EFFECT OF MICROWAVE RADIATION AND PRE-STEAMING TREATMENTS ON THE CONVENTIONAL DRYING CHARACTERISTICS OF FIR WOOD (*ABIES ALBA* L.)

Hadi Dashti,[a] Asghar Tarmian,[a,]* Mehdi Faezipour,[a] and Mahdi Shahverdi [a]

In this research, the effect of microwave radiation and steaming pretreatments on drying rate and residual stresses of fir wood (*Abies alba* L.) was investigated. Wood samples with green dimensions of 340 × 100 × 50 mm and initial moisture content of about 50% were exposed to either steam or microwave radiation treatment before being conventionally dried. The pre-steaming was performed at temperatures of 120, 140, and 160°C for 1 hour, and the microwave treatment was applied with 2.45GHz frequency for 7 and 10 minutes at three different conditions. Results revealed that the pre-steaming at 140 and 160°C and the microwave radiation for 10 minutes imposed greater effect on the drying rate. The residual drying stresses were reduced due to the microwave radiation; in contrast, they were increased as a result of steaming at 140 and 160°C.

Key words: Drying rate; Residual stress; Steaming; Microwave; Fir wood

*Contact information: a: Department of Wood and Paper Science & Technology, Faculty of Natural Resources, University of Tehran, Karaj, Iran. *Corresponding author: Department of Wood and Paper Science & Technology, Faculty of Natural Resources, University of Tehran, P. O. Box 31585-4314, Karaj, Iran, E-mail: tarmian@ut.ac.ir*

INTRODUCTION

Wood drying is time consuming and cost intensive. Research is being conducted to find new and highly efficient drying methods to be adapted industrially. For this purpose, some new drying methods, such as dielectric (microwave and radiofrequency), vacuum or combined drying methods have been applied to achieve the mentioned objectives in this industry. In addition, some pretreatments of wood before drying, such as steaming and microwave radiation were used to increase the wood drying rate (LV *et al.* 1994; Zhao *et al.* 1998; Zielonka and Dolowy 1998; Zhao *et al.* 2003; Yu *et al.* 2002; Zhang and Cai 2006). Alexiou *et al.* (1990) reported the increase of wood drying rate was a result of pre-steaming due to the movement and elimination of some parts of wood extractives which increases water molecules accessibility to the cell walls. Harris *et al.* (Harris *et al.* 1989) also found that the drying rate of red oak increased by pre-steaming. Zhang and Cai (2006) observed the rupture development in *Abies lasiocarpa* wood due to pre-steaming above 130°C, and the rupture intensity increased by increasing steaming temperature from 130°C to 160°C. Turner *et al.* (1998) demonstrated that the drying rate and quality of pine wood significantly increased by microwave radiation before drying. Brodie (2009) performed microwave pretreatment on two species of poplar and eucalyptus, and then dried them in a solar oven. He found out that as a result of microwave pretreatment, drying rate increased due to occurrence of microscopic cracks in the cell walls, and permeability and diffusion coefficients were consequently increased. Fei *et al.* (2003) and Zhao *et al.* (2003) also showed that microwave pretreatment improved moisture diffusion coefficient and reduced drying time of eucalyptus wood. In recent years, fir wood (*Abies alba*) comprises a great percentage of wood used in Iran. This research aims to investigate the effects of microwave and steaming pretreatments on the drying rate and quality of *Abies alba*.

EXPERIMENTAL

Sampling

Fir wood (*Abies alba* L.) flat-sawn boards with green dimensions of 340 × 100 × 50 mm and initial moisture content of about 50% were selected from a wood yard for the study. Six replications were tested for each set of experiment.

Microwave Radiation and Steaming Procedures

Pre-steaming was applied at three temperatures of 120 (ST120), 140 (ST140) and 160°C (ST160) for 1 hour under a pressure of 2-3 bars inside a laboratory steaming device. A microwave oven with frequency of 2.45 GHz was used for microwave radiation under three conditions (Table 1). To prevent the occurrence of severe checking of wood samples, at every 30 to 60 seconds intervals during microwave application, the heating was stopped for 60 to 120 seconds to equilibrate for the temperature of the wood specimens (rest time).

