption in percentage, W_2 is the weight of the oven-dried samples before soaking in deionized water and W_2 is the saturated weight of the samples after soaking for 2 days.

To determine weight loss, the oven-dried weight of the samples was measured before TTT and after the treatment of the wood, the samples were oven-dried to a constant weight and the weight was taken again. Weight loss was calculated using Equation (7).

$$Wl\ (\%) = {(M_2 - M_1)}/{M_2}\ X\ 100 \qquad (7)$$

where: Wl is weight loss in percentage, M_2 is the oven-dried weight of the samples before TTT and M_2 is the oven-dried weight of the samples after TTT.

Statistical analysis

All the properties tested were subjected to a one-way analysis of variance (ANOVA) and the means were separated using Tukey's multiple comparison test (TMCT). The results were interpreted at a 95% confidence interval. All the analyses were implemented in R version 4.3.1 statistical software (Team 2016).

RESULTS AND DISCUSSION

Durability of tin-based thermal treated *P. massoniana* wood subjected to *P. placenta* and *C. versicolar*.

The effect of TTT on the wood samples exposed to *P. placenta* and *C. versicolor* was evaluated following AWPA E10-16 (2016). The durability test of control and TTT *P. massoniana* wood samples at 210°C for 8h exposed to *P. placenta* fungus after 12 weeks is shown in Fig. 1. The mycelia in the control samples developed unsuppressed because the wood was susceptible to fungal attack (Fig. 1a). However, for the tin-based thermal treated wood samples at 210°C for 8h, the mycelia's development on the feeder strips was suppressed (Fig. 1b) demonstrating the effectiveness of the treatment. The mass loss of tin-based thermal treated wood samples subjected to fungi is displayed in Fig. 2. The ANOVA showed significant differences in the mass loss for tin-based thermal treated wood samples when subjected to *P. placenta* and *C. versicolor* (Table 1). Tin-based thermal treated wood samples showed a significantly lower mass loss when compared to the control wood samples. Mass loss in the control samples subjected to *P. placenta* and *C. versicolor* were 45.34% and 44.64% in Fig. 2. The lowest mass loss occurred in the tin-based thermal treated samples at 210°C for 8h subjected to *P. placenta* (4.44%) and *C. versicolor* (4.99%) with decay resistance improved by 89.99% and 88.82%. Treated wood samples exposed to *C. versicolor* exhibited lower decay mass loss, compared to samples exposed to *P. placenta.* This could be because of the lower attacking speed of *C. versicolor* fungal on softwood (Rowell *et al*. 2009). The control samples were severely attacked by both fungi with high mass losses compared to the tin-based thermal treated samples (Table 2). Based on the classification in Table 2, *P. massoniana* wood moved from durability class 4 (i.e., one in which the mass loss is > 31.0%) before treatment to durability class 1 (i.e., one in which the mass loss is between 0 to 10%) after TTT. According to earlier research, the reduced water absorption by the cell wall, the degradation of hemicellulose, and the modification of the lignin-carbohydrate complex in the cell wall that prevents the availability of nutrients to fungi are the main causes of the increased durability of thermally treated wood (Boonstra *et al*. 2007, Hakkou *et al*. 2006, Okon *et al*. 2018a).

