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CATALYTIC HEAT TREATMENT OF WOOD

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Abstract

In recent years, heat treatment has been one of the processes for modifying the properties of wood. In this study, it was intended to reduce the negative effects caused by the heat treatment of wood by choosing a suitable catalyst. The catalytic heat treatment of wood was studied in nitrogen atmosphere at 212°C. The effects of two different catalysts, acetic acid and potassium hydroxide, on mass loss and dimensional stability of wood were investigated. The specimens exposed to catalytic heat treatment using 10 wt% acetic acid did not show a significant difference in the mass loss as compared to the heat treated specimens without acetic acid. However, the specimens exposed to the catalytic heat treatment using 10 wt% acetic acid showed a significant difference in the mass loss as compared to the 10 wt% KOH solution (47% solution of KOH solution). The catalytic heat treatment slightly improved the swelling of wood as compared to the control group. Acetic acid as catalyst showed better performance as compared to the potassium hydroxide in the catalytic heat treatment

Key words: *catalytic heat treatment; wood; mass loss; dimensional stability.*

INTRODUCTION

Wood is degraded by decay, insect attack or both and also shrinkage and swelling may occur in wood when the moisture content is changed. Heat treatment of wood at high temperature is one of the wood modification methods to improve the dimensional stability and bio-durability of wood. So heat treatment is used for improve the dimensional stability and increase the biological durability of wood (Stamm 1964; Shi et al. 2007)

The heat-treated wood has a growing market in outdoor applications such as exterior cladding, window and door joinery, garden furniture, and decking. There are also many indoor applications for heat-treated wood such as flooring, paneling, kitchen furnishing, and interiors of bathrooms and saunas (Viitaniemi 2000). The heat treatment of wood changes its chemical composition by degrading cell wall compounds and extractives (Militz 2002; Tjeerdsma and Militz 2005). As a consequence of the loss of strength properties, heat-treated wood is not recommended for use in loadbearing construction (Viitaniemi 1997).

Pyrolysis is degradation of biomass by heat in the absence of oxygen which results in the production of charcoal, liquid and gaseous products. Pyrolysis is similar to heat treatment process, but occurs at temperatures above 300°C (Özbay et al. 2013). As previously reported that the use of catalysts in pyrolysis processes changes the chemical composition of the pyrolysis products (Chen et al. 2008; Lu et al. 2010; Shao et al. 2010).

OBJECTIVE

The use of catalysts in heat treatment process can improve physical properties of the wood. In this study, it was focused on the effect of two different catalyst, acetic acid and potassium hydroxide, on mass loss and dimensional stability of wood were investigated. The catalytic heat treatment of wood was studied in nitrogen atmosphere at 212°C.

MATERIAL, METHOD, EQUIPMENT

Materials

Fir sapwood was selected as test materials because of wide usage of industry. Special emphasis is given for the selection of the wood material. Accordingly, non-deficient, proper, knotless, normally grown (without zone line, without reaction wood and without decay, insect mushroom damages). The specimens were oven dried at 103±2°C until a constant oven-dry weight was obtained prior to experiments.

The commercial catalysts used in these experiments are 47% potassium hydroxide (KOH) solution and acetic acid purchased from Sigma Aldrich and all of them purity exceeded 99 wt%. The technical specifications of the catalysts were given in Table 1.

Table 1

Technical specifications of the catalysts

Specification	KOH Solution	Acetic Acid
Resolution	20°C	-
Melting point	20°C	16°C
Density	1.475 g/cm^3 (20°C)	1.049 g/cm^3 (25°C)
pH	>13.5 (H_2O, 20°C)	>7 (H_2O, 20°C)
Boiling point	135°C	118°C

Catalytic heat treatment

Heat treatment experiments were performed in a vacuum oven under nitrogen atmosphere. During the experiments, the heating rate and temperature were controlled with a PID (Proportional–Integral–Derivative) controller. 18 sapwood specimens were used for each heat treatment and control. In a non-catalytic heat treatment experiment, specimens were weighted and placed into the oven, which was heated by an electric furnace. The catalyst (10 %wt) was used in the catalytic heat treatment experiments. The oven was loaded with the specimens and 10 %wt of catalyst. The specimens were heated until a final temperature of 212 °C and maintained for 2 h at this temperature.