Table1. Three Different Conditions Applied for Microwave Radiation of *Abies alba* Wood Specimens

Treatment	Total time (min)	Microwave radiation period (s)	Rest time (s)
Control	-	-	-
MW1	7	30	120
MW2	7	60	120
MW3	10	60	60

Drying Method

After either microwave radiation or steaming, the boards were end coated using oil-based paint to avoid the moisture flow through the end sections. Subsequently, they were conventionally dried inside a laboratory kiln at a constant temperature of 60°C and a relative humidity of 50% to the final moisture content of 10%.

Initial moisture content was determined based on the primary dry weight of each board. In addition, drying rate was also assessed according to the percentage of moisture content of each sample before and after the drying procedure with taking the overall drying time into account.

Residual Stresses and Moisture Gradient Measurement

In equation (1) , PR is prong response (or casehardening) of test sample (mm^{-1}), x is the distance between outer prong edges before cutting (mm), x' is the distance between outer prong edges after cutting (mm), and l is the length of each test sample's prong (Fig. 1). To determine the moisture content gradient along the thickness of dried boards, slice cutting method using four layers of 10 mm in thickness was applied.

$$PR = \frac{x - x'}{l^2} \tag{1}$$

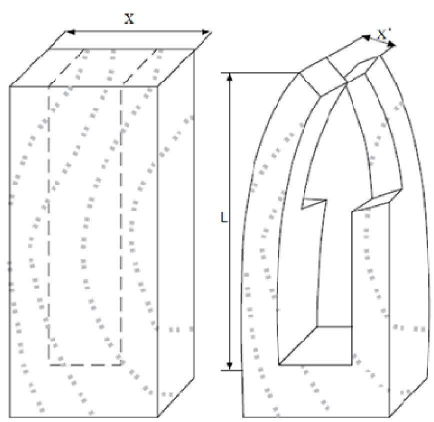

Fig. 1. Cutting method of specimens for measurement of casehardening (internal residual stresses)

Surface and Internal Checking Measurement

After drying, the intensity of surface and the internal checking were determined for all dried boards. Five specimens with 20 mm in length were used for measuring of internal checks. Internal crack abundance was assessed with millimeter precision and then reported in the four ranges from 1 to 40mm in length.

RESULTS AND DISCUSSION

Effect of Microwave Radiation and Steaming on Drying Rate

Figure 2 shows the drying rate of the wood samples exposed to either microwave radiation or steaming compared to the control samples. Steaming at 140°C and 160°C increased the drying rate. However, no increasing effect was observed by increasing the drying temperature from 140°C to 160°C. Microwave radiation for the duration of 10 min and rest time of 60 seconds (MW3 condition) improved the moisture loss rate. In contrast, microwave radiations under MW1 and MW2 conditions were not effective to improve the drying rate. A close relationship between wood drying rate and its permeability and diffusion coefficients was observed. In fact, these two factors play a pivotal role in the drying behavior of wood within the free water and bound water domains. The permeability coefficient is affected by the wood porous and anatomical structure (Tarmian and Perre 2009), and the diffusion coefficient by the structure of cell walls (Tarmian *et al.* 2012). In previous study, Dashti *et al.* (2012) showed that the radial permeability and diffusion coefficients of fir wood significantly increased as a result of pre-steaming at 160°C and microwave radiation. Thus, the improved drying rate can be related to the increasing of both permeability and diffusivity parameters of fir wood. The increasing effect of microware radiation on the drying rate of *Abies alba* L may be attributed to the rupture occurrence in the ray parenchyma cells. Torgovnikov and Vinden (2009) mentioned that when the microwave energy is applied to wood, steam is generated within the wood cells, and thus under high internal steam pressure, the pit membranes on the cell walls and the weak ray cells rupture to form pathways for easy fluid transfer. The hydrolysis of bordered pit torus material in fir wood due to steaming as previously reported by Dashti *et al.* (2012) can be the main reason for the increasing of the drying rate. The similar findings were also reported by other researchers (Nicholas and Thomas 1968; Jianxiong *et al.* 1994; Zhang and Cai, 2008).

