WOOD RESEARCH
60 (6): 2015
899-906

EFFECTS OF MOISTURE ON DRYING RATE OF MICRO-EXPLOSION-PRETREATED FAST-GROWING POPLAR WOOD

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(Received April 2015)

ABSTRACT

A new technique, micro-explosion, was applied to pretreat the fast-growing poplar wood and assist the drying process. After experimental samples, with the moisture content of 90, 70, 50, 40 and 30 %, had been pretreated five times with a pressure of 1.0 MPa, the experimental and control samples were oven-dried at 103 ± 2°C. Results showed that the average drying rate of samples pretreated by micro-explosion was greater than that of the untreated samples. The improvement of the drying rate of the test group could be attributed to the fractures on the pit membranes, which indicated an increase in the permeability of the pretreated wood. The effective water diffusion coefficient in wood below the fiber saturation point of the test group was greater than that of the control group, especially with the moisture content of 30, 40 and 50 %. Micro-explosion could be applied in the wood drying industry as an effective method for improving drying rate.

KEYWORDS: Micro-explosion, poplar wood, drying rate, micro-structural changes, effective water diffusion.

INTRODUCTION

To expedite the wood drying process, heat is a useful tool. However, this drying means results in a 40 to 70 % consumption of the total energy spent on wood processing (He et al. 2013), thus finding ways to improve the drying rate is crucial for reducing energy consumption in the drying process. A moist convection drying process, resulting from the evaporation of surface moisture and removal of internal moisture, is highly affected by the permeability of wood (Torgovnikov and Vinden 2009). Therefore, improving permeability can speed up the removal of internal moisture, thus shortening drying time and reducing energy consumption during the wood drying process.

Steam pretreatment has been reported as an effective method of improving the permeability of wood, and therefore the drying rate (Pokki et al. 2010). Steam explosion, a kind of steam pretreatment, has begun to be used to pretreat lumber, especially wetwood, which contains wet pockets (Zhang and Cai 2006; Kang et al. 2010). Steam explosion breaks down the bordered pit pairs between earlywood tracheids in order to reach the wet pockets. The complete process cycle is about 10 min long, and the time during which steam is released from the steam explosion chamber is about 20 s (Zhang and Cai 2006). Although steam explosion can be used to increase the drying rate, in addition to improving the quality of final products, its function is limited because of the long cycle of the process. The lengthy preheating required by this process may offset the energy it saves. This technology is more suitable for some other uses, such as enhancing the enzymatic saccharification of lignocellulosic materials (Martin-Sampedro et al. 2014) and investigating efficient fiber retting (Sheng et al. 2014).

Currently, a new technology called "micro-explosion," using air at room temperature, has begun to be applied to the wood drying process. Compared to steam, air is more convenient and safer. The mechanism of micro-explosion is similar to that of steam explosion. The pressure differential inside and outside the wood is the key. An instantaneous exhaust process of pressurized air results in a number of fine fractures at the weakest part of cells, such as pits, which are benefit for permeability. (Zhang and Cai 2006).

Steam explosion has been studied by several researchers (Kanagawa et al. 1992; Zhang and Cai 2006), while the literature related to micro-explosion in wood processing is limited. The main objectives of this study were to determine the effect of this technique on the drying rate of wood and then to experimentally determine the drying behavior and drying characteristics of micro-explosion pretreated poplar wood.

MATERIAL AND METHODS

Materials

The logs selected in this study were fresh-cut poplar (*Populus cathayana* Rehd) from a forest near the outskirts of Beijing, China. The trees from which the logs were taken were 15 to 20 years of age, with diameters of 25 to 30 cm.

The sample lumber pieces were cut in a tangential direction to produce uniform blocks 200 long x 100 wide x 20 mm thick. The initial moisture content of the samples ranged from 95 to 110 %.