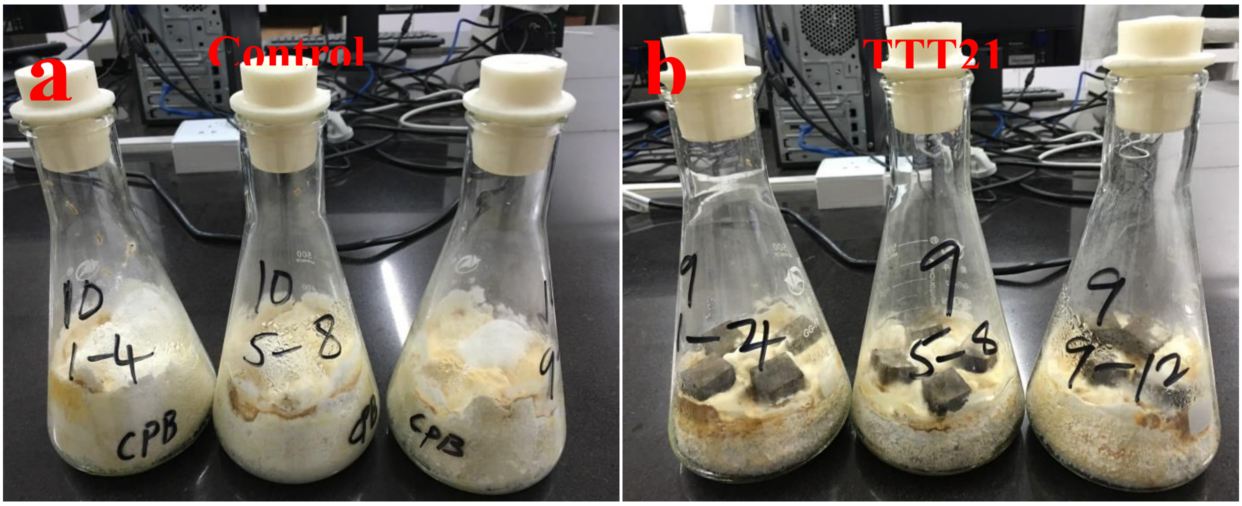

Fig 1.

Photograph of representative of P. massoniana wood (a) Control and (b) tin-based thermal treated at 210°C for 8h exposed to Poria placenta (brown fungus) after 12 weeks.

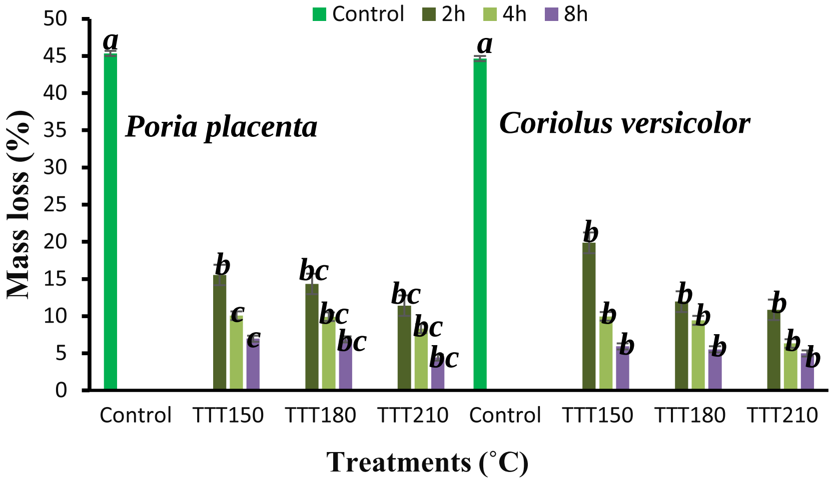

Fig. 2.
Mass loss of tin-based thermal treated and control P. massoniana wood exposed to Poria placenta (brown fungus) and Coriolus versicolor (white fungus) for 12 weeks.

Table 1
ANOVA of the effect of tin-based thermal treated P. massoniana wood subjected to P. placenta and C. versicolor

	Factor	df	Sum of square	Mean square	F-value	Significant Level, p
Poria placenta	Treatment	9	14912	1656.9	33.1	***
	Error	110	5506	50.1		
Coriolus versicolor	Treatment	9	15485	1720	4.317	***
	Error	110	18740	170.4	10.1	

*** - significant, P < 0.05 (Tukey's test)

Table 2
Durability classification

Durability class	Mass loss (%)
1. Very durable	0 -10
2. Durable	11-20
3. Moderately durable	21 - 30
4. Not durable	>31

Shrinkage and swelling

The results of shrinkage and swelling of control and tin-based thermal treated wood samples are shown in Table 3. ANOVA shows that there are significant differences in the tin-based thermal treated wood samples with regard to shrinkage and swelling (Table 4). The shrinkage values obtained in all the directions (tangential, radial and longitudinal) decrease with an increase in TTT temperature (Table 3). The maximum shrinkage value decrease was 3.95% in the tangential, 3.71% in the radial and 0.42% in the longitudinal treatments at 210^{o}C at 8h. This trend is consistent with the findings of other research as shrinking reduction in the tangential direction is greater compared to reductions in the redial and longitudinal directions. Moisture content gradient along the radial direction was much smaller than those in the tangential direction (Yang 2021, Newman *et al*. 2016, Zhang *et al*. 2020, Behr *et al*. 2014). It is because more bordered pits can be found in the radial cell walls of wood, which opens up more tangential water migration along the tangential direction according to Yang (2021). Previous studies attributed the reduction in swelling to the moisture exclusion capacity of the treatments (Devi *et al*. 2003) in this case TTT and the vertical orientation of microfibrils in the S2 layer of the cell walls because the microfibril angle in the tangential direction is greater with regards to those in the radial and longitudinal directions (Barnett and Bonham 2004). In this study, it was observed that tin-based thermal treated wood absorbed less water, which reduces its ability to shrink, thus improving the dimensional stability of the wood. Swelling in the tangential (4.14%), radial (3.71%) and longitudinal (1.06%) directions decreased with the increase in TTT temperature with the highest swelling value obtained at 210°C for 8h (Table 3). This is in line with the reports from other studies, as they reported that the most important variables to consider when determining the dimensional stability of wood are swelling coefficients in the tangential and radial directions (Skaar 2012, Wood *et al*. 2018). TTT reduced the amount of water absorbed, which in turn decreased swelling.

