Brief note

EXPERIMENTAL STUDY ON COMBINED INFRARED AND MICROWAVE DRYING OF POROUS MEDIA WITH PARTICULAR APPLICATION IN WOOD INDUSTRY

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Porous materials such as wood have microscopic capillaries and pores which cause a mixture of transfer mechanisms to occur simultaneously when subjected to heating. Infrared and microwave heating of wood products has not been used to a larger extent by the wood industries and manufactures. This could be explained by the insufficient knowledge of the complex interaction between a porous material and process parameters during drying. This article uses the drying experiments to study the effects of drying modes, density and moisture content on wood hardness.

Brinell hardness is measured on wood surfaces of Guilan spruce at two angles to the grain.

Key words: porous material, wood, hardness, microwave, infrared.

1. Introduction

Drying is one of the most energy-intensive processes in industry. Economy and rapidity are common to the drying of some industrial products and in some cases these products should be dried under some specific conditions. This is the case for wood products.

Wood is a hygroscopic, porous, anisotropic and nonhomogeneus material. Wood is an extremely versatile material with a wide range of physical and mechanical properties. Drying of wood is one of the most important industrial processes in wood manufacturing (Siau, 1984). Drying influences the mechanical properties of wood in three ways, namely through the direct effect of moisture loss, the internal drying stresses and strains. Almost all mechanical properties of wood can be improved by carefully controlling these factors (Plumb *et al.*, 1985). Most research on wood drying aims at reducing energy and material loss. The methods of conducting the research are, however, different, depending on the researchers. Convective drying is usually encountered in wood industry and therefore, the study of this type of drying has been very important for several decades. Investigations on microwave drying of wood have been performed since late fifties, but today it is possible to carry out simultaneous measurements of important factors. This allows indicating the electromagnetic field distribution, evaporation rate and absorbed power in wood during the process (Basilico and Martin, 1984). The knowledge and understanding of the process will be improved as well as applying this technique in the most effective way (Antti, 1999).

The research field of wood drying, therefore, varies widely, from trial and errors drying tests, to investigations of the bonding of water molecule to cellulose chains (Pougatch *et al.*, 2003).

Drying is influenced by heat and mass transfer between the airflow and wood, as well as by the complex moisture transport processes which take place in the wood (Pougatch *et al.*, 2003). Our contribution consists in experimental investigations on the effects of different drying modes on the wood hardness.

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Experimental work .2

The experimental work under consideration concerned fifty cylindrical green wood samples of spruce obtained from Guilan province. Samples of *300* (diameter) × *21* (height) mm of spruce wood were cut from a fresh log shortly before the experiment. Then the samples were end-sealed with nitrocellulose lacquer to prevent moisture loss. A programmable domestic microwave oven (Deawoo, KOC-1B4K), with a maximum power output of $1000\,W$ at $2450\,MHz$ was used. The oven has the facility to adjust power (Wattage) supply and the time of processing. The hot air drying experiments were performed in a pilot tray dryer consisted a temperature controller. Air was drawn into the duct through a mesh guard by a motor driven axial flow fan impeller whose speed can be controlled in the duct. The infrared dryer was equipped with eight red glass lamps (Philips) with power $175\,W$, each emitting radiation with peak wavelength $1200\ nm$. Radiators were arranged in three rows, with three lamps in each row. The dryer was equipped with measuring devices, which made it possible to control air parameters. The amount of water in a piece of wood is known as its moisture content.

In general, the average moisture content may be defined as

$$y = \frac{\omega_i - \varpi}{\omega - \omega_e}$$

ω_i is the initial, ϖ the average and ω_e the empty lumen moisture content.

3. Hardness measurement

Wood hardness was measured in the direction parallel and perpendicular to the grain according to Brinell where the elliptical indentation caused by sinking into the surface under test. All hardness measurements were done by force of a steel ball of $10\ mm$ diameter and load of $1000\,N$. Brinell hardness is given by

$$H_B = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}, \qquad \left(\frac{N}{mm^2}\right)$$

where:

P – the applied load, *N*.
D – the diameter of the steel bar, *mm*.
d – the diameter of indentation, *d*.

