International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(4): 260-267
www.biochemjournal.com
Received: 01-01-2024
Accepted: 09-02-2024

Raveena Thakur
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Bhupender Dutt
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Rajneesh Kumar
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Yash Pal Sharma
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Akshay Pingale
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Corresponding Author:
Raveena Thakur
Department of Forest Products, College of Forestry, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Optimizing physical and mechanical attributes of *Acrocarpus fraxinifolius* wood via heat treatment

Raveena Thakur, Bhupender Dutt, Rajneesh Kumar, Yash Pal Sharma and Akshay Pingale

DOI: https://doi.org/10.33545/26174693.2024.v8.i4Sd.958

Abstract
Heat treatment of wood is an effective and eco-friendly approach to increase the durability as well as dimensional stability of the wood. It involves the treatment of wood with high temperatures in controlled conditions. In the present investigation, heat treatment of wood samples was carried out at 80, 120, 160 and 200 °C for 2,4 and 6 hours in a stability oven supplied with vacuum conditions. The study revealed significant variation among the physical properties of thermally modified wood of *Acrocarpus fraxinifolius* Wight & Arn. The highest value of specific gravity 0.538 was noticed at 200 °C (6h) and maximum moisture content (181.04%) was recorded in control, whereas the lowest value for specific gravity 0.400 in control and maximum moisture content (120.86%) at 200 °C (6h) were recorded. The colour of the wood became darker while no significant differences were observed in the texture of the wood. Shrinkage and swelling coefficients decreased with an increase in temperature ranges thus ultimately enhancing the dimensional stability of the wood.

Keywords: *Acrocarpus fraxinifolius,* dimensional stability, heat treatment, eco-friendly

Introduction
Wood, for many decades, has been recognized as a sustainable, renewable, and aesthetically pleasing material for indoor and outdoor applications because of its unique properties and versatility, it is considered one of the best renewable construction materials. Moreover, wood is technologically diverse, energy-efficient and an easily accessible natural substance, making it an ideal choice for a wide range of uses. (Rowell, 2013) [25]. Wood is nothing but secondary xylem of the tree, thus is a vital part of the plant's structure, providing support and strength to the plant and chemically composed of cellulose, hemicelluloses, lignin and extractives like; resins, fats, waxes, terpenes *etc*. Each of these components lead to fibre properties that eventually have an impact on ultimate strength properties of wood. Therefore, the mechanical properties i.e. fitness and ability of wood to resist the applied and external forces such as tension, compression, bending, shear, cleavage *etc*. are governed by both physical as well as chemical properties of wood (Mvondo *et al*., 2017) [22].
The increasing human population is ultimately leading to continuous demands of timber and its derived products thus, there is significant pressure on forests that produce high quality timber which eventually has resulted in the unavailability of the production of quality and durable timber from the forests. Hence, one way to meet this demand along with neutralizing the pressure on the forests, is to modify the wood species having undesirable properties like hygroscopicity, anisotropy, dimensional instability and biodegradability through some treatment/modifications, which is also environment friendly. Heat treatment, also known as thermal modification, is one of those treatments (Hill, 2006) [15].
Thermal modification of wood involves treatment of wood at high temperatures in the limited supply of oxygen that modifies their constituents and alters the chemical composition of wood cells by decomposing their cell wall components (chiefly hemicelluloses and cellulose) and extractives, which eventually improve the quality, increase durability, enhance dimensional stability and decrease hygroscopicity as well as equilibrium moisture content of wood (Esteves *et al.*, 2008; and Boonstra and Tjeerdsma, 2006) [13, 9]. Heat-treated wood has contributed significantly for improving wood properties in various countries for several decades. The improved characteristics of heat-treated timber offer the furniture industries

new scopes and opportunities, because of its good weather and decay resistance and therefore, the modified timber can be put into its market value. Heat-treated wood has a promising market in applications like; paneling, home interiors and decors, garden and kitchen furnishing, ceilings, doors and windows, musical instruments *etc*. The method of heat treatment of wood is considered very effective to produce sustainable building material having less toxicity as all the improvements in wood properties are achieved only by heat treating the wood at different temperatures without adding any chemicals. Hence, thermally modified wood has also been designed as an ecological alternative material to impregnated wood (Kamdem *et al*., 2002) [18]. Heat-treated wood has been commercialised and produced on a large scale during the last decade (Sundqvist, 2004) [27]. Many tree species that have no commercial value can be used for specific purposes and put into better utilization by heat treatment (Epmeier *et al*., 2011; Unsal and Ayrilimis, 2005; Kubojima *et al*., 2000) [12, 29, 20].