Methods

After the treatment, test specimens with dimensions of 45 mm x 20 mm x 50 mm in axial, tangential and radial directions, respectively were prepared with a planer-type table saw. Then the specimens were cooled in a dry environment and weighted. The mass loss (ML) of the specimens was determined according to equation (1):

$$ML = [(M_0-M_1)/M_1]*100 \qquad (1)$$

where:
ML: Mass loss (%)
M_0: Initial oven-dry mass of the specimen before heat treatment (g)
M_1: Oven-dry mass of the same specimen after heat treatment (g)

The shrinkage of the specimens was performed according to ISO 4469 (1981). Test specimens with dimensions of 40mm x 20mm x 20mm in axial, tangential and radial directions, respectively were soaked in water until a constant dimensions were obtained. Then, the measured dimensions specimens were oven dried at 103±2°C until a constant oven-dry weight was obtained. After drying, the dimensions were measured for the determination of tangential and radial dimensional changes of test specimens. The shrinkage of the specimens was measured according to equation (2):

$$\beta= [(w_m- d_m)/w_m]*100 \qquad (2)$$

where:
β: Shrinkage of the specimens (%),
w_m: Wet measurement of the specimens (mm)
d_m: Dry measurement of the specimens (mm)

The swelling of the specimens was performed according to ISO 4859 (1982). Test specimens with dimensions of 40mm x 20mm x 20mm in axial, tangential and radial directions, respectively were oven dried at 103°C until a constant oven-dry weight was obtained. Afterwards, the oven dried specimens were measured from tangential and radial directions. Then, the test specimens were soaked in water until constant dimensions were obtained. Swelling of the specimens was measured according to equation (3):

$$\alpha = [(w_m - d_m)/d_m]*100 \quad (3)$$

where:
α: Swelling of the specimens (%),
w_m: Wet measurement of the specimens (mm)
d_m: Dry measurement of the specimens (mm)

Statistical analysis

An analysis of variance, ANOVA, was conducted ($p \leq 0.05$) to evaluate the effect of catalysts on the mass loss, and swelling and shrinkage properties of particleboards. Significant differences between the average values of types of the particleboards were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

The mass loss rates results depending on the heat treatment type were given in Table 2. The catalytic heat treatment or non-catalytic heat treatment of wood was performed at 212°C. According to Table 2 the mass loss rate was found to be 3.76% for the non-catalytic heat treatment, 3.21% for the catalytic heat treatment used KOH solution, and 3.86% for the catalytic heat treatment used acetic acid. The decrease in the mass loss rate for the catalytic heat treatment used KOH solution was found to 14.62% as compared with the non-catalytic heat treatment. The increase in the mass loss rate for the catalytic heat treatment used acetic acid was determined as 2.65% as compared with the non-catalytic heat treatment. The increase in the mass loss rate for the catalytic heat treatment used acetic acid was not statistically significant although the decrease in the mass loss rate for the catalytic heat treatment used KOH solution was statistically significant.

Table 2

Mass loss rates of heat treatment groups

Treatment type	Group code	Chemical percentage [%]	Number of specimen [N]	Mass loss [%]		
				Mean	Duncan's multiple range Test	Standard deviation
Heat treatment	T	0	18	3.76	A	0.57
Catalytic heat treatment	P	10	18	3.21	B	0.54
	A	10	18	3.86	A	0.67

T: Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group, A: Catalytic heat treatment (acetic acid) group. Groups with same letters in column indicate that there is no statistical difference ($p \leq 0.05$) between the specimens according to Duncan's multiply range test.

The mass loss rates of heat treatment groups are presented in Fig. 1.

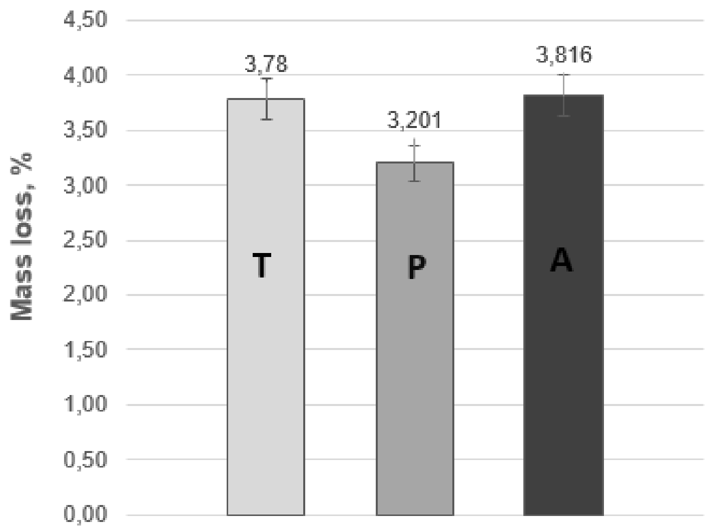

Fig. 1.
The mass loss rates of heat treatment groups: T: Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group,
A: Catalytic heat treatment (acetic acid) group

The shrinkage ratios of the catalytic and non-catalytic heat treatment experiments were given in Table 3 and Fig. 2. The highest shrinkage rate was found in the tangential direction. In addition, there was no significant difference in the axial direction. The volumetric shrinkage rate was found to be 9.36% for the non-catalytic heat treatment, 10.84% for the catalytic heat treatment used KOH solution, and 10.34% for the catalytic heat treatment used acetic acid. Although the shrinkage for the catalytic heat treatment groups increased, there was no significant difference (Table 3).