4. Results and discussion

At the start of drying, when the initial water content is sufficient, the porous medium approaches the temperature of the wet bulb. During this transition phase, the higher the initial temperature is, the greater the drying rate. When drying becomes stable, the temperature is uniform within the porous medium. When the liquid phase becomes discontinuous, the liquid migration stops. Thus the moisture content decreases notably at the surface of the medium which becomes hygroscopic. The pressure of the vapour acts at the interface, and the drying rate decreases. The gradient of vapour pressure generates gaseous diffusion towards the surface and causes evaporation inside the porous medium.

Table 1 indicates the notations used in the figures.

In general, from Fig.1 it can be seen that the slope of the moisture content versus time is constant up to a certain drying time and then decreases indicating two regions of drying, namely, constant rate and falling rate periods. It can be observed that drying usually takes place in the falling rate period. In essence, air in the oven is saturated, with time, and forms a thick film around the wood sample. That prevents effective separation of the evaporated moisture from the wood. This may be the reason for the existence of the constant rate period in this study. In Fig.2 the effect of changing the power output in the microwave oven on the drying rate is shown. It is thus possible to make full use of the increase in power which can be achieved by raising the temperature to the maximum value which particular timbers species can tolerate without excessive degradation.

Table 1. Notations used in the figures and their explanations.

No.	Notations	Explanation
1	MCD 100%	Microwave Drying Power *100%*
2	MCD 80%	Microwave Drying Power *80%*
3	MCD 50%	Microwave Drying Power *50%*
4	CT,100	Convective $T = 100^0 C$
5	CT,40	Convective $T = 40^0 C$
6	INF	Infrared
7	NC	Natural Convection
8	CB11	Combined dryer, $T = 100^0 C$ $P = 100\%$
9	CB18	Combined dryer, $T = 100^0 C$ $P = 80\%$
10	CB41	Combined dryer, $T = 40^0 C$ $P = 100\%$
11	PD	Perpendicular to wood Grain
12	P	Parallel to wood Grain
13	MW	Microwave drying

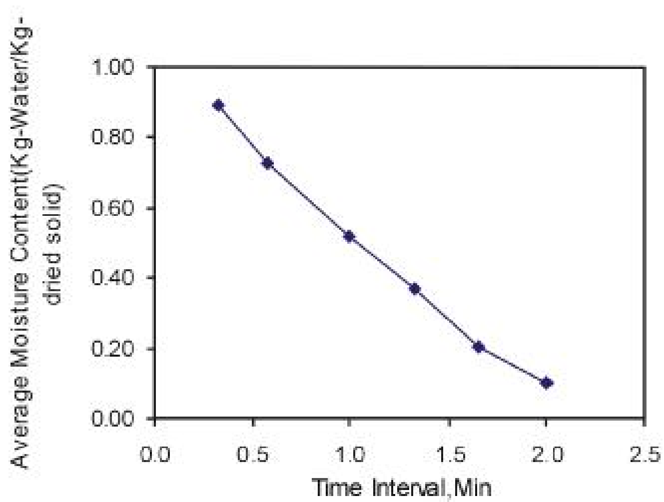


Fig.1. Average moisture content vs. time for combined microwave and infrared drying (MCD*80%*).