Acrocarpus fraxinifolius Wight & Arn. commonly known as Pink Cedar, Indian Ash or Mundani, is a large, deciduous, fast-growing tree species of the family Fabaceae and is widely spread around the world, especially in Africa and Asia but the native places for the species are India, Bangladesh, Nepal, China, Indonesia, Myanmar and Thailand. The species is also cultivated in the high rainfall zone of Himachal Pradesh between 600 to 1200 m elevations. The tree generally has a long straight bole up to 75 per cent of its height (Troup, 1921) [28]. The wood of this tree is heavy, moderately hard, compact and easy to work with tools, so is suitable for turnery, carving, paneling, cabinet work and majorily used as packaging material. It is also used in manufacturing of shingles, tea crates, beehive frames, tea boxes *etc*. but is not considered good enough for general construction and furniture making due to its lesser durability. One of the alternatives to address the issues with the species is heat treatment.

Materials and Methods

The present investigation was conducted during year 2018-19 and 2019-20. Thermal modification and laboratory analysis were conducted in the laboratory of the Department of Forest Products, College of Forestry, Dr. Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP).

Experimental details

Wood samples of *Acrocarpus fraxinifolius* Wight & Arn. were acquired from the twenty nine years old tree, felled in the area of Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan (HP). The experiments were laid in the Completely Randomized Block Design (CRD) Factorial.

Preparation of samples

After felling of *Acrocarpus fraxinifolius* Wight & Arn. Tree, it was converted into logs and further cut into the smaller dimensions as per the test specifications. The samples were planed and sanded to make the surface smooth and to give good finish.

Different Temperatures and Time Periods for Heat treatment of Wood

Sr. No.	Temperature (°C)	Time (h)
1.	Control (Room Temperature)	
2.	80 °C	2,4,6 h
3.	120 °C	2,4,6 h
4.	160 °C	2,4,6 h
5.	200 °C	2,4,6 h

Observations Recorded

Specific Gravity

To determine the specific gravity of wood, the method of Maximum Moisture Content was employed (Smith, 1954). The wood samples of dimension 20 mm x 20 mm x 20 mm were submerged in distilled water till saturation. The weight of wood samples was recorded regularly at saturation point and this is known as weight at maximum moisture content level. Further, these samples were oven dried at 105± 2 °C until a constant weight was acquired. The specific gravity of wood was then calculated as per the formula given below:

$$\text{Specific Gravity} = \frac{1}{\frac{Mm-Mo}{Mo}+\frac{1}{GS}}$$

Where,

M_m = Fresh/Green weight of the sample having maximum moisture (g)

M_o = Oven dried constant weight of the sample (g)

GS = Average density of wood substance, a constant, having value 1.53

Maximum Moisture Content (MMC %)

Maximum Moisture Content (MMC) of the wood samples was determined as per the guidelines of Indian Standard IS: 1708. The wood samples of 20 mm x 20 mm x 20 mm dimension were immeresed in distilled water for 7 days to ascertain complete saturation. The saturated samples were then taken out and weighed. This is known as "Saturated weight of wood samples". These samples were further air dried first and after that in an oven at 105±2 °C till constant weight. The Maximum Moisture Content (%) was calculated by formula given below:

$$\text{Maximum Moisture Content (MMC) \%} = \left\{\frac{Mm-Mo}{Mo}\right\} \times 100$$

Where,

M_m = Saturated weight of wood samples (g)

M_o = Oven dried weight of wood sample (g)

iii) Texture

Texture was determined and reported under four main classes based upon the range of tangential vessel diameters narrated as follows:

a) **Very fine:** Mean tangential diameter of vessels <100 µm

b) **Fine:** Mean tangential diameter of vessels 100-200 µm

c) **Medium:** Mean tangential diameter of vessels 200-300 µm

d) Coarse: Mean tangential diameter of vessels >300 µm

iv) Colour

Royal Horticultural Society (RHS) Chart (2015) was used to assess colour of thermally treated wood samples.

v) Tensile Strength (kN/mm^2)

The standard size of the specimens taken for conducting this test was 300×10×10 mm. The computer-generated data and graph were developed with the help of the software and the values of maximum load, maximum displacement and breaking pattern of thermally modified wood were also obtained. Proper care was taken so that each samples faced similar type of test measures.

