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EFFECTS OF THERMO-VACUUM TREATMENT ON THE ANATOMICAL STRUCTURES OF SZEMAO PINE WOOD AND ALDER BIRCH WOOD

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ABSTRACT

The anatomical structures of both untreated and thermo-vacuum treated (the temperature of 200°C, the duration of 4h and the relative pressure of -0.08 MPa) Szemao pine wood (*Pinus kesiya* var. *langbianensis*) and alder birch wood (*Betula alnoides*) were observated and analysed by light microscopy. The obtained results were as follows. (1) Szemao pine wood with thiner earlywood cell walls and thicker latewood cell walls, which was an abrupt transition from earlywood to latewood, was not susceptible to the thermo-vacuum treatment (TVT) in this test. Only smaller radial cracks were observed in the cross section, and ray parenchyma cells which they were non-lignified cells were partially destroyed. Longitudinal tracheids walls remained intact and were not destroyed. (2) No destruction was also observed except part of the scalarform perforations plates in alder birch wood under the TVT. The results indicated that effects of the TVT on the anatomical structures of woods were slight. In addition, the extractives of both szemao pine wood and alder birch wood were removed, playing an important roles in improving the permeability of wood after the TVT.

KEYWORDS: Szemao pine wood, *Pinus kesiya* var. *langbianensis*), alder birch wood (*Betula alnoides*), thermo-vacuum treatment (TVT), anatomical aspects.

INTRODUCTION

Heat treatment of wood at high temperatures from 150 to 260°C is an environment-friendly method to modify both chemical and physical properties. It can decrease amorphous polysaccharide content and remove certain extractives due to heat treatment at high temperatures (Sivonen et al. 2002, Kotilainen et al. 1999). It also can reduce hygroscopicity of the woods (Kamdem et al. 2002, Petrissans et al. 2003; Olek et al. 2013) , improve dimensional stability (Tjeerdsma et al. 1998; Boonstra et al. 2006a, Esteves et al. 2008, Gunduz et al. 2009) and biological durability (Kamdem et al. 2002; Weiland et al. 2003, Gosselink et al. 2004, Calonego et al. 2010), whereas mechanical properties simultaneously decreases (Poncsak et al. 2006; Kocaefe et al. 2007, Surini et al. 2012, Rautkari et al. 2014). Moreover, Depending on the specific heat treatment process parameters such as heat treatment temperature, heating rate, treatment duration and oxygen content, changes in the anatomical structures may happen (Welzbacher et al.2011, Poncsak et al. 2006, Kocaefe et al. 2007). Defects such as cracking (internal and/or surface cracks), collapse and deformation (bow, spring and twist) during heat treatment occurred due to changes in the anatomical structure of wood (Boonstra et al. 2006b, 2006c). These structural defects may also contribute to the high strength loss of thermally modified timber (Welzbacher et al.2011).

Wood anatomical structures may change significantly with the synergistic effect of steam and heat during the heat treatment processes, such as Thermowood process, Plato process or oil heat treatment process (Welzbacher et al. 201, Boonstra et al. 2006b, 2006c, Yang et al. 2010, Huang et al. 2012, Jiang 2013). Due to thermo-vacuum treatment process without oxygen or little oxygen, almost no oxidation reaction in wood occurred. In addition, since the water boiling point decreases under vacuum conditions, water evaporation occurs at lower temperature, leading to less water in wood participating the hydrolysis of chemical composition. Less weight loss and strength loss occured under the vacuum conditions (Srinivas et al. 2012, Allegretti et al. 2012, Wang 2012).

Despite the enormous work about the effects of heat treatment on wood properties was done, very little has been done about the anatomical changes (Awoyemi et al. 2011). Though the changes of anatomical structures during the heat treatment process were less than those of chemical degradation, it was another reason for changes in wood properties, especially in mechanical properties (Awoyemi et al. 2011). In this paper, the effects of TVT under the relative pressure of -0.08 MPa, with temperature of 200°C and treatment time of 4 h on the anatomical property of both szemao pine wood and alder birch wood were investigated by means of light microscopy, aiming to explore the explainations for the effects of TVT on mechanical properties of woods from the wood anatomy in the future work.

MATERIALS AND METHOD

Materials

The szemao pine logs were collected from Munaihe forest in Cuiyun District, Puer City, Yunnan Province, China in April 2007. Five Szemao pine logs were about 35 years old with the breast height diameter (BHD) of 22 cm or so and the height of 16 m or so. The alder birch logs were obtained from Jinghan Town, Longchuan County, Dehong City, Yunnan Province, China, in December 2008. The average height and BHD of these trees were 10 meters and 20-25 cm, respectively. All boards were performed into a size of 150 (length-axial direction) × 50 (width-tangential direction) × 20 mm (thickness-radical direction) with be free of cracks, decay, knots and other obvious defects before high-temperature heat treatment. The air drying moisture content of wood samples was about 10 %.