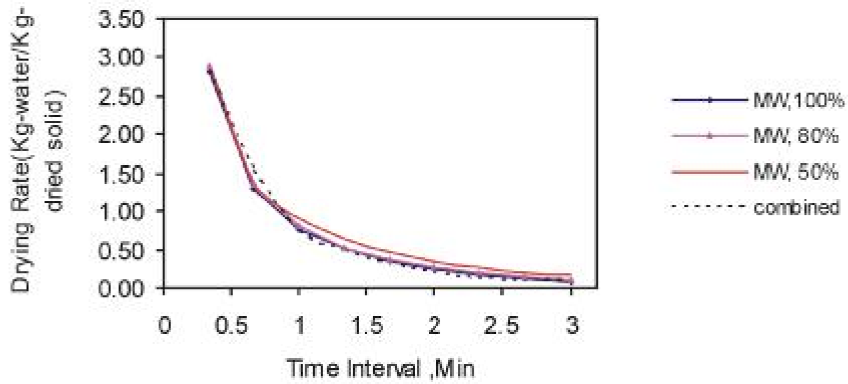


Fig.2. Drying rate vs. time for combined microwave and infrared drying.

Table 2 presents the density of wood samples with *10%* and *14%* moisture content. Figure 3 shows the average Brinell hardness plotted against the density presented in Tab.2. Figure 4 shows Brinell hardness vs. the average moisture content for combined microwave and infrared drying. The measurement of Brinell hardness shows the influence of moisture content and density of hardness. The samples that were dried to *0.07* moisture content tend to be harder.

Table 2. Density of woods with *10%* and *14%* moisture content.

Description	Density (Kg/m^3), for moisture content *10%*	Density (Kg/m^3), for moisture content *14%*
MCD *100%*	*682.7±42.9*	*682.7±63.2*
MCD *80%*	*624.2±44.7*	*624.2±64*
MCD *50%*	*671.7±42.4*	*671.7±59.7*
CT, *100*	*692.4±43.9*	*692.4±58.2*
CT, *40*	*594±50.8*	*594±74.9*
INF	*616.9±47.2*	*616.9±66.4*
NC	*638.2±42.8*	*638.2±51.2*
CB11	*697.5±14.7*	*697.5±19.5*
CB18	*578.6±15.2*	*578.6±21*
CB41	*656.7±20.8*	*656.7±29.5*
MCD *100%*	*682.7±42.9*	*682.7±63.2*

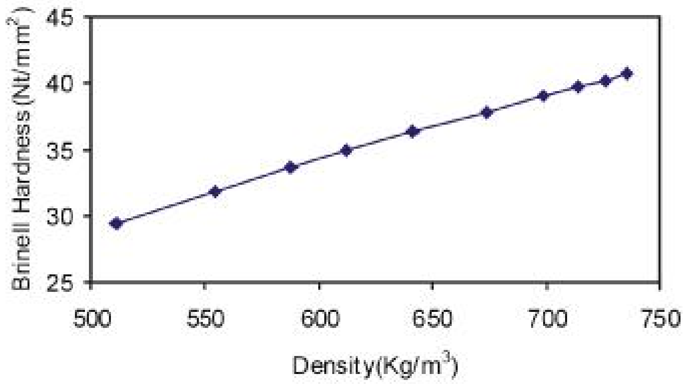


Fig.3. Brinell hardness vs. density for combined microwave and infrared drying.