Bending Strength (kN/mm^2)

The standard size of the specimens taken for this test was 300×20×20 mm. Proper care was taken so that each specimen faced similar type of test measures. The data recorded was used for further analysis and comparison.

Compression Strength Parallel to the Grain (kN/mm^2)

This test was done along the direction of grain of wood specimen of (50×20×20) mm dimensions and the data was generated in the Universal Testing Machine (Model: UTN-10).

Compression Strength Perpendicular to the Grain (kN/mm^2)

The wood specimen of size (50×20×20) mm was taken across the direction of grain for carrying out this test in the Universal Testing Machine (Model: UTN-10).

Results

i) Specific Gravity of Wood

The critical analysis of data related to specific gravity of thermally modified wood revealed significant variation among temperatures, duration and their interactions at 5 per cent level of significance (Table1). For different temperatures, the highest value of specific gravity (0.510) was observed at 200 °C and the lowest value (0.400) was recorded in control which was statistically at par with the value obtained at 80 °C (0.414). Among different time durations, the maximum value of specific gravity (0.453) was noticed at 6h which was statistically at par with 0.443 at 4h while; the lowest value (0.430) was recorded at 2h. For interactions between temperatures and durations, the highest value (0.538) was found at 200 °C (6h) and was statistically at par with 0.518 at 200 °C (4h) whereas; lowest value (0.400) was recorded in control which was at par with 0.408 at 80 °C for 2h; 0.417 at 80 °C for 4h and 6h; 0.420 at 120 °C for 2h and with 0.421 at 120 °C for 4h (Fig 1).

Table 1: Specific Gravity of heat-treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2h	4h	6h	Mean
80 °C	0.408	0.417	0.417	0.414
120 °C	0.420	0.421	0.448	0.430
160 °C	0.448	0.458	0.461	0.456
200 °C	0.473	0.518	0.538	0.510
Control	0.400	0.400	0.400	0.400
Mean	0.430	0.443	0.453	
	$CD_{0.05}$			
	Temperature (T)		0.015	
	Duration (D)		0.012	
	Temperature × Duration (T×D)		0.026	

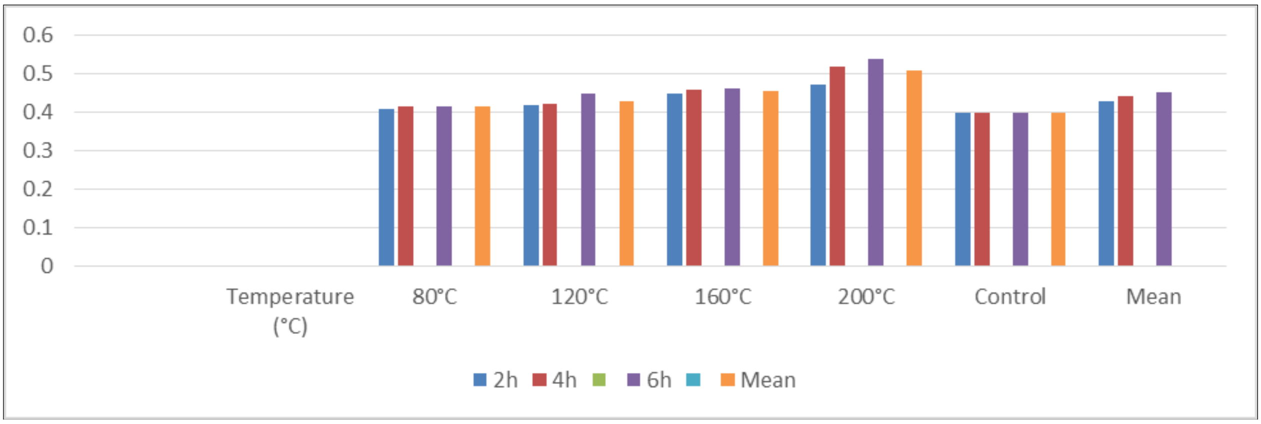

Fig 1: Specific Gravity of heat treated wood of *Acrocarpus fraxinifolius*

ii) Maximum Moisture Content (%)

The table 2 given below depicts the results obtained by statistical analysis of the data pertaining to maximum moisture content of thermally modified wood of Pink cedar. The critical analysis of data has shown pronounced differences in maximum moisture content of heat treated wood among different treatments at 5 per cent level of significance. The highest value for maximum moisture content 181.04 per cent was observed in control which was at par with 176.41 per cent at 80 °C. While, lowest value (131.95%) was obtained at 200 °C. The temperature durations has also significant effect on maximum moisture content. The highest value of 167.74 per cent was observed at 2h and lowest value of 156.99 per cent was found at 6h which was statistically at par with 161.91 per cent observed at 4h. Whereas, the interaction of temperature and duration was observed to be non- significant and the values varied from 120.86 to 181.04 per cent.