Table 3

Shrinkage and swelling of tin-based thermal treated P. massoniana wood

Temp. (°C)	Time (h)	Shrinkage (%)			Swelling (%)		
		Tangential	Radial	Longitudinal	Tangential	Radial	Longitudinal
Control		6.20 ± 1.30^{a}	5.50 ± 1.04^{a}	0.92 ± 0.55^{a}	6.63 ± 1.53^{a}	5.83 ± 1.17^{a}	5.83 ± 1.17^{a}
TTT150	2	5.85 ± 1.04^{b}	5.03 ± 2.03^{b}	0.91 ± 0.28^{b}	6.23 ± 1.18^{b}	5.34 ± 2.26^{b}	5.34 ± 2.26^{b}
	4	5.44 ± 1.30^{ac}	4.88 ± 1.14^{ab}	0.87 ± 0.38^{a}	5.44 ± 1.30^{ac}	4.83 ± 1.14^{ac}	4.83 ± 1.14^{a}
	8	5.26 ± 1.49^{ab}	4.51 ± 0.99^{ab}	0.80 ± 0.10^{a}	5.26 ± 1.49^{ab}	4.74 ± 1.04^{ab}	4.74 ± 1.04^{a}
TTT180	2	5.17 ± 1.34^{bc}	4.46 ± 1.00^{ab}	0.73 ± 0.12^{a}	5.19 ± 1.45^{ab}	4.68 ± 1.09^{ab}	4.68 ± 1.09^{a}
	4	4.65 ± 1.43^{ab}	4.02 ± 0.99^{ab}	0.65 ± 0.16^{ab}	4.65 ± 1.48^{ab}	4.02 ± 1.03^{ab}	4.02 ± 1.03^{ac}
	8	4.52 ± 1.52^{bc}	3.91 ± 1.09^{b}	0.63 ± 0.19^{ab}	4.52 ± 1.52^{bc}	4.00 ± 1.17^{bc}	4.00 ± 1.17^{ab}
TTT210	2	4.41 ± 1.04^{bc}	3.83 ± 1.45^{b}	0.44 ± 0.30^{ab}	4.51 ± 1.02^{b}	3.97 ± 1.57^{bc}	3.97 ± 1.57^{ab}
	4	4.28 ± 1.21^{bc}	3.82 ± 1.23^{b}	0.43 ± 0.22^{b}	4.49 ± 1.31^{b}	3.90 ± 1.30^{bc}	3.90 ± 1.30^{bc}
	8	3.95 ± 1.79^{b}	3.71 ± 1.06^{b}	0.42 ± 0.25^{b}	4.14 ± 1.94^{b}	3.71 ± 1.06^{bc}	3.71 ± 1.06^{bc}

The values represent the mean ± standard deviation of fifteen replicates. Means within a column, followed by the same superscript are not significantly different by Tukey tests at $p < 0.05$.

Table 4

ANOVA of shrinkage and swelling of tin-based thermal treated P. massoniana wood

	Factor	df	Sum of square	Mean square	F-value	Significant Level, p
Sht	Treatment	9	972.65	8.072	4.625	***
	Error	140	140244.34	1.745		
Shr	Treatment	9	949.43	5.492	3.562	***
	Error	140	140215.88	1.542		
Shl	Treatment	9	95.303	0.5893	7.272	***
	Error	140	14011.345	0.081		
Swt	Treatment	9	989.07	9.896	4.787	***
	Error	140	140289.44	2.067		
Swr	Treatment	9	966.02	7.336	4.12	***
	Error	140	140.249	1.78		
Swl	Treatment	9	95.713	0.6348	7.852	***
	Error	140	14011.319	0.0808		

*** - significant, $P < 0.05$ (Tukey's test). Sht is tangential shrinkage; Shr is radial shrinkage; Shl is longitudinal shrinkage. Swt is tangential swelling; Swr is radial swelling; Swl is longitudinal swelling.