Micro-explosion processing device

The schematic diagram of the micro-explosion processing device is shown in Fig. 1, consisting of a pressure chamber and a circumscribed air compressor (not shown), linked together by an intake-tube.

The micro-explosion process is described as follows. The hermetical chamber was accessed using the front-end cover. After specimens were placed in the chamber, a burst of high-pressure, room temperature air was let in through the inlet port, and the pressure of the chamber could be monitored with the pressure gauge located at the crest of the chamber. The pressurized state of the micro-explosion equipment is shown in Fig. 1a. After 2 min of quiescence, the high-pressure room temperature air was instantaneously released through the outlet port and the discharge port, leaving the wood a pressure relief process, as in Fig. 1b. This momentary exhaust process lasted less than 0.1 s. The outlet port was then closed, and the treatment cycle repeated for a pre-specified number of times.

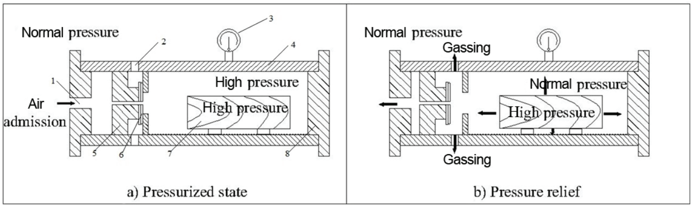

Fig. 1: The working states of micro-explosion equipment: 1) inlet port, 2) outlet port, 3) pressure gauge, 4) chamber, 5) piston, 6) rubber gasket, 7) wood, and 8) front-end cover.

Methods

The micro-explosion pretreatment proceeded before drying process. To investigate the effects of moisture content of the samples to the micro-explosion, all the samples were adjusted to their target moisture content (90, 70, 50, 40 and 30 %) before taken any other further treatment. This procedure was finished with the hygro-thermostat set at high humidity, after determining the initial moisture content of the batch of wood and the target mass of the samples using specified dimensions.

After the test samples were pretreated in the micro-explosion processing device 5 times at a pressure of 1.0 MPa, the drying experiments were performed at 103±2ºC using a convection oven. On the contrary, the control group did not undergo any pretreatment.

The initial masses of all the samples were recorded before the drying operation. During the drying experiment, change in sample mass because of moisture loss was recorded every 2 hours. Drying was continued until the change in sample mass was less than 0.02 g or until no mass change was detected. To eliminate experimental error, each group was carried out in triplicate.

After drying, sixteen slices of 3 to 5 mm were cut from the pretreated and control groups. Samples with standard radial and tangential surfaces were examined in order to analyze the influence of micro-explosion pretreatment on microstructure, with a scanning electron microscope (SEM, Hitachi S-3400NII, Tokyo, Japan).

RESULTS AND DISCUSSION

Fiber saturated point

The fiber saturated point (FSP) of wood is defined as a cell-by-cell phenomenon in wood drying when all free water has moved out of the cells, leaving only the cell walls completely saturated with bound water (Babiak and Kúdela 1995). The fiber saturated point decreases linearly as temperature increases. With each temperature increase of 1, the fiber saturated point reduces by 0.1 %, and when the temperature is 20°C, the FSP is 30 % (Stamm and Loughborough 1935). Therefore, the FSP at various temperatures can be determined using following relation (Eq. 1):

$$M_{fsp} = [0.3 - 0.001(T - 20)] \times 100 \qquad (\%) \qquad (1)$$

where: M_{fsp} - the fiber saturation point (%),
T - the temperature (°C) (He et al. 2012).

According to Eq. (1), when the temperature is 103°C, fiber saturation point is 21.7 %.

Drying rates

Drying rate is the intuitive embodiment of the drying efficiency, and it is determined by the loss of moisture, free water and bound water, inside wood. Although the loss of moisture is not strictly abide by bound water after free water, the fiber saturated point can influence the drying rate. To analyze the differences between the samples that had and had not received micro-explosion pretreatment, the average drying rates of the pretreated and control groups below and above the FSP were calculated for each group, respectively. It should be noted that the boundary of moisture content of below and above fiber saturated point was different, due to the limitation of the recorded experimental data.

