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Effects of Heat Treatment on Some Physical Properties of Douglas Fir (Pseudotsuga Menziesii) Wood

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Abstract. In this study the effect of heat treatment on some physical properties of Douglas fir (Pseudotsuga menziesii) was investigated. Wood specimens were subjected to heat treatment at 160, 180, 200 and 220℃ for 1, 2, 3 and 4h. The results show that heat treatment resulted in a darkened color, decreased moisture performance and increased dimensional stability of wood. Compared with untreated wood, equilibrium moisture content (EMC), water absorption (WA) and volume swelling (VS) for treated wood decrease up to 42.63%, 34.93% and 67.47%. The higher the treatment temperature and the longer the treatment time, the lower EMC, WA and VS. The VS of treated specimens has a more significant reduction than EMC and WA when the heat treatment temperature is above 180℃. The visual color changes were more distinct after heat treatment above 180℃. Temperature has a greater influence than time on these properties of specimens.

Introduction

Faced with increasing environmental pressure, worldwide wood manufactures started to gradually decrease the amount chemicals used in wood treatment and are looking for alternative ways of wood modification. The heat treatment of wood at high temperature, as a wood modification method, seems to be an eco-friendly and viable alternative.

During the heat-treatment, a large number of chemical changes occur, including the esterification of hydroxyl groups and the reduction in hemi-cellulose and the number of accessible OH group within wood[1-2]. As a result, heat treatment can serve to improve the natural quality and properties of the wood such as dimensional stability and resistance to bio-corrosion and equip the wood material with new properties[3-5]. However, heat treatment generally causes a apparent decrease in wood mechanical properties due to the material loses in cell wall, hemicellulose degradation and the modification of long chain molecules[6-7].

Most of earlier experiments show that heat treatment reduces the equilibrium moisture content (EMC) and thickness swelling, and slows down water absorption (WA) and wettability of wood[8-9]. However, Kortelainen et al.[10] reported that heat treatment actually increased the WA of pine sapwood heat-treated at 170, 190, 210℃. The effect of heat treatment on the modification of mass transfer properties in poplar wood (***P. robusta***) was investigated by Rousset et al[11]. It was noticed that heat treatment significantly reduced the ability of bound water to migrate through the wood sample due to the chemical modification of the cell wall, but the permeability value did not change significantly. In the color change studies, most researches show that heat treatment at high temperature induced extensive darkening and reddening of wood [12-13].

Light color Douglas fir (***Pseudotsuga menziesii***) which contains a large amount of resin and gum causing poor permeability is the main wood species for industrial-scale use in the world. Improving the characteristics of Douglas fir through heat treatment would offer the timber product industry many interesting opportunities. To our knowledge, there is no information about the influence of heat treatment on physical properties, such as color, EMC, WA and dimensional stability of Douglas fir. The target in this research was to determine how heat treatment affects these physical properties of Douglas fir wood.

Material and Methods

Wood samples measuring 200 mm (length) ×90 mm (width) ×20 mm (thickness) were prepared form the same Douglas fir (Pseudotsuga menziesii) timber with the dimension of 4000 mm (length) × 100 mm (width) ×25 mm (thickness). In total, 17 samples including 1 untreated control samples were prepared. Prior to the treatments, all wood samples were numbered and conditioned in a humidity room at relative humidity 60% and temperature 26℃for 2 weeks. After that, heat treatment was performed at four controlled temperatures (160, 180, 200 and 220 ℃) for four durations (1, 2, 3 and 4h) under steam and atmospheric pressure in a laboratory oven which provided 16 different treatment conditions. All heat-treated samples were planed in order to eliminate the effect of resin overflowing to wood surface during heat treatment on the measurement of moisture performance and dimensional stability.

Four small specimens measuring 40 mm (length) ×50 mm (width) ×16 mm (thickness) were cut from each sample for moisture performance and dimensional stability testing. All treated and untreated samples were placed in an oven at 103±2℃ for 48 h to obtain the oven-dried mass and dimensions. All samples were equilibrated in a humidity room at temperature 26℃ and high relative humidity (RH=90%) for 30 days and their weight and dimensions were measured. Finally, the specimens were placed in a water tank. The weight and dimension of wood specimens were measured after they were submerged separately and horizontally under 25 mm of water with stainless steel mesh under and on the specimens for 7 days. Based on the testing data of mass and dimension for samples under different conditions, the moisture content (MC) and volume swelling (VS) can be calculated as an index of moisture performance and dimensional stability properties according to the formula below:

$$\boldsymbol{MC}(\%) = \frac{\boldsymbol{W} - \boldsymbol{W}_0}{\boldsymbol{W}_0} \times 100 \quad (1)$$

$$\boldsymbol{VS}(\%) = \frac{\boldsymbol{V} - \boldsymbol{V}_0}{\boldsymbol{V}_0} \times 100 \quad (2)$$

where $\boldsymbol{W}$ and $\boldsymbol{V}$ are the weight and volume of specimens under different conditions, $\boldsymbol{W}_0$ and $\boldsymbol{V}_0$ are the weight and volume of oven-dried specimens.