TVT process

Heat treatment was carried out at 200°C under the relative pressure of -0.08 MPa for 4 hours in a vacuum treatment chamber (Shanghai Yiheng DZF-6210). Ten replicates were conducted at the treatment condition. Heat-treatment time was counted from the time point when the wood surface layer reached the target temperature. After reaching the target treatment times, heating power was turned off and the samples were cooled toward to room temperature. Vacuum chamber was released and the samples were removed from the vacuum treatment chamber.

Light microscopy

Small blocks with the size of 10×10×10mm were cut from the treated and untreated boards and boiled in water carefully for approximately 5 hours in order to soften the wood. Three sections of the cross section, tangential section and radial section of wood were respectively cut for microscopy with a microtome (Laika, SM2000R). In the slicing process, blades should be sharp to reduce damage to the section. If possible, the thicknesses of three sections were no more than 15 µm. The anatomical property were analysed with a binocular microscope (Nikon, ECLIPSE 80i). Enlargements of 4x, 10x, 20x, 40x (objective) were used. All observed anatomical features of heat-treated samples should be consistent with that of untreated samples.

RESULTS AND DISCUSSIONS

TVT influence on anatomical aspects of szemao pine wood

Anatomical structures of untreated and thermo-vacuum treated szemao pine wood are illustrated in Figs. 1 to Fig. 8. It can be clearly seen from the comparable features before and after TVT that the structures of szemao pine wood appeared to be only slightly damaged by the impact of TVT. The shape of earlywood tracheids between untreated and heat-treated wood samples were still polygons and rectangles, while that of latewood tracheids were also still rectangles, squares and polygons (Figs. 1 and Fig. 2), showing that the cell wall shapes of tracheids were not destroyed. However, radial cracks were found in Fig. 2 (Position 1), which may be caused by large stresses occurring between the earlywood and latewood tracheids which were subjected to TVT. The tracheids were cleaved but the cell walls seemed to be still intact. Tracheids around the resin canal were still obvious after heat treatment. No damage of these parenchymatic and epithelial cells was observed, but extractives deposited in the resin canal before TVT (Fig. 1 (Position 1)), while disappeared after TVT (Fig. 2 (Position 2, 3 and 4)). The result was in good agreement with the previous research (Huang et al. 2012, Inari et al. 2006). The removal of extractives is important to improve the permeability of wood. No deformations of longitudinal tracheids of both earlywood walls and latewood walls were found (Fig. 3 (Position 1)) in heat-treated sample, appearring to be undamaged and remaining to be as straight and intact as untreated sample (Fig. 4 (Position 1)). The ray parenchyma cells with thinner cell wall, which were non-lignified cells, seemed to be severely affected after TVT (Fig. 5 (Position 1) and Fig. 6 (Position 1)) compared to untreated sample (Fig. 7 (Position 1) and Fig. 8 (Position 1)), but no damages were observed in ray tracheids with thicker cell wall which were lignified cells, and ray tracheids were still intact (Fig. 5 (Position 2)). Fig. 3 (Position 2) and Fig. 4 (Position 2) showed the micrographs of bordered pits of longitudinal tracheids in untreated and heat-treated szemao pine wood, illustrating that TVT did not cause damage to the bordered pits. As a whole, anatomical structural changes which were subjected to TVT were slighter than that which were subjected to the medium of hot oil with temperature of 200oC (Rautkari 2014). Under the conditions of temperature of 200oC in the medium of hot oil, more radial cracks were observed. Though no damages was found in ray tracheids, more serious in ray parenchyma cell wall were found. In addition, longitudinal tracheids of earlywood walls were also more seriously deformed and curved.

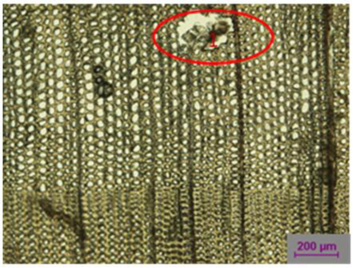

Fig. 1: Extractives deposited in the resin canal in untreated szemao pine wood sample (cross section, 10x.).

