Crossref

IJBSM March 2024, 15(3): 01-06

Article AR5065a

Research Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2024.5065a

Impact of Heat Treatment on Dimensional Stability of *Salix tetrasperma* Roxb. Wood

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0009-0004-2527-2413

ABSTRACT

The present investigation was carried out during the years October, 2021–September, 2022 in the Laboratory of the Department of Forest Products, Dr. Y S Parmar University of Horticulture and Forestry Nauni, Solan. Thermal modification was performed on the samples of *Salix tetrasperma* at various temperatures 60, 80, 100, 120, 140, 160 and 200°C for 2, 4 and 6 h under stability oven, to asses its impact on wood dimensional stability. The data pertaining on maximum moisture content, swelling coefficient and shrinkage coefficient shows significant variation. The maximum moisture content at different temperature treatment, was recorded to be maximum (192.03%) in control and minimum (140.09%) at 200°C, whereas for durations the maximum moisture content (164.77%) was observed at 2 h while minimum (161.77%) at 6 h. Among interactions, the maximum value (192.03%) was observed in control and minimum (139.42%) was found at 200°C (6 h). In volumetric swelling and shrinkage coefficient, maximum values (8.03%) and (7.42%) among temperatures were found in control and minimum values (3.85%) and (3.42%) were observed at 200°C (6 h). Among durations, the highest values (5.94%) and (5.73%) were found at 2 h and the lowest values (5.60%) and (5.50%) were observed at 6h. The interactions in volumetric swelling coefficient showed significant results and the highest value (8.03%) was noticed in control and the lowest value (3.74%) at 200°C (6 h), However, interactions in volumetric shrinkage coefficient were found to be non-significant. This indicated that after thermal treatment, wood becomes less hygroscopic and exhibits less wear and tear, even in a harsh environment.

KEYWORDS: Thermal treatment, dimensional stability, swelling coefficient, shrinkage coefficient

Citation* (VANCOUVER)*: Shabir et al., Impact of Heat Treatment on Dimensional Stability of *Salix tetrasperma* Roxb. Wood. *International Journal of Bio-resource and Stress Management,* 2024; 15(3), 01-06. HTTPS://DOI.ORG/10.23910/1.2024.5065a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 16th December 2023 RECEIVED in revised form on 20th February 2024 ACCEPTED in final form on 09th March 2024 PUBLISHED on 24th March 2024

1. INTRODUCTION

Wood is one of the most versatile and valuable natural resource on this planet, and is, therefore, considered as one of the best renewable constructional material (Rowell, 2013). It is commonly chosen construction material because of its favorable characteristics, such as its low weight and notably impressive strength-to-weight ratio (Bal, 2016). Due to its unique features, such as texture, colour, density, strong strength to weight ratio, and aesthetic look, wood find wide range of uses in different industries (Ates et al., 2009). Besides, versatile properties of wood, it has some limitations as it is moisture sensitive, dimensionally unstable, have lesser durability and is prone to insect and fungus attack. To overcome these limitations, various modification methods are frequently used to enhance the functional attributes of wood. Presently, there is a growing demand for modification outcomes to be achieved with minimal or even zero reliance on harmful chemicals (Sandberg and Kutna, 2016). Wood modification could be either active modification (change in chemical nature of wood) or passive modification (change without affecting chemical parameters). Other method of wood modification i.e. chemical treatment is hazardous to the environment and involves higher cost, therefore, thermal modification is a better option. Thermal modification is typically viewed as an environmentally sustainable method for modifying wood since it relies solely on the use of heat and water in the treatment process, avoiding the need for chemical additives. (Sandberg et al., 2017). Suitable heat treatment increases hydrophobic properties, reduces the mass and modify other physical properties of wood, especially colour, specific gravity, density, swelling, shrinkage, weathering resistance etc. (Petrissans et al., 2003; Jamsa and Viitaniemi, 2001). The heat treatment process, as observed in the study by (Olek and Bonarski, 2014), leads to significant modifications in both the chemical composition and the ultrastructure of wood cell walls. These alterations ultimately result in changes to the material's properties. These changes are observed in wood elasticity and dimensional stability that increases the effectiveness of wood for construction purpose (Boonstra et al., 2007). As a result, thermally modified wood has been developed as an environmental friendly alternative to impregnated wood (Kamdem et al., 2002).