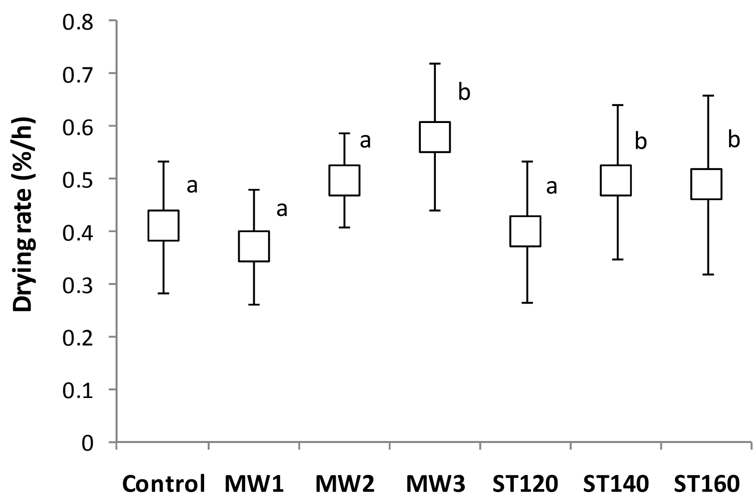

Fig. 2. Drying rate of microwave and steam exposed fir wood specimens compared to the unexposed ones

Effect of Microwave Radiation and Steaming on Residual Stresses and Moisture Content Gradient

In all specimens, the prongs of casehardened samples showed inwards deviation, suggesting the residual stresses in the dried boards. Steaming at 140°C and 160°C resulted in a higher intensity of the residual stress compared to the control specimens (Fig. 3). In contrast, the microwave exposed specimens showed lower residual stress intensity than the unexposed ones. As shown in Fig. 4, the moisture gradient was more uniform in the microwave exposed boards compared to the unexposed ones, and a fairly flatter moisture profile was attained. In contrast, steaming had a negative impact on the moisture profile uniformity, and the most heterogeneous moisture profile occurred due to steaming at 160°C (Fig. 5). In contrast to the microwave exposed specimens, a typical MC profile pattern with a parabolic shape was developed along the thickness of all steamed and control specimens. This can be due to the different heating and moisture flow mechanisms occurred in microwave drying method. The more heterogeneous moisture profile of steamed specimens compared to the control ones may be a reason for their greater residual stress intensity. While there was no internal and surface checks in the microwave exposed specimens, the intensity of both surface and internal checking increased as a result of steaming (Tables 2 and 3). The higher checking in the steamed specimens can be attributed to their higher drying stresses. When the drying stresses exceed wood strength, they cause surface and internal checks.

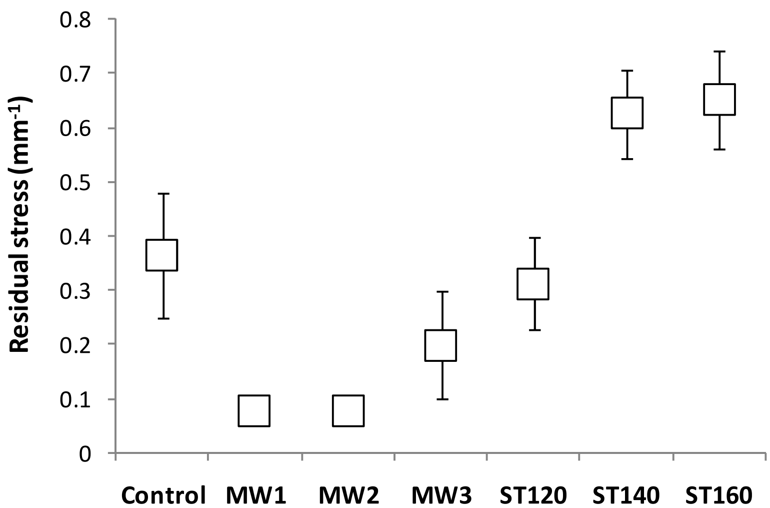

Fig. 3. Intensity of residual drying stresses in microwave and steam exposed fir wood specimens compared to the unexposed ones