Anti-swelling efficiency, weight loss and water absorption

The results of anti-swelling efficiency, weight loss and water absorption in the control and tin-based thermal treated wood samples are presented in Table 5. The ANOVA in Table 6 showed there were significant differences after TTT. It was observed that with an increase in TTT temperature, anti-swelling efficiency effectively increased (Table 5). The samples treated at 210°C for 8h had the highest anti-swelling efficiency (265.96%). Several studies have reported an increase in the anti-swelling efficiency of thermally modify wood samples as the temperature rises (Deka *et al*. 2000, Yan and Morrell 2014). Sailer *et al*. (2000) in their study reported improvement in the anti-swelling efficiency of thermally treated wood at 220°C. The results in Table 5 show increase weight loss with rising TTT. The highest weight loss value (17.52%) was obtained when the wood samples were treated at 210^{o}C for 8h. At high temperatures, it is reported that hemicellulose and lignin degradation are the main causes of weight loss (Čermák *et al*. 2021). The results of water absorption of the control and tin-based thermal treated samples are shown in Table 5. From the table, the control wood samples showed higher water absorption compared to the tin-based thermal treated samples. The water uptake is reduced due to the seeps of the melted alloy into the wood's voids. In the study by Kaya (2023), water absorption of maple wood treated by impregnating with linseed oil decreased by 72% at 240^{o}C compared to the control sample. The quantity of accessible hydroxyl groups has a significant effect on the dimensional stability of wood. The increase in the anti-swelling efficiency of the TTT wood could be attributed to the diminishing amount of accessible hydroxyl groups due to depolymerization of hemicellulose, increase in inaccessible crystalline cellulose and crosslinking of lignin network that inhibits the accessibility of free hydroxyl groups to water according to Tjeerdsma *et al*. (1998) and Lee *et al.* (2017). Furthermore, the degradation of cellulose in the amorphous region and polycondensation reactions in lignin are the primary cause of the reduction in water absorption of the thermally modified wood (Jämsä and Viitaniemi 2001, Mitani and Barboutis 2014).

Table 5

Anti-swelling efficiency, weight loss and water absorption of tin-based thermally treated P. massoniana

Temp. (˚C)	Time (h)	Anti-swelling efficiency (%)	Weight loss (%)	Water absorption (%)
Control				145.45 ± 29.76^{a}
TTT150	2	7.90 ± 4.10^{a}	8.35 ± 2.25^{a}	106.00 ± 29.05^{b}
	4	14.55 ± 6.41^{a}	8.49 ± 4.50^{a}	103.92 ± 22.90^{c}
	8	25.56 ± 6.51^{ab}	8.57 ± 6.57^{a}	97.41 ± 21.61^{c}
TTT180	2	100.63 ± 28.63^{ac}	8.85 ± 9.38^{a}	94.53 ± 31.94^{c}
	4	126.98 ± 72.15 ^{ac}	9.13 ± 6.68^{a}	90.49 ± 26.05^{c}
	8	129.82 ± 53.20 ^{ac}	9.21 ± 2.05^{a}	57.93 ± 30.27^{c}
TTT210	2	139.24 ± 68.10^{bc}	10.83 ± 1.20^{a}	53.90 ± 20.86^{b}
	4	182.58 ± 8.41^{cd}	12.66 ± 1.54^{ab}	46.12 ± 23.14^{b}
	8	265.96 ± 10.20^{d}	17.52 ± 10.88^{b}	30.05 ± 9.04^{b}

The values represent the mean ± standard deviation of fifteen replicates. Means within a column, followed by the same superscript are not significantly different by Tukey tests at $p < 0.05$.

Table 6

ANOVA of anti-swelling efficiency, weight loss and water absorption of tin-based thermally treated P. massoniana

	Factor	df	Sum of square	Mean square	F-value	Significant Level, p
ASE	Treatment	8	868191	108524	9.345	***
	Error	126	1463210	11613		
WL	Treatment	8	1100	137.45	4.317	***
	Error	126	4012	31.84		
WA	Treatment	9	163514	18168	28.73	***
	Error	140	88520	637		

*** - significant, $P < 0.05$ (Tukey's test). ASE means anti-swelling efficiency; WL means weight loss and WA means water absorption.