Salix tetrasperma Roxb. (Indian Willow), a medium sized tree, belongs to the family Salicaceae. It grows upto about 1800 m altitude in the sub-Himalayan and outer Himalayan ranges, and about 2100 m in the Nilgiris (Prakesh, 1991). It is a common indigenous willow growing gregariously along river and stream banks and in wet swampy places throughout the greater part of India. The heart wood is red, soft and porous, which is mainly used for construction, match industry, planks, house buildings, bent wood furniture, ploughs and agricultural implements. The wood is also used in the manufacture of boxes, brooms, cricket bats, cradle boards, chairs and other furniture, dolls, willow flutes, poles, toys, tool handles, wood veneers etc. The twigs of the trees are used for basket making (Luna, 1996). Owing to the utilization potential of wood for different purposes and to enhance its strength and durability the present study was proposed. Wood species that have no commercial value can be thermally modified and put for better utilization (Reiterer and Sinn, 2002; Epmeier et al., 2004; Unsal and Ayrilims, 2005; Kubojima et al., 2008). Heat-treated wood is gaining popularity in outdoor applications such as garden furniture, panelling, kitchen furniture, and the interiors of bathtubs and saunas due to its improved weather resistance (Viitaniemi, 2000).

2. MATERIALS AND METHODS

The present investigation was carried out during the years October, 2021–September, 2022 in the Laboratory of the Department of Forest Products and the material was procured from 30 year old tree of *Salix tetrasperma* Roxb. from the Botanical Garden of Dr. Y S Parmar University of Horticulture and Forestry Nauni, Solan (HP), located at 32.8°N Latitude and 74.7°E Longitude. The wood sample size, 20×20×20 mm^3 (for maximum moisture content) and 50×25×25 mm^2 (for swelling and shrinkage coefficient) were used for the investigation. The samples were treated at 60, 80, 100, 120, 140, 160 and 200°C for 2, 4 and 6 h under stability oven. After thermal treatment, the samples were submerged in distilled water to ensure complete saturation. The saturated samples were taken out and their weight and dimensions were measured with the help of electronic weighing balance and digital caliper. Samples were dried first in air and then in oven at 105±2°C till constant weight was attained. Maximum moisture content, swelling coefficient and shrinkage coefficient were calculated as per the procedure given by Indian Standard IS:1708 (BIS, 1986). The recorded data were subjected to Completely Randomized Design (CRD) Two Factorial analysis and by using OP STAT software analysis were done.

2.1. *Parameters to be observed in the present study*

2.1.1. *Maximum moisture content (MMC %)*

Maximum Moisture Content (MMC) of the wood samples was determined by the procedure prescribed as per the Indian Standard IS: 1708 (BIS, 1986). Wood samples of size 20×20×20 mm^2 were submerged in distilled water to ensure complete saturation. The saturated samples were taken out and weighed. Samples were dried first in air and then in oven at 105±2°C till constant weight. The Maximum Moisture Content (%) was calculated by the following formula:

Maximum moisture content (MMC) %=$(M_m - M_o / M_o) \times 100$

Where,

M_m=Saturated weight of wood samples (g)

M_o=Oven dried weight of wood samples (g)

2.1.2. Volumetric swelling coefficient (%)

Volumetric swelling coefficient is defined as the cumulative increase in all the planes of wood due to addition of water. To measure swelling coefficient, the wood samples of size 500×25×25 mm^2 were taken and measured with digital caliper after thermal treatment. Afterwards, samples were put into beaker containing distilled water. Observations were recorded until the weight of the samples became constant. The dimensions of samples were measured again with digital caliper at saturation point, volume was obtained by multiplying all the dimensions of the specimens and the swelling coefficient was calculated as follows:

S =$(V_2 - V_1 / V_1) \times 100$

Where,

S=Volumetric Swelling Coefficient

V_1=Wood volume of a oven-dried wood sample before treatment (cc)

V_2 =Wood volume with treatment (cc)

2.1.3. Volumetric shrinkage coefficient

Volumetric shrinkage coefficient is defined as the overall decrease in all the planes of wood due to removal of bound water. To measure shrinkage coefficient, the same samples (used for swelling) after being saturated in water were kept in an oven at 105±2°C till constant weight. The dimensions of samples were measured again with digital caliper at constant weight, volume was obtained by multiplying all the dimensions of the specimens and the shrinkage coefficient was calculated as follows:

S =$(V_2 - V_1 / V_2) \times 100$

Where,

S=Volumetric shrinkage coefficient

V_1=Wood volume of a oven-dried sample after treatment (cc)

V_2=Wood volume (wet) with treatment (cc)

3. RESULTS AND DISCUSSION

The results of present study has been described under the following headings:

3.1. Maximum moisture content of wood

The data revealed substantial changes in Maximum moisture content of thermally treated wood among different treatment temperatures, durations and their interactions (Table 1). The highest value (192.03%) was found in control and the lowest (140.09%) was noticed at 200°C. Among durations, the maximum value (164.77%) was found at 2h and the minimum value (161.77%) was found at 6h. The maximum value (192.03%) for the interactions of temperature and duration was observed in control and the minimum (141.71%) was observed at 6 h.