Table 3

Shrinkage ratios of heat treatment groups

Treatment type	Group code	Chemical percentage [%]	Number of specimen [N]	Direction	Shrinkage ratio [%]		
					Mean	**Duncan's multiple range test**	**Standard deviation**
Non-catalytic heat treatment	T	0	16	Tangential	6.04	A	2.17
				Radial	3.45		0.93
				Axial	0.18		0.19
				Volume	**9.36**		2.58
Catalytic heat treatment	P	10	16	Tangential	6.97	A	1.33
				Radial	4.14		1.01
				Axial	0.07		0.04
				Volume	**10.84**		1.20
	A	10	16	Tangential	6.43	A	1.32
				Radial	4.22		0.86
				Axial	0.15		0.08
				Volume	**10.34**		1.51

Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group, A: Catalytic heat treatment (acetic acid) group. Groups with same letters in column indicate that there is no statistical difference ($p \leq 0.05$) between the specimens according to Duncan's multiply range test.

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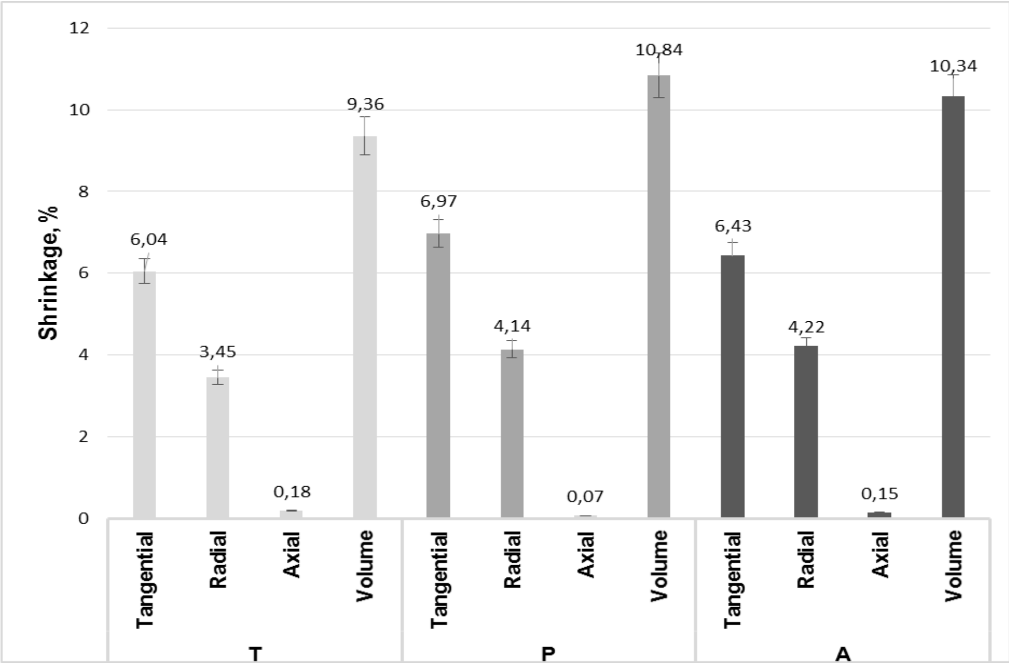

Fig. 2
Shrinkage ratios of heat treatment groups: T: Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group, A: Catalytic heat treatment (acetic acid) group

The swelling ratio of the catalytic and non-catalytic heat treatment experiments was given in Table 4 and Fig. 3.