Results and Discussion

Fig.1 shows the change in visual color of Douglas fir wood treated at different temperature and duration levels. The color of samples become darker and more attractive with increased temperature and duration, and the color changes is drastic after heat treatment above 180℃. Temperature seems to

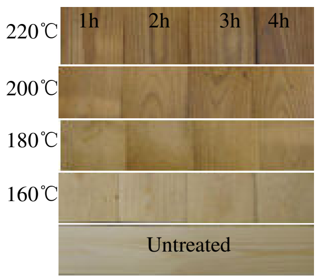

Fig.1 The color comparison of thermal treated and control samples

have a greater influence than time on color change of samples. The result is almost the same as previously reported[14]. The color changes in treated wood are probably caused by the formation of colored degradation products of hemicelluloses and extractives, especially pentosan. In addition, the formation of oxidation products such as quinones is also referred as the reason for color change of wood during heat treatment[15-16]. Another interesting finding is that the darkening of the treated samples occurred evenly throughout the wood and not only on the surface when duration is above 1 hour. In species with pale colored wood which are usually considered less appellative, the darkening would be an important advantage of the heat treatment giving the wood a “tropical flavor” that is valued in many countries.

The effect of heat treatment on EMC of wood at high humidity condition is shown in Fig. 2. Each column represents the average values of 4 replicate samples. From the figure, it can be found that heat treated wood has an evident lower EMC than the untreated wood. The higher the treatment temperature and the longer the treatment time, the lower the EMC, with temperature having a greater influence than time on the EMC of wood. The results clearly indicate that heat treatment can significantly decrease moisture adsorption in wood, higher temperature with longer duration cause the lower hygroscopic property of wood. The previous study showed that the heat treatment strongly affected the chemical composition and structure. During heat treatment, the content of hemicellulose, which is relatively easy to hydrolyse at elevated temperature, significantly decreases with increased exposure duration and temperature. The crystallinity content of wood can be increased due to crystallization in quansicrystalline region in wood cellulose and even in hemicelluloses[17]. In addition, the esterification of hydroxyl groups and cross-linking reactions occurs during heat treatment of wood. Based on the combined effect of above factors, the OH groups available for moisture adsorption are significantly reduced by the heat treatment, which in turn decreases the hygroscopicity and EMC of wood. In all of the above factors, the decrease in hemicellulose content of wood is usually believed the main factor to decrease the hygroscopicity of wood. Compared with the untreated samples, the average EMC of treated wood can be decreased by 5.34 to 42.63%.

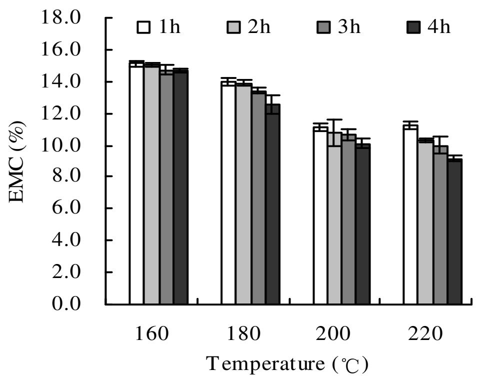

Fig.2 EMC of heat treated samples
The EMC of untreated samples is
16.0% at the same condition.

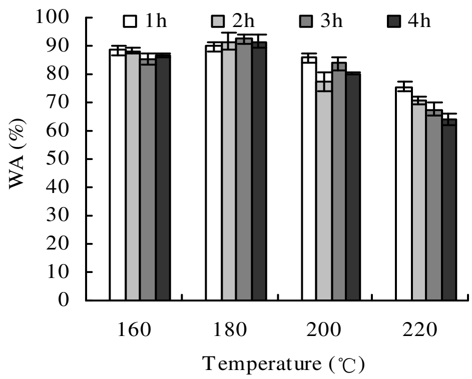

Fig.3 WA of heat treated samples.
The WA of untreated samples is
98.7% at the same condition