Table 2: Maximum Moisture Content (%) of heat treated wood of *Acrocarpus fraxinifolius*

Duration(h) Temperature (°C)	2h	4h	6h	Mean
80 °C	180.02	174.87	174.36	176.41
120 °C	172.61	172.53	158.14	167.76
160 °C	157.98	153.15	150.57	153.90
200 °C	147.04	127.96	120.86	131.95
Control	181.04	181.04	181.04	181.04
Mean	167.74	161.91	156.99	

CD0.05
Temperature (T)
Duration (D)
Temperature × Duration (T×D)

Texture

The observation related to the texture of different heat treated wood is shown in table 3 which revealed fine texture at all treatments.

Table 3: Texture of heat treated wood of *Acrocarpus fraxinifolius*

Duration(h) Temperature (°C)	2h	4h	6h
80 °C	Fine	Fine	Fine
120 °C	Fine	Fine	Fine
160 °C	Fine	Fine	Fine
200 °C	Fine	Fine	Fine
Control	Fine	Fine	Fine

Colour

Table 4 represents the variation observed in colour of thermally modified wood samples of Pink cedar.

Table 4: Colour Variation in heat treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2h	4h	6h
80 °C	159 A (Light Yellowish Pink)	159 A (Light Yellowish Pink)	156 A (Yellowish Grey)
120 °C	159 A (Light Yellowish Pink)	159 B (Pale Orange Yellow)	173 D (Moderate Yellowish Pink)
160 °C	177 A (Moderate Reddish Brown)	177 A (Moderate Reddish Brown)	175 A (Moderate Reddish Brown)
200 °C	N199 C (Moderate Yellowish Brown)	200 D (Moderate Brown)	200 C (Moderate Brown)
Control	159 A (Light Yellowish Pink)	159 A (Light Yellowish Pink)	159 A (Light Yellowish Pink)

Tensile Strength of wood (kN/mm^2)

The scrutinal analysis of the data recorded on tensile strength of thermally modified wood of *Acrocarpus fraxinifolius* showed significant differences for different temperatures and durations at 5 per cent level of significance. The highest tensile strength (0.057 kN/mm^2) was recorded at 120 °C which was statistically at par with 0.55 kN/mm^2 at 80 °C and control whereas; the lowest tensile strength was noticed at 200 °C (0.052 kN/mm^2) which was statistically at par with 160 °C (0.053 kN/mm^2). The maximum value (0.056 kN/mm^2) among durations was found at 2h and minimum (0.053 kN/mm^2) at 6h. The interactions between temperatures and durations was also found to be significant where highest tensile strength (0.061 kN/mm^2) was observed at 120 °C for 2h and was at par with 120 °C for 4h (0.058 kN/mm^2) while, the lowest tensile strength (0.049 kN/mm^2) was observed at 160 °C (6h) which was statistically at par with 0.051 kN/mm^2 at 120 °C (6h), 0.052 kN/mm^2 at 200 °C (4h) and 200 °C (6h).

Table 5: Tensile Strength (kN/mm^2) of heat treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2h	4h	6h	Mean
80 °C	0.053	0.054	0.057	0.055
120 °C	0.061	0.058	0.051	0.057
160 °C	0.056	0.053	0.049	0.053
200 °C	0.053	0.052	0.052	0.052
Control	0.055	0.055	0.055	0.055
Mean	0.056	0.054	0.053	

$CD_{0.05}$
Temperature (T): 0.002
Duration (D): 0.001
Temperature × Duration (T×D): 0.003

Bending Strength of Wood (kN/mm^2)

Table 6 depicted the significant variation at 5 per cent level of significance among different temperatures on bending strength. The maximum bending strength (0.010 kN/mm^2) was noticed in control and was at par with 0.009 kN/mm^2 at 80 °C while; minimum strength (0.007 kN/mm^2) was observed at 200 °C and was at par with 0.008 kN/mm^2 at 120 °C and 160 °C. Among the durations, non-significant results were found. The interactions of temperatures and durations were also found to be non-significant and the values ranged between 0.007 to 0.010 kN/mm^2.