Table 4
Swelling ratios of heat treatment groups

Treatment type	Group code	Chemical percentage [%]	Number of specimen [N]	Direction	Swelling ratio [%]		
					Mean	Duncan's multiple range Test	Standart Deviation
Non-catalytic heat treatment	T	0	16	Tangential	6.69	A	1.47
				Radial	4.26		0.60
				Axial	0.11		0.07
				Volume	**11.31**		1.54
Catalytic heat treatment	P	10	16	Tangential	6.37	A	0.81
				Radial	4.45		0.83
				Axial	0.08		0.07
				Volume	**11.14**		0.92
	A	10	16	Tangential	5.88	A	1.54
				Radial	3.76		0.87
				Axial	0.16		0.11
				Volume	**10.02**		1.96

T: Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group,
A: Catalytic heat treatment (acetic acid) group. Groups with same letters in column indicate that there is no statistical difference ($p \leq 0.05$) between the specimens according to Duncan's multiply range test.

As shown in Table 4, the highest swelling rates were found in the tangential directions. Also there was no significant difference in the axial directions. According to Table 4 and Fig. 3 the volumetric swelling was found to be 11.31% for the non-catalytic heat treatment, 11.14% for the catalytic heat treatment used KOH solution, and 10.02% for the catalytic heat treatment used the acetic acid. There was no significant difference in the swelling values of the samples treated with and without KOH solution. The decrease in the volumetric swelling of the specimens exposed to the catalytic heat treatment used acetic acid was found to be 11.4% as compared with the non-catalytic heat treatment. There was no significant difference among the heat treatment groups in swelling.

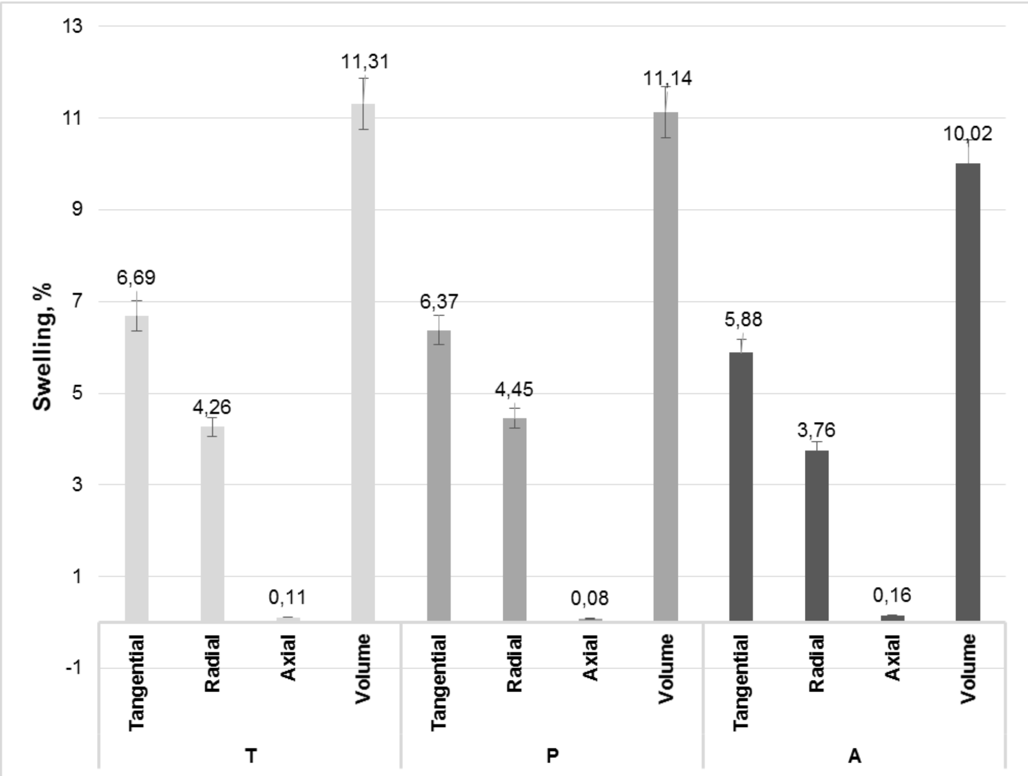

Fig. 3
Swelling ratios of heat treatment groups: T: Heat treatment (control) group, P: Catalytic heat treatment (KOH solution) group, A: Catalytic heat treatment (acetic acid) group

CONCLUSIONS

The following conclusions have been drawn from the results of the present work:

1. The specimens exposed to catalytic heat treatment using 10 wt% acetic acid did not show a significant difference in the mass loss as compared to the heat treated specimens without acetic acid. However, the specimens exposed to the catalytic heat treatment using 10 wt% acetic acid showed a significant difference in the mass loss as compared to the 10 wt% KOH solution (47% solution of KOH solution).
2. The catalytic heat treatment slightly decreased the swelling of wood as compared to the control group.
3. Acetic acid as catalyst showed better performance as compared to the potassium hydroxide in the catalytic heat treatment.

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