As is shown in Tab. 1, the drying rates above FSP of the samples that had received micro-explosion pretreatment are larger than that of the control samples. The drying rate below the FSP was increased except the test moisture content of 70 and 30 %. It could be attributed to the limitation of the recorded experimental data. The boundary of moisture content of the test group with moisture content of 70 and 30 % was much lower than the control group. Tab. 1 indicated that, as expected, micro-explosion pretreatment speeded up the wood drying process, especially the drying rate above FSP.

Tab. 1: Drying rates of the treated and untreated samples above and below FSP at specific moisture content.

Moisture content	90 %		70 %		50 %		40 %		30 %	
	T	C	T	C	T	C	T	C	T	C
Drying rate above FSP (%/h)	10.50	6.57	6.44	5.55	8.73	5.17	10.24	4.89	10.04	4.73
Drying rate bellow FSP (%/h)	0.65	0.48	0.46	0.55	0.94	0.51	0.91	0.53	0.48	0.54

T: test group, C: control group.

To depict the effect of micro-explosion intuitively, the drying rate of the test and control group below and above the FSP is graphed in Fig. 2.

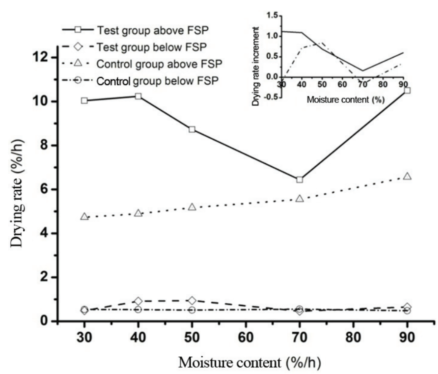

Fig. 2: Drying rates of the treated and untreated samples above and below FSP: The curves in the little graph is the increment of the drying rate at each test moisture content.

The curve in Fig. 2 indicates that micro-explosion treatment was of little sense to the drying rate under the FSP, except the increase about 70-85 % at the moisture content of 40 and 50 %. The raise can be attributed to the micro-explosion. Compared to the drying rate below the FSP, the increase of the drying rate above FSP was more notable. Although the drying rate above FSP of micro-explosion treated samples was not along with the increasing path of the control group, the drying rates at each test moisture contents were larger than the control ones. The trend of the drying rate increment of micro-explosion pretreated wood above and below the FSP is of similar tendency, going down followed by a small rise with the increase of the test moisture content. The difference is the front increase of the increment below the FSP. The trend of the increase of drying rates indicated that the effects of micro-explosion treatment were in connection with the moisture content. The drying rates both above and below the FSP was praised for the treated condition with the moisture content of 40 and 50 %. The improvement could be attributed to the accelerated travel rate of moisture inside the wood, which was of significant influence of the channel of the moisture movement. All these transformations were come from the effects of micro-explosion to the micro-structure of the treated samples.

Micro-structural changes

The micro-structural changes resulting from micro-explosion pretreatment can express the origin of the increase in drying rate of the test samples. Fig. 3 shows the structure of poplar wood that did and did not received micro-explosion pretreatment.

As is shown in Fig. 3, significant differences of the microstructure between the two groups can be observed. The pit membranes of the treated poplar samples were fractured. Fractures, of 0 to 4.36 μm width and 0 to pit diameter which is about 8 μm long, in these connective channels are favorable for increasing drying rate (Haghi 2003). Micro-explosion amplified the channels of the internal moisture significantly, thus increasing the permeability of the treated lumbers (Torgovnikov and Vinden 2010). The mobility of moisture inside the treated wood was increased because of the increasing permeability, caused by these voids.