Table 6: Bending Strength (kN/mm^2) of heat treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2 h	4 h	6 h	Mean
80 °C	0.010	0.009	0.008	0.009
120 °C	0.008	0.009	0.008	0.008
160 °C	0.008	0.009	0.008	0.008
200 °C	0.007	0.007	0.008	0.007
Control	0.010	0.010	0.010	0.010
Mean	0.009	0.009	0.009	

$CD_{0.05}$
Temperature (T): 0.002
Duration (D): NS
Temperature × Duration (T×D): NS

vii) Compression parallel to grain (kN/mm^2)

Table 7 depicted the significant variation among different temperatures on compression parallel to grain at 5 per cent level of significance. Among temperatures, the highest value of compression parallel to grain was found at 120 °C (0.051 kN/mm$^{2)}$ and the lowest value was observed at 200 °C (0.041 kN/mm^2). The data was also found to be significant among the durations where; maximum value was recorded to be 0.048 kN/mm^2 at 2h and minimum value was 0.044 kN/mm^2 at 4h and 6h which was at par with data recorded at 6h. The combinations of temperatures and durations were also found to be statistically significant and the highest value was found to be 0.057 kN/mm^2 at 120 °C (2h) and the lowest value was 0.040 kN/mm^2 at 200 °C (6h) which was statistically at par with 0.042 kN/mm^2 at 200 °C (2h and 4h) and with 0.041 kN/mm^2 at160 °C (6h).

Table 7: Compression Parallel to the Grain (kN/mm^2) of heat treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2h	4h	6h	Mean
80 °C	0.046	0.046	0.043	0.045
120 °C	0.057	0.048	0.048	0.051
160 °C	0.051	0.046	0.041	0.046
200 °C	0.042	0.042	0.040	0.041
Control	0.045	0.045	0.045	0.045
Mean	0.048	0.044	0.044	

$CD_{0.05}$
Temperature (T): 0.002
Duration (D): 0.002
Temperature × Duration (T×D): 0.003

Compression Perpendicular to Grain (kN/mm^2)

The critical evaluation of data for compression perpendicular to grain is represented in Table 8 showing significant variation among different temperatures at 5 per cent level of significance. The highest value for compression perpendicular to grain (0.034 kN/mm^2) was noticed at 80 °C which was at par with 0.033 kN/mm^2 in control and lowest value (0.030 kN/mm^2) was found at 200 °C which was statistically at par with 0.031 N/mm^2 at 160 °C. However, the data was observed to be non-significant for different time durations (0.032 kN/mm^2). The interactions of temperatures and durations were recorded to be significant where, the maximum value for compression perpendicular to grain was 0.036 kN/mm^2 at 80 °C (4h) which was at par with 0.035 kN/mm^2 at 80 °C (6h) and 0.034 kN/mm^2 at 120 °C (6h) while; the minimum value was recorded to be 0.028 kN/mm^2 at 160 °C (6h) which was at par with 0.029 kN/mm^2 at 200 °C (4h) and (6h) and with 0.030 kN/mm^2 at 120 °C (4h).

Table 8: Compression Perpendicular to the Grain (kN/mm^2) of heat treated wood of *Acrocarpus fraxinifolius*

Duration (h) Temperature (°C)	2h	4h	6h	Mean
80 °C	0.032	0.036	0.035	0.034
120 °C	0.032	0.030	0.034	0.032
160 °C	0.033	0.031	0.028	0.031
200 °C	0.031	0.029	0.029	0.030
Control	0.033	0.033	0.033	0.033
Mean	0.032	0.032	0.032	

$CD_{0.05}$
Temperature (T): 0.001
Duration (D): NS
Temperature × Duration (T×D): 0.002

Discussion

Specific gravity

Specific gravity of wood is described as the amount of structural material in a tree that is responsible for its strength and provides support. Aydin *et al*. (2015) [4] reported a decrease in specific gravity with increase in temperature and time in Oriental beech (*Fagus orientalis)* wood. Preston *et al.* (2006) [23] reported that specific gravity of wood depends upon anatomical parameters like vessel area, vessel frequency and vessel density that determines the amount of lumen space in wood. In the present study, the specific gravity of wood increased with increase in temperature. This happened because high temperature during thermal modification results in decreased accessibility of hydroxyl group to water molecules (Bhuiyan and Hirai, 2005) [7]. Thus, the ability of wood to hold the moisture decreases, which ultimately increases specific gravity.