Table 1: Maximum moisture content of thermally modified wood of *Salix tetrasperma* (%)

Temperature/ Duration	2h	4h	6h	Mean
60°C	188.04	184.15	183.78	185.33
80°C	176.30	174.26	173.34	174.63
100°C	170.60	168.35	164.72	167.89
120°C	163.90	161.58	160.41	161.96
140°C	154.70	152.34	151.24	152.76
160°C	150.41	149.59	149.24	149.75
180°C	146.43	144.48	141.71	144.21
200°C	140.54	140.30	139.42	140.09
Control	192.03	192.03	192.03	192.03
Mean	164.77	163.01	161.77	
CD (p=0.05)				
Temperature (T)		0.36		
Duration (D)		0.21		
Temperature×Duration (T×D)		0.62		

The primary benefit of subjecting wood to heat treatment is the enhancement of its dimensional stability. This involves increasing its resistance to moisture and reducing its equilibrium moisture content. Heat treatment is particularly effective in reducing the moisture absorption of wood, a critical factor in maintaining the overall performance of wood when used in various applications. This is especially valuable in scenarios where water resistance is a priority, such as in lowland areas, for constructing fences, and for altering indoor climate conditions when used in furniture, wall panels, or slats. Bytner et al., 2021, subjected black poplar wood (*Populus nigra* L.) to heat treatment at temperatures of 160, 190, and 220 °C for 2 hours, as well as at 160 and 190 °C for 6 hours, all within a nitrogen atmosphere. They then measured how the equilibrium moisture content of the treated wood changed under simulated conditions of relative humidity at 34%, 65%, and 98%. The results revealed that as the relative humidity increased, the equilibrium moisture content decreased, and the rate at which the heat-treated wood absorbed water decreased noticeably during the initial 7-hour soaking periodTop of Form. During thermal treatment of beech wood, Bal (2015) has also observed reduction in equilibrium moisture content with increase in temperature and duration. The change in equilibrium moisture content in *Quercus petraea, Castanea sativa, Pinus brutia*, and *Pinus nigra* wood have been due to decrease in OH^- groups, chain cleavage, and substance loss following exposure to high temperatures (Akyildiz and Ates, 2008).

3.2. Swelling coefficient of wood

The data presented in Table 2 revealed statistically significant values for volumetric swelling coefficient at different temperatures, durations and their interactions at 5 per cent level of significance. The highest volumetric swelling coefficient (8.03%) was recorded in control and the lowest value (3.85%) was observed at 200°C. Amongst durations, the highest (5.94%) was found at 2h and the lowest (5.60%) was found at 6h, whereas the values for interaction between temperatures and durations were found to be between 3.74% (200°C at 6h) to 8.03% (control).

The maximum swelling coefficient was observed in control and the minimum was observed at 200°C. Jimenez et al. (2011) also found decreased water absorption capacity of thermally treated Malapapaya wood after 2 hours at 220°C. After 24-hours, hygroscopicity of the treated material decreased significantly. Heat treatment has the capacity to substantially decrease the equilibrium moisture content of wood, and this reduction becomes more pronounced with higher treatment temperatures, (Hidayat et al., 2018). Top of Form Tjeerdsma et al. (1998) have reported that thermal modification allowed the decrease in total swelling (volumetric swelling) from 7.3 to 5.7% in *Fagus sylvatica* and from 4.7 to 2.8% in *Pinus sylvestris.* Cademartori et al. (2015) have also reported that with increase in heat treatment the value of volumetric swelling decreases significantly, for both *Eucalyptus* species i.e. approximately 64% (Rose gum) and 65% (Sydney blue gum). Thermal treatment increases cellulose crystallinity due to homogenous breakdown of the amorphous region in hemicelluloses and increases inaccessibility of OH^- groups to water molecules (Wikberg and Maunu, 2004; Bhuiyan and Hirai, 2005; Boonstra and Tjeerdsma, 2006 and Esteves et al., 2008). In a study conducted by Zhou et al. (2020), subjected mahogany wood (*Swietenia macrophylla* King) to heat treatment across a range of temperatures from 150 to 210°C, with intervals of 15°C, for a duration of 4 hours. The objective was to investigate the impact on the fiber saturation point and surface wettability of the wood. The findings indicated that heat treatment led to a reduction in both the fiber saturation point (measured using nuclear magnetic resonance spectroscopy) and the surface wettability of the wood, resulting in a decrease in its overall moisture-absorbing properties (swelling coefficient). Furthermore, it was observed that wood treated at higher temperatures exhibited a more pronounced decrease in its moisture-absorption characteristics. Similar conclusions were drawn by Zhang et al. (2017) and Nourian and Avramidis (2021).