CONCLUSION

This study not only enhance the properties of *pinus massonniana* wood but also showed that tin-based alloy can potentially be used as heating media that otherwise would not be considered for thermal modification of wood. The treatment temperatures showed a significant effect on the wood samples and the results of the durability test on the tin-based thermal treated wood samples show that TTT suppressed the attack of *P. placenta* and *C. versicolor* fungi on the wood and helped maintain the original appearance of the wood. The shrinkage and swelling, anti-swelling efficiency, weight loss and water absorption of the tin-based thermal treated wood samples were significantly improved with increasing treatment temperature. Tin-based thermal treated wood materials can be used in various applications by modifying some of the properties of the wood. *P. massoniana* wood can become more competitive in the wood market.

REFERENCES

Akyildiz MH, Ates S (2008) Effect of heat treatment on equilibrium moisture content (EMC) of some wood species in Turkey.

American Wood Protection Association (AWPA) (2016) Laboratory Method for Evaluating the Decay Resistance of Wood-based Materials Against Pure Basidiomycete Cultures: soil/block Test. pp. E10–E16.

Barnett JR, Bonham VA (2004) Cellulose microfibril angle in the cell wall of wood fibres. *Biological reviews* 79(2):461-472.

Behr VC, Hill SJ, Meder R, Sandquist D, Hindmarsh JP, Franich RA, Newman RH (2014) Carbon-13 NMR Chemical-shift Imaging Study of dewatering of green sapwood by cycling carbon dioxide between the supercritical fluid and gas phases. Journal of Supercritical Fluids 95:35-540.

Boonstra M, Van Acker J, Kegel E, Stevens M (2007) Optimisation of a two-stage heat treatment process: durability aspects. Wood Science and Technology 41:31-57.

Brocco VF, Paes JB, da Costa LG, Brazolin S, Arantes MDC (2017) Potential of teak heartwood extracts as a natural wood preservative. Journal of Cleaner Production 142:2093-2099.

Cao Y, Lu J, Huang R, Zhao Y, Wu Y (2011) Evaluation of decay resistance for steam-heat-treated wood. Bioresources 6(4).

Čermák P, Hess D, Suchomelová P (2021) Mass loss kinetics of thermally modified wood species as a time-temperature function. European Journal of Wood and Wood Products 79:547-555.

Deka M, Saikia C, Baruah K (2000) Treatment of wood with thermosetting resins: effect on dimensional stability, strength and termite resistance. Indian Journal of Chemical Technology 7(6):312-317.

Devi RR, Ali I, Maji T (2003) Chemical modification of rubber wood with styrene in combination with a crosslinker: effect on dimensional stability and strength property. *Bioresource technology* 88(3):85-188.

Hakkou M, Pétrissans M, Gérardin P, Zoulalian A (2006) Investigations of the reasons for fungal durability of heat-treated beech wood. Polymer degradation and stability 91(2):393-397.

Hill, CA (2007) Wood modification: chemical, thermal and other processes. John Wiley and Sons.

Jämsä S, Viitaniemi P (2001) Heat treatment of wood–Better durability without chemicals. Proceedings of a special seminar held in Antibes, France.

Kamdem EF, Samba ON, Manemo CT, Kouam BBF, Abogo S, Tambe J, Amougou JCM, Guegang E, Zeh OF, Moifo B (2022) Establishment of Local Diagnostic Reference Level for Routine Paediatric Computed Tomography Examinations in Bafoussam West Cameroon. Radiation Protection Dosimetry 198(12):815-820.

Kaya A (2023) Combined effects of linseed oil and heat treatment on the properties of cypress and maple wood Part 1: Water absorption, mechanical properties, and sound absorption capacity. **BioResources** 18(2):2940-2963. DOI: 10.15376/biores.18.2.2940-2963

Korkut S, Akgül M, Dündar T (2008) The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood. Bioresource Technology 99(6)1861-1868.