Maximum moisture content

The moisture content of wood represents the percentage of water present in the wood's total mass. The moisture content (MC) at which the cells are fully saturated with bound water (in cell wall) and free water (in cell cavity) is referred as equillibrium moisture content. Bal (2015) [6] has recorded a decrease in equilibrium moisture content with rise in temperature and time during thermal treatments of Beech wood. Cademartori *et al*. (2015) [11] has also found similar results in two *Eucalyptus species* (Rose gum and Sydney blue gum). Icel *et al*. (2015) [16] observed that the equillibrium moisture content of heat treated samples of *Picea abies* and *Pinus sylvestris* was almost half as that of control samples. This happens because at higher temperatures, there is a reduction in OH groups of hemicelluloses, breakage of chains and loss of many extractives from the wood (Akyildiz and Ates, 2008) [1]. Consequently, number of hydroxyl groups and accessibility of reactive sites to water molecules become less due to the rise in cellulose crystallinity. Also, cross-linking in lignin lead to the decrease in moisture content of wood (Weiland and Guyonnet, 2003; Boonstra and Tjeerdsma, 2006) [30, 9].

Texture

Texture is defined as the relative size and the degree of variation in size of the wood cells. Principally, the wood texture describes how a wood feels when touched. Different wood have different textures which depends upon some factors such as size of the cells, proportion of the cells and their distribution. Although, the impact of thermal treatment on the anatomical structure of wood are finite: however, it may be dependent on the wood species to be considered. In earlier study by Mahmood and Athar (1997) [21], no changes were observed in the microscopic properties of thermally modified wood. According to Boonstra (2008) [8], this happens because heat treatments do not damage the ray parenchyma pit membranes, bordered pits and large pit membranes, therefore, the fibrils are seen without any damage. In the present findings, there has been no significant variation in the texture of heat-treated samples.

Colour

The colour of the wood is helpful in defining its market value and to put the wood into better utilization for its end use by the consumer. The interaction of chemical components of wood with light characterizes the colour of wood. Jimenez *et al.* (2011) [17] observed that increase in treatment temperature from 160 °C (30 min) to 220 °C (2h) lead to the colour change from yellowish to very dark brown in thermally treated Malapapaya wood. Similarly, Korkut *et al*. (2013) [2]; Akgul and Korkut (2012) [2] also found the wood samples showed lower redness and yellowness after thermal modification and the colour changed strikingly to dark brown. But, according to Aydemir and Gunduz (2009) [5], treatment temperature showed a more significant effect on colour changes as compare to the duration of the treatment. Oxidation of lignin and polysaccharides occurs during heat treatment which leads to the formation of phenolic compounds that induce color change, as well as the formation of quinones during hydrothermolysis. (Sundqvist, 2004 [27]; Fengel and Wegener, 1985 [14]. Generally, cellulose and hemicelluloses in untreated wood do not absorb light in the visible region hence, they are not responsible for colour change. But, according to Kocaefe *et al*., 2008 [19], the decomposition of hemicelluloses during heat treatments slightly contributes to colour change. In the present findings, the colour changed from light yellowish pink to moderate reddish brown.

Tensile strength

The ability of a timber to resist the external forces acting on it in a direction away from its ends in such a way that it tends to pull the fibres of the timber apart (tensile stresses) is termed as its tensile strength. Since time immemorial, wood has been used as a raw material in both indoor and outdoor applications, as well as in construction, due to its unique properties such as sustainability, renewability, and energy-efficiency. As a result, it is exposed to various forces during use. Silva *et al*. (2015) [26] observed a decrease in tensile strength parallel to grain upto 55 per cent in Corymbia citriodora with increase in temperature. According to Boonstra and Tjeerdsma (2006) [9] the degradation of hemicelluloses and amorphous region of cellulose as well as reduction in the quantity of extractives could be the reason for observed decrease in the tensile strength. In the present study also, a similar decreasing trend in tensile strength was noticed in the thermally modified wood of Acrocarpus fraxinifolius.