Table 2: Volumetric swelling coefficient of thermally modified wood of *Salix tetrasperma* (%)

Temperature/ Duration	2 h	4 h	6 h	Mean
60°C	7.94	7.83	7.24	7.67
80°C	7.04	6.86	6.36	6.76
100°C	6.16	6.06	6.05	6.09
120°C	5.95	5.86	5.56	5.79
140°C	5.25	5.04	4.94	5.08
160°C	4.85	4.75	4.46	4.69
180°C	4.27	4.12	4.01	4.13
200°C	3.96	3.85	3.74	3.85
Control	8.03	8.03	8.03	8.03
Mean	5.94	5.82	5.60	
CD (p=0.05)				
Temperature (T)		0.03		
Duration (D)		0.01		
Temperature×Duration (T×D)		0.04		

3.3. Shrinkage coefficient of wood

Data on volumetric shrinkage presented in Table 3, revealed statistically significant values at different temperatures and durations while their combinations revealed non-significant results at 5% level of significance. The maximum value (7.42%) was recorded in control which was statistically at par with 60°C (7.23%) and 80°C (6.92%) whereas, the minimum value (3.42%) was observed at 200°C which was statistically at par with 180°C (3.94%). However, the duration of the treatment revealed that maximum volumetric shrinkage coefficient value (5.73%) at 2 h duration which was statistically at par with 4 h (5.63%) and 6h (5.50%), whereas, minimum (5.50%) was found at 6h and was statistically at par with 4 h (5.63%) and (5.73%) at 2 h. Interaction between temperatures and durations were found to be non significant and values of volumetric shrinkage varied from 3.26 to 7.42%.

The maximum shrinkage coefficient was observed in control and the minimum was observed at 200°C. Akyildiz et al. (2008) have reported that the value of volumetric shrinkage decreases with increase in temperature from 130°C (2h) to 230°C (8 h) in thermally modified Black pine wood. Sinkovic et al. (2011) found similar results in heat treated Hornbeam wood, Beech wood, Ash wood and Oak wood. The results have revealed that the wood become dimensionally more stable in all the planes with increase in temperature, because heat causes some alteration in the

Table 3: Volumetric shrinkage coefficient of thermally modified wood of *Salix tetrasperma* (%)

Temperature/ Duration	2 h	4 h	6 h	Mean
60°C	7.26	7.25	7.17	7.23
80°C	7.06	6.96	6.74	6.92
100°C	6.45	6.24	6.07	6.25
120°C	5.97	5.85	5.76	5.86
140°C	5.06	5.01	4.97	5.01
160°C	4.75	4.56	4.27	4.53
180°C	4.03	3.94	3.84	3.94
200°C	3.53	3.45	3.26	3.42
Control	7.42	7.42	7.42	7.42
Mean	5.73	5.63	5.50	
Mean	5.94	5.82	5.60	
CD (p=0.05)				
Temperature (T)		0.64		
Duration (D)		0.37		
Temperature×Duration (T×D)		NS		

chemical composition of wood *viz*., depolymerisation of the carbohydrates which causes removal of hydroxyl groups, decomposes hemicelluloses and results in further lignin network reticulation which decreases hygroscopicity of wood. Furthermore, Yang et al. (2016) observed comparable outcomes when studying Japanese cedar (*Dryptomeria japonica*) wood. They noted that the dimensional stability of Japanese cedar wood improved as the temperature and treatment duration increased leads to decrease in shrinkage coefficient. Kol (2010) and Kaymakci (2021) has also reported that the values of volumetric shrinkage decreases in thermally modified Pine, Fir and Poplar wood, treated at 190, 212°C for 2 h and 210°C for 4 h.

4. CONCLUSION

The maximum moisture content of wood decreased with the increase in treatment temperature and duration. The volumetric shrinkage and swelling coefficient also decreased with thermal treatment; therefore, thermally treated wood became dimensionally more stable as compared to untreated wood.

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