The WA of the specimens during immersion tests is shown in Fig. 3. Heat treated wood shows decreased WA compared with untreated wood. In general, the WA of heat treatment specimens decreases as the temperature increased, with the exception that specimens heat treated at 180℃ shows a little higher WA than specimens heat treated at 160℃. The effect of treatment time on WA is not significant when the temperature is below 200℃. A increase in treatment time tends to decrease WA of wood heat treated above 200℃. Compared with untreated wood, the average WA of treated specimens can be decreased by 6.33 to 34.93%. In the hygroscopic ranges, the moisture content of specimens is dominated by the number of hydrophilic sites in wood, especially hydroxyl groups of carbohydrate. However, WA after immersion is mainly determined by the permeability of wood. The main factor influencing permeability of wood is the radius and number of effective openings on pit membranes. When wood is subjected to heat treatment, lignin softens and blocks the cell pores probably decreasing the radius and number of effective openings on pit membranes[17]. This may be the main reason contributing to the reduction in water absorption of heat treated wood.

VS shown in Fig.4 to Fig.5 is lower for heat treated wood compared with control specimens when equally exposed to the different conditions. In general, the VS of treated samples decrease with increased treatment time and duration. The decrease is slight for the specimens treated at 160℃ for 1-4h. Heat treatment is effective enough to decrease the VS of specimens above 180℃. Compared with the untreated wood, the average VS of treated specimens can be decreased by 2.86 to 61.01% and 4.29 to 67.47% when the wood samples were placed in a humidity room with a relative humidity of 90% for 30 days or submerged in water for 7 days. The decrease in VS of heat treatment wood is attributed to a decrease in moisture performance. It is also a very interesting finding that treated specimens have a more significant reduction in VS compared to moisture performance when the heat treatment temperature is above 180℃. The reason may be that an amount of resin and gum in the resin cavities of Douglas fir wood is decomposed and volatilized during high temperature heat treatment, and forms some new valid void to adsorb moisture and hold free water. So, the new voids formed in resin cavities within specimens partly counteract the effect of heat treatment on moisture performance of wood.

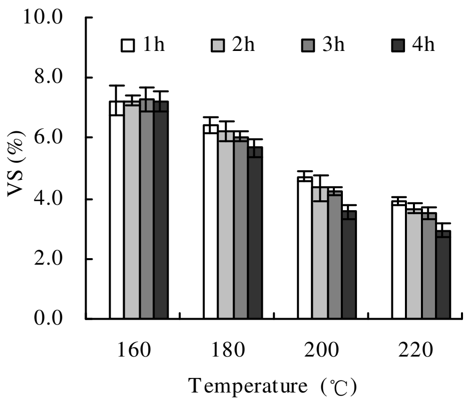

Fig.4 VS of heat treated samples. The VS of untreated samples is 7.5% at the same condition

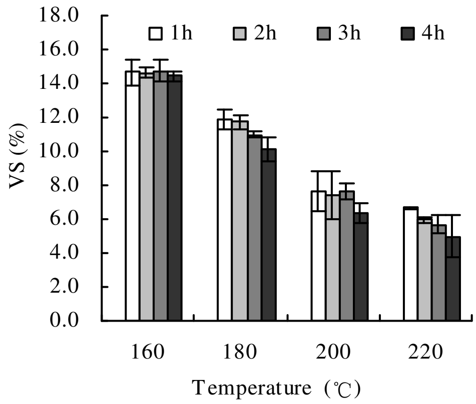

Fig.5 VS of heat treated samples. The VS of untreated samples is 15.3% at the same condition

Conclusions

In this study wood samples were subjected to heat treatment at four different temperatures (160, 180, 200 and 220℃) and four different duration levels (1, 2, 3 and 4h), and the effect of heat treatment on color, moisture performance and dimensional stability was investigated. The results show that heat treatment resulted in a darkened color, decreased moisture performance and increased dimensional stability of wood. Compared with untreated wood, EMC, WA and VS for treated wood decrease up to 42.63%, 34.93% and 67.47%. The higher the treatment temperature and the longer the treatment time, the lower EMC, WA and VS. The VS of treated wood has a more significant reduction than EMC and WA when the heat treatment temperature is above 180℃. The visual color changes is drastic after heat treatment above 180℃. Temperature has a greater influence than time on these properties of specimens. Due to its more attractive darken color, decreased moisture performance and improved stability attributes, heat treated Douglas fir can be used in some areas where they had no use previously. Further studies are in progress to determine if heat treatment affects the microscopic structure, chemical composition and combustion properties of wood.

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