Bending Strength (kN/mm2)

The ability of wood to resist the forces acting on it which tend to bend the wood is referred as its bending strength. Romagnoli *et al*. (2015) [24] observed a slight reduction in bending strength with increasing treatment temperature in Douglas fir and Corsican pine whereas, duration has a moderate impact on it. The degradation of hemicelluloses during heat treatments is mainly responsible for the decrease in bending strength. The bending strength increased in the beginning of the thermal treatment in air and decreased afterwards (Kubojima *et al*., 2000) [20]. Zhang *et al*. (2012) [33] observed that the modulus of rupture was affected moderately below 200 °C but decreased rapidly above 200 °C in thermally modified Phyllostachy spubescens bamboo wood. Similar trends has been noticed in the present findings in the thermally modified wood of Acrocarpus fraxinifolius which showed decrease in bending strength with increase in treatment temperature while duration has no significant effects on it.

Compression Strength Parallel to the Grain (kN/mm2)

Compressive strength of wood is the ability of wood to resist the forces so applied that the opposite ends tend to come closer to each other. Determining the compressive strength of wood helps in better utilization for its end utilisation. Factors like porosity of wood and its cellular compositions are responsible for compression of wood. The previous study by Aydin *et al*. (2015) [4] revealed that Oriental beech (Fagus orientalis) wood treated under hot air in an oven for 2, 6, and 10h at 125, 155 and 185 °C has shown reduction in the value for compression strength parallel to grain (CSPG) after heat treatments except for 2 and 6 hours heating at 125 °C. As, the amount of bound water must be higher to affect the strength properties but during thermal modifications, the amount of bound water is reduced in wood, thus increase the compressive strength in the longitudinal direction. The results of present study on the thermally modified wood of Acrocarpus fraxinifolius are in line with above statements.

Compression Strength Perpendicular to the Grain (kN/mm2)

Compressive strength perpendicular to the grain is always less than compressive strength parallel to the grain. The reason behind this might be the presence of strong and stiff bonds along the grain as compare to weak and soft secondary bonds in the transverse direction of grain. Boonstra *et al*. (2007) [10] also found a significant decrease in the compression perpendicular to the grain with increasing treatment temperatures from 165 °C and 185 °C. Kubojima *et al*. (2000) [20] observed that compression perpendicular to grain in Picea sitchensis increased in the first 2h of treatment at 120ºC and 160ºC and remained constant afterwards. Whereas; at 200ºC, initially the compressive strength increased but later got decreased. This could be due to increase of cellulose crystallinity and decrease in wood moisture. The effect of crystallinity is more in the beginning of the treatment but with the increase in treatment temperature, the heat degradation is dominant, leading to the decrease in the compressive strength of wood. In the present investigation, similar results were observed in thermally modified wood of Acrocarpus fraxinifolius.

Conclusion
The decrease in maximum moisture content with heat treatment resulted in improved dimensional stability as compared to untreated wood, which is one of the most desirable trait for industrial use of wood. Also, the colour of the wood became darker with the temperature rise which is important from marketing point of view of the wood and its products. However, no significant variations were observed in tensile, bending and compressive strength properties.

Acknowledgement
The research was funded by Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.)