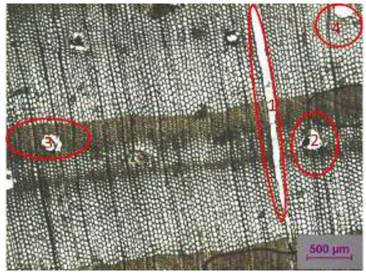

Fig. 2: The radial cracks occurred and extractives disappeared in heat-treated szemao pine wood sample (cross section, 4x).

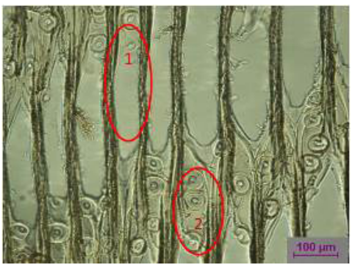

Fig. 3: Longitudinal tracheids remained to be straight and intact in heat-treated szemao pine wood sample (radial section, 20x).

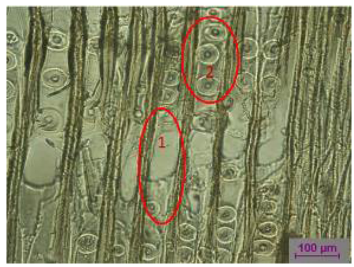

Fig. 4: Longitudinal tracheids was straight and intact in untreated szemao pine wood sample (radial section, 20x).

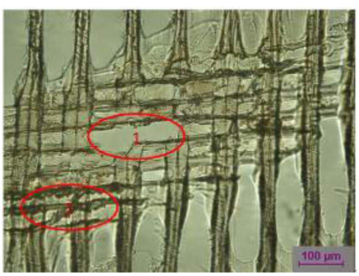

Fig. 5: Part of ray parenchyma cells appeared to be damaged, but ray tracheids remained to be intact in heat-treated szemao pine wood sample (radial section, 20x).

Fig. 6: Part of ray parenchyma cells,appeared to be damaged in heat-treated szemao pine wood sample (tangential section, 10x).

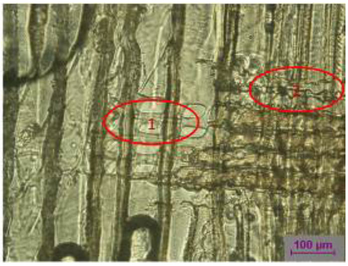

Fig. 7: No damages both ray parenchyma cells and ray tracheids were observed in untreated szemao pine wood sample (radial section, 20x).

Fig. 8: No damages both ray parenchyma cells and ray tracheids were observed in untreated szemao pine wood sample (tangential section, 10x)

TVT influence on anatomical aspects of alder birch wood

Figs. 9 - 16 presents the anatomical structures of alder birch wood before and after TVT. Neither radial cracks nor tangential cracks was found in transverse cross section. In transverse cross section, the shape of vessels between untreated and heat-treated wood samples were still rotundities and ovals with no deformation (Fig. 9 (Position 1) and Fig. 10 (Position 1)). Not only no collapse in the vessels but also in the fibres and ray parenchyma cells was observed. They were still obviously intact after TVT, indicating that anatomical structures was almost not affected during TVT. Part of destructions were observed in scalariform perforation plate of the vessel cell wall after TVT (Fig. 11 (Position 1), Fig. 12 (Position 1) and Fig. 13 (Position 1)). This may be attributed to the lower pressure of the wood surface compared to the internal wood in the vacuum champer, leading to a pressure difference between inside and outside of the wood. When the pressure in the scalariform perforations plate was lower than that in vessel lumen, the scalariform perforations plate would be broken. This is important to improve the permeability of wood. The opposite intervessel pits and alternate intervessel pits of vessel cell walls were still intact both before and after TVT (Fig. 13 (Position 2) and Fig. 14 (Position 1)). The ray cells contained brown-red extractives before TVT (Fig. 15 (Position 1)), which were disappeared and clean open after TVT (Fig. 16 (Position 1)). This may be attributed to the partial removal of the abundant carbon-rich extractives in wood during high temperature heat treatment (Yang et al. 2010). The extractive which was situated on the cell wall would block the pits, preventing the transport of air and moisture through the pits before TVT, but improving the transport of air and moisture through the pits after TVT.

Fig. 9: The shape of vessels with rotundities and ovals in untreated alder birch wood sample (cross section, 4x).

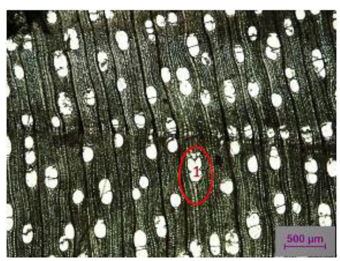

Fig. 10: Neither radial crack nor tangential crack, and neither collaps in the vessels nor in the fibres and ray cells was observed in heat-treated alder birch wood sample (cross section, 4x).