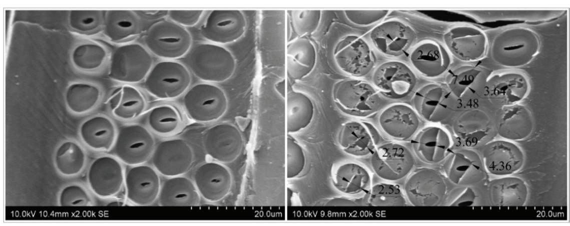

Fig. 3: SEM photographs of micro-explosion treated (right) and untreated (left) poplar samples.

Moisture was removed through the big and the tiny capillary system. The SEM photographs showed the expansion of the big capillary system of the micro-explosion treated samples. The difference of growth in drying rates may be related to the fractures on cell wall. When the wood was at high moisture content, the volume of free water diminished the cell cavity, which determined the size of high pressured air and may also be occupied the channel of the pressured air. However, it is not the unique factor. The tenacity of cell wall may also be different at different moisture content. Therefore, the increase of drying rate was caused by many factors.

Effective water diffusion

The increased drying rate of the pretreated group can also be characterized in terms of effective water diffusion enabled by micro-explosion, which improved the ability of the water to escape the wood (Salinas et al. 2013). Effective water diffusion in wood below the FSP can be calculated according to the following equations (Eqs. 2-4):

$$MR = \frac{M - Me}{M_0 - Me} = A\exp(-kt) \tag{2}$$

$$\frac{dMR}{dt} = -k(M - Me) \tag{3}$$

$$De = KL^2 / \pi^2 \tag{4}$$

where: *MR* - non-dimensional moisture content (%);
M - moisture content at time (%);
Me - equilibrium moisture content (%);
M_0 - initial moisture content at time (%);
k - the drying rate constant (s^{-1});
t - the drying time (hr);
De - the effective diffusion coefficient of water ($m^2 \cdot s^{-1}$),
L - the thickness of the specimen (m) (He et al. 2013).

As is shown in Fig. 4, the effective water diffusion coefficient of wood below the FSP of the pretreated group was greater than that of the control group, which meant the faster moisture migration efficiency.

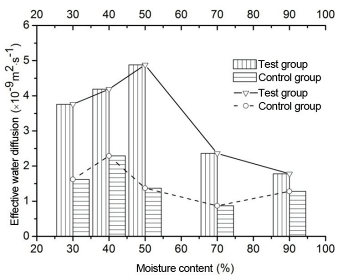

Fig. 4: The effective diffusion coefficient (De) of water in wood below the FSP.

The effective water diffusion coefficient, along with the change of the drying moisture content, is with similar trend both the test and the control group. Compared to the control group, the trend of the effective water diffusion coefficient of the micro-explosion pretreated samples is more obvious and simple, an up followed by a down. The different tendency of the test and the control groups is at the 40 to 50 and 70 to 90 %. The results demonstrated that the application of micro-explosion was beneficial to improve the effective water diffusion, and then reduce the drying time, especially at the moisture content of 30, 40 and 50 %.

CONCLUSIONS

1. The drying rates of the micro-explosion pretreated samples were faster than the control ones, especially above FSP. The drying rate below the FSP was increased inconspicuously, and even decreased at the test moisture content of 70 and 30 %.
2. The fractures on the pit membranes of the pretreated poplar samples were the origin of the improvement of the drying rate of the micro-explosion treated samples, and the fractures was about 0 to 4.36 μm wide and 0 to pit diameter long which is about 8 μm.

3. The effective water diffusion coefficient of the test group below the FSP was greater than that of the control group, especially at the moisture content of 30, 40 and 50 %.
4. The micro-explosion can be considered as an effective treatment to improve the drying rate and then reduce the energy consumption.

ACKNOWLEDGMENTS

This research was supported by the Special Fund for Forest Scientific Research in the Public Welfare (201404502).

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