References
1. Akyildiz MH, Ates S. Effect of heat treatment on equilibrium moisture content (EMC) of some wood species in Turkey. Res J Agric Biol Sci. 2008;4:660-665.
2. Akgul M, Korkut S. The effect of heat treatment on some chemical properties and colour in Scots pine and Uludag fir wood. Int J Phys Sci. 2012;7:2854-2859.
3. Alen R, Kotilainen R, Zaman A. Thermochemical behaviour of Norway spruce (Picea abies) at 180–225 degrees C. Wood Sci Technol. 2002;36:163-171.
4. Aydin E, Baysal E, Toker H. Decay Resistance, Physical, Mechanical, and Thermal Properties of Heated Oriental Beech Wood. Wood Res. 2015;60:913-928.
5. Aydemir D, Gunduz G. Heat treatment wood; physical properties and mechanical properties. J Bartinb Orman Fakultesi Derg. 2009;11:71-81.
6. Bal BC. Physical properties of beech wood thermally modified in hot oil and in hot air at various temperatures. Maderas Ciencia y tecnología. 2015;17:789-798.
7. Bhuiyan T, Hirai N. Study of crystalline behaviour of heat-treated wood cellulose during treatments in water. J Wood Sci. 2005;51:42-47.
8. Boonstra MJ. A Two-Stage Thermal Modification of Wood. Ph.D. Thesis, Department of Forest and water management, University of Lorraine, France; c2008. p. 297.
9. Boonstra MJ, Tjeerdsma BF. Chemical analysis of heat treated softwoods. Holz als Rohund Werkstoff. 2006;64:204–211.
10. Boonstra MJ, Acker JV, Tjeerdsma BF, Kegel EV. Strength properties of thermally modified softwoods and its relation to polymeric structural wood constituents. Ann Forest Sci. 2007;64:679-690.
11. Cademartori PHG, Missio AL, Mattos BD, Gatto DA. Effect of thermal treatments on technological properties of wood from two Eucalyptus species. J Anais da Academia Brasileira de Ciencias. 2015;87:471-481.
12. Epmeier H, Westin M, Rapp A. Differently modified wood: comparison of some selected properties. Scand J Forest Res. 2011;19:31-37.
13. Esteves B, Graca J, Pereira H. Extractive composition and summative chemical analysis of thermally treated Eucalyptus wood. Holzforschung. 2008;62:344–351.
14. Fengel D, Wegener G. Wood: chemistry, ultrastructure and reactions. Walter de Gruyter. 1985;23:601-602.
15. Hill CAS. Wood Modification: Chemical, Thermal and Other Processes. John Wiley and Sons, Chichester. 2006;260p.
16. Icel B, Guker G, Isleyen O, Beram A, Murlubas M. Effects of industrial heat treatment on the properties of Spruce and Pine woods. J BioResource. 2015;10:5159-5713.
17. Jimenez JP, Menadro NA, Ramon AR, Ponciano SM. Physico-mechanical properties and durability of thermally modified Malapapaya wood. Philippine J Sci. 2011;140:13-23.
18. Kamdem D, Pizzi A, Jermannaud A. Durability of heat-treated wood. Holz als Roh-und Werkstoff. 2002;60:1-6.
19. Kocaefe D, Poncsak S, Boluk Y. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. Bioresources. 2008;3:517-537.
20. Kubojima Y, Okano T, Ohta M. Bending strength and toughness of heat-treated wood. J Wood Sci. 2000;46:8-15.
21. Mahmood M, Athar M. Xylotomic investigations of coniferous woods from Pakistan. Pak J Bot. 1997;29:43-73.
22. Mvondo RRN, Meukam P, Jeong J, Menses DS, Nkeng EG. Influence of water content on the mechanical and chemical properties of tropical wood species. Results Phys. 2017;7:2096-2103.
23. Preston KA, Cornwell WK, DeNoyer JL. Wood density and vessel traits as distinct correlates of ecological strategy in 51 California coast range angiosperms. New Phytol. 2006;170:807–818.
24. Romagnoli M, Cavalli D, Pernarella R, Zanuttini R, Togni M. Physical and mechanical characteristics of poor-quality wood after heat treatment. Biogeoscience and Forestry. 2015;8:884-891.
25. Rowell RM. Acetylation of wood-A Review. Int Product of Lignocellulosic Products. 2013;1:1-27.
26. Silva MRD, Brito JO, Govone JS, Machado GO, Calil C, Christoforo AL, Lahr FAR. Chemical and mechanical properties change in Corymbia citriodora wood submitted to heat treatment. Int J Mater Eng. 2015;5:98-104.

27. Sundqvist B. Color Changes and Acid Formation in Wood During Heat. Ph.D. Thesis. Lulea University of Technology, Lulea Sweden. 2004;50p.
28. Troup RS. Silviculture of Indian Trees. Clarendon Press, Oxford. 1921;1(3):1757.
29. Unsal O, Ayrilmis N. Variations in compression strength and surface roughness of heat-treated Turkish river red gum. Holz als Roh-und Werkstoff. 2005;51:405-409.
30. Weiland JJ, Guyonnet R. Study of chemical modifications and fungi degradation of thermally modified wood using DRIFT spectroscopy. Holz als Roh-und Werkstoff. 2003;61:216-220.
31. Wikberg H, Maunu S. Characterisation of thermally modified hardwoods and softwoods by 13C CPMAS NMR. Carbohydrate Polymer. 2004;58:461-466.
32. Yildiz UC, Yildiz S, Gezer ED. Mechanical and chemical behavior of beech wood modified by heat. Wood Fiber Sci. 2005;37:456-461.
33. Zhang YM, Yu LY, Yu JW. Effect of thermal treatment on the physical and mechanical properties of *Phyllostachys pubescen* bamboo. J Wood Prod. 2012;71:61-67.