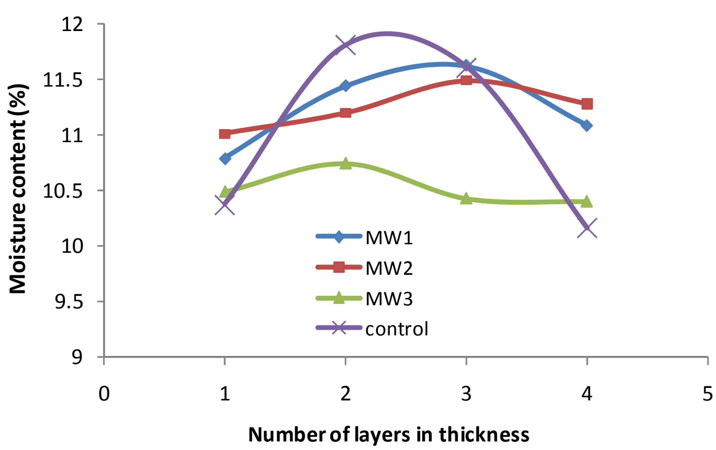

Fig. 4. Moisture content gradient in microwave exposed fir wood specimens compared to the unexposed ones

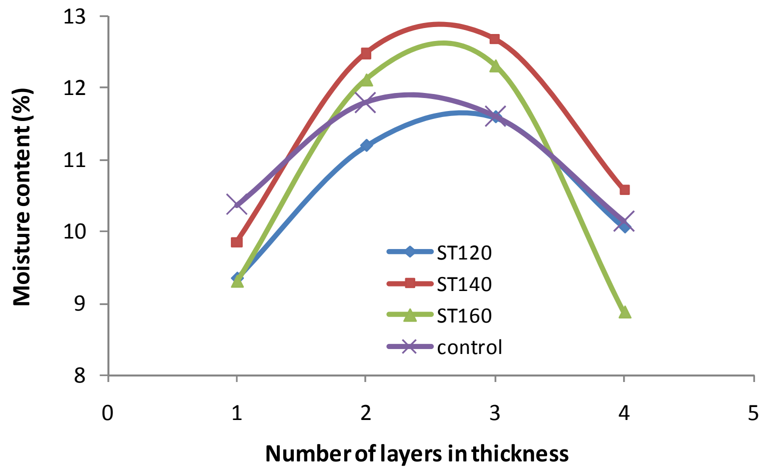

Fig. 5. Moisture content gradient in steam exposed fir wood specimens compared to the unexposed ones

Table 2. Intensity of Internal Checking in Microwave and Steam Exposed Fir Wood Specimens Compared to the Unexposed Ones

Crack length (mm)	Control	MW1	MW2	MW3	ST120	ST140	ST160
1-10	1	0	0	0	0	0	1
11-20	1	0	0	0	2	3	11
21-30	2	0	0	0	0	6	4
31-40	0	0	0	0	2	1	3

Table 3. Intensity of Surface Checking in Microwave and Steam Exposed Fir Wood Specimens Compared to the Unexposed Ones

Crack length (mm)	Control	MW1	MW2	MW3	ST120	ST140	ST160
1-30	0	0	0	0	2	0	0
31-60	0	0	0	0	0	0	2
61-90	0	0	0	0	1	1	1
91-120	0	0	0	0	0	1	0

CONCLUSIONS

In the present study, effect of pre-steaming and microwave radiation on the conventional drying characteristics of fir wood (*Abies alba* L.), a gymnosperm species with torus margo pit membrane was investigated. Results revealed that both steaming and microwave radiation improve the drying rate of fir wood. However, the effectiveness of pre-steaming method depends on the steaming temperature and that of microwave on the microwave radiation duration. Based on our previous study regarding the effect of microwave radiation and pre-steaming on the air permeability and water vapor diffusivity of fir wood (Dashti *et al.* 2012), it can be concluded that the improved drying rate is due to the modification effect of both pretreatments on the wood permeability and diffusivity. In addition to the drying rate improvement, the microwave radiation resulted in the lower residual drying stresses and better drying quality (more uniform MC profile and less drying checking) compared to the unexposed specimens. In contrast, pre-steaming imposed negative effects on the wood drying quality. Since considerable drying residual stress occurred in all pre-steamed specimens, stress relief treatment with sufficient duration time is recommended. The effectiveness of both microwave radiation and pre-steaming methods to increase the drying rate also depends on the wood anatomical structures. Therefore, the potential application of such pretreatments to improve the drying rate of other wood species is recommended for further research.

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