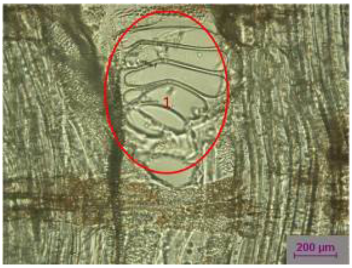

Fig. 11: The scalariform perforation plates of the vessel cell wall were intact in untreated alder birch wood sample (radial section, 10x).

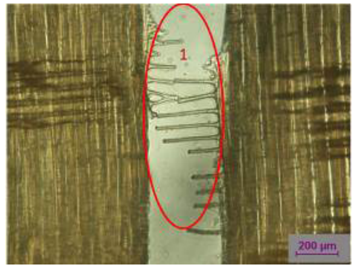

Fig. 12: Part of scalariform perforation plates of the vessel cell wall were destroyed in heat-treated alder birch wood sample (radial section, 10x).

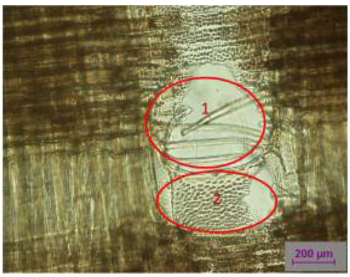

Fig. 13: Part of scalariform perforation plate of the vessel cell wall were destroyed, but the opposite intervessel pits and alternate intervessel pits of vessel cell walls were still intact in heat-treated alder birch wood sample(radial section, 10x).

Fig. 14: The opposite intervessel pits and alternate intervessel pits of vessel cell walls were intact in untreated alder birch wood sample (radial section, 10x).

Fig. 15: The ray cells contained brown-red extractives in untreated alder birch wood sample (tangential section, 10x).

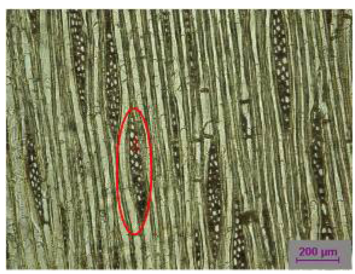

Fig. 16 Brown-red extractives in the ray cells were disappeared in heat-treated alder birch wood sample (tangential section, 10x).

On the whole, the influence of TVT on the anatomical structures of wood was slight. This was in good agreement with the previous research conducted by Wang (2012).

Usually, the influence of anatomical structures of wood differed largely according to the different subjected heating mediums. The anatomical structural changes of cell wall in jack pine (Pinus banksiana) took place under the condition of maximum temperature of 210°C using

Finland ThermoWood technology (Huang et al. 2012). The Plato process consists of two phases, the liquid full hydro thermolysis treatment and the steam hydro thermolysis treatment. In the first phase of Plato process, large tangential cracks occurred in the latewood section of Scots pine wood (*Pinus sylvestris*) and Norway spruce wood (*Picea abies*) (Boonstra et al. 2006b). And large radial cracks was found in the vicinity of the rays and collapse of the vessels of birch wood (*Betula pendula*) (Boonstra et al. 2006c). But in the second phase of Plato process, the occurrence of radial cracks and collapse of the vessels were reduced (Boonstra et al. 2006b. Boonstra et al. 2006c). Welzbacher et al. (2011) found that tangential cracks in the heat-treated Norway spruce wood still occurred, and radial cracks near the rays and deformation of vessels in heat-treated beech (*Fagus sylvatica*) were also observed, which were carried out in a drying oven at reduced oxygen content.

However, vacuum condition was adopted in this paper. Due to the processing environment of the TVT without oxygen or little oxygen, almost no oxidation reaction in wood occurred. In addition, since the water boiling point reduces under vacuum conditions, much evaporation occured at lower temperatures, leading to less water in wood participating in the hydrolysis of chemical composition. Therefore, almost no or less influences of anatomical structures occurred under the vacuum conditions.

CONCLUSIONS

The anatomical structures of both untreated and thermo-vacuum treated szemao pine wood and alder birch wood were observated by light microscopy. Almost no destruction was observed except the smaller radial cracks and ray parenchyma cells in szemao pine wood and the scalariform perforations plate in alder birch wood. This results indicated that the effect of the TVT process on the anatomical structures of woods was slight. In addition, the removals of extractives of both szemao pine wood and alder birch wood played an important roles in improving the permeability of wood after heat treatment. The anatomical structures of the wood were not greatly damaged, so it was predicted that the mechanical properties of the wood would not be largely reduced.

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