Lee SH, Ashaari Z, Lum WC, Halip JA, Ang AF, Tan L, Chin KL, Tahir PM (2018) Thermal treatment of wood using vegetable oils: A review," **Construction Building and Material** 181:408-419. DOI: 10.1016/j.conbuildmat.2018.06.058

Liu H. Li Z, Zhang X, Tang B, Wan C, Wang K (2022) The Effect of Different Moderate Thermal Modification Durations on the Wood Properties of American Alder. Materials 15(24)8839.

Metsä-Kortelainen S, Paajanen L, Viitanen H (2011) Durability of thermally modified Norway spruce and Scots pine in above-ground conditions. Wood Material Science & Engineering 6(4)163-169.

Metsä-Kortelainen S, Viitanen H (2017) Durability of thermally modified sapwood and heartwood of Scots pine and Norway spruce in the modified double layer test. Wood Material Science & Engineering 12(3):129-139.

Metsä-Kortelainen S, Viitanen H (2012) Wettability of sapwood and heartwood of thermally modified Norway spruce and Scots pine. European Journal of Wood and Wood Products 70(1/3):135-139.

Minkah, MA, Afrifah, KA, Antwi-boasiako C, Wentzel M, Batista, DC, Militz, H (2021) Physical and moisture sorption properties of thermally-modified Gmelina arborea wood. Pro Ligno 17(1).

Mitani A, Barboutis I (2014) Changes caused by heat treatment in colour and dimensional stability of beech (*Fagus sylvatica* L.) wood. Drvna industrija 65(3):225-232.

Newman RH, Franich RA, Meder R, Hill SJ, Kroese H, Sandquist D, Hindmarsh J, Schmid MW, Fuchs J, Behr VC (2016) Proton magnetic resonance imaging used to investigate dewatering of green sapwood by cycling carbon dioxide between supercritical fluid and gas phase. Journal of Supercritical Fluids 111:36-42.

Okon KE, Lin F, Chen Y, Huang B. (2018a) Decay resistance and dimensional stability improvement of wood by low melting point alloy heat treatment. Journal of Forestry Research 29(6):1797-1805.

Okon KE, Lin F, Lin X, Chen C, Chen Y, Huang B. (2018b) Modification of Chinese fir (*Cunninghamia lanceolata* L.) wood by silicone oil heat treatment with micro-wave pretreatment. *European Journal of* Wood and Wood Products (76)221-228.

Park Y, Jeon WS, Yoon SM, Lee H.M, Hwang WJ (2020) Evaluation of cell-wall microstructure and anti-swelling effectiveness of heat-treated larch wood. Journal of the Korean Wood Science and Technology 48(6):780-790.

Rowell RM, Ibach RE, McSweeny J, Nilsson T (2009) Understanding decay resistance, dimensional stability and strength changes in heat-treated and acetylated wood. Wood material Science and engineering 4(1-2):14-22.

Ruwoldt J, Toven K (2022) Alternative wood treatment with blends of linseed oil, alcohols and pyrolysis oil. Journal of Bioresources and Bioproducts 7(4):278-287.

Sailer M, Rapp A, Leithoff H (2000) Improved resistance of Scots pine and spruce by application of an oil-heat treatment. International Research Group Wood Pre

Skaar C (2012) Wood-water relations. Springer Science and Business Media

Syrjanen T (2001) Production and classification of heat-treated wood in Finland. Proceedings of the special seminar held in Antibes, France.

Team RC (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. *http://www. R-project. org/*

Tjeerdsma BF, Boonstra M, Pizzi A, Tekely P, Militz H (1998b) Characterisation of thermally modified wood: Molecular reasons for wood performance improvement. Holz als Roh-und Werkstoff 56(3):149-153. DOI: 10.1007/s001070050287

TS 4084 (1983) Wood-Determination of Radial and Tangential Swelling. Turkish Standards Institution, Ankara.

Wood D, Vailati C, Menges A, Rüggeberg M (2018) Hygroscopically actuated wood elements for weather responsive and self-forming building parts-Facilitating upscaling and complex shape changes. *Construction and Building Materials* 165:782-791.

Yang L (2021) Effect of temperature and pressure of supercritical CO_2 on dewatering, shrinkage and stresses of Eucalyptus Wood. Applied Sciences 11(18):8730.

Yang L, Liu HH (2020) Effect of Supercritical CO_2 drying on moisture transfer and wood property of *Eucalyptus urophydis*. Forests 11:1115.

Yan L, Morrell JJ (2014) Effects of thermal modification on physical and mechanical properties of Douglas-fir heartwood. BioResources 9(4):7152-7161.