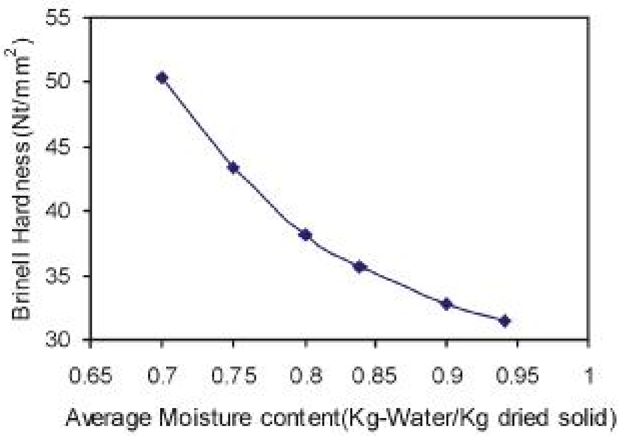
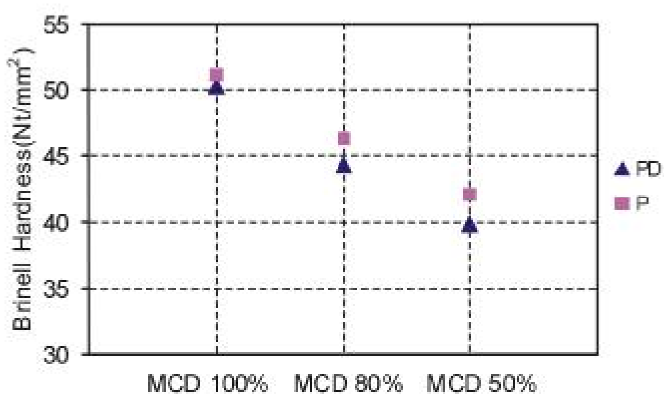
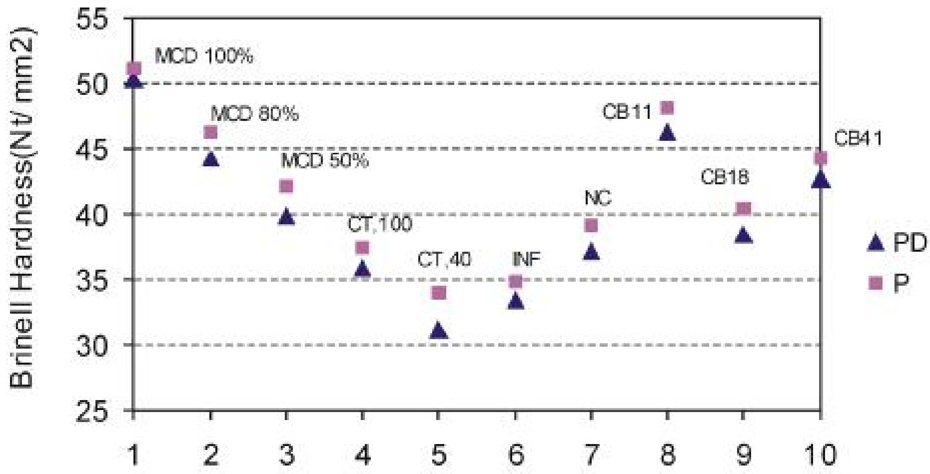


Fig.4. Brinell hardness vs. the average moisture content for combined microwave and infrared drying.

Figure 5 shows the variation of Brinell hardness for combined microwave and infrared dried samples perpendicular and parallel to the grain for different power**.** These variations are shown in Fig.6 for samples dried by infrared and convective dryers as well. It can be seen that there is a significant improvement in wood hardness when indentation is made perpendicular to the grain during combined drying.



Average values of Brinell hardness for combined microwave and infrared dried samples perpendicular Fig.5. and parallel to the grain for different power.



Variation of Brinell hardness for combined microwave and infrared, convective and infrared dried Fig.6. samples perpendicular and parallel to the grain for different power.

Conclusion .5

In the present investigation, at all power levels, drying rates tended to end at about the same time. The observed initial acceleration of drying may be caused by allowing rapid evaporation and transport of water.

Convective drying has some advantages over convective heating. Heat transfer coefficients are high, the process time is short and the cost of energy is low. The drying time was reduced as compared to hot air drying.

It can be noted that the time interval of drying process is solely determined by drying conditions. Once the drying process has entered the falling rate period, the external conditions become relatively unimportant compared to the internal parameters.

In general, by comparing runs with the same initial moisture, we see that as the oven temperature increases, the transition points are reached more quickly and total drying times are shorter. The experimental study suggests that the humidity of the free stream should be as low as possible. Partial recirculation, *100%* fresh air intake, or dehumidifications are some of the possible ways to accomplish this task, but a cost analysis is imperative before deciding on any option.

Reduction of the drying time in microwave heater seems to be a motivating cost saving factor for industries. The results indicated that there is a significant difference in wood hardness parallel and perpendicular to the grain between different drying methods.

The above discussion suggests further investigation for future work on different specimens.

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