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RESEARCH ARTICLE

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Aspirated pits in wetwood and micromorphology of microbial degradation in subalpine fir

Abstract Differentiating from normal wood, pit membranes in wetwood of subalpine fir contain bacteria of water drop shape or orbicular shape, and flaky shape, as observed using Scanning Electronic Microscope. Not only are ray parenchyma cells in wetwood partially degraded but also margo strands in pit membranes are somewhat degraded by bacterial activities. Most of the bordered-pit membranes in normal wood are unaspirated in green conditions and the proportions of aspirated pits in earlywood and latewood account for only 6.8% and 13.4%, respectively. Nevertheless, most of the bordered-pit membranes in wetwood are aspirated in green conditions and the proportions of aspirated pits account for 77.7% and 72.1%, respectively. The problem of hard-to-dry for subalpine fir could be reasoned from the considerable amount of aspirated pit membranes in wetwood.

Keywoods subalpine fir, wetwood, bacteria, pit membranes, the proportions of aspirated pits

1 Introduction

Subalpine fir (*Abies lasiocarpa* [Hook] Nutt) accounts for a high portion of the timber harvested in British Columbia, Canada. The ages of trees range from 50 to 215 years. The standing trees are tall and straight, which have high recovery in timber production. However, most of the subalpine fir trees present large volumes of wetwood (wet-pocket) in its stems. Wetwood has a visible, water-soaked translucent appearance in fresh cross sections or lumber sections and located in heartwood, sapwood, and also between heartwood and sapwood. It is characterized by its extremely high moisture content with high concentrations of anaerobic bacteria. The existence of wetwood has no significant effect on living trees, which may be alive for several more years, and have no effect on wood strength. However, during kiln drying of subalpine fir lumber containing wetwood, it is hard-to-dry and more prone to collapse, develop ring shake, and deep surface checks. In order to figure out the reasons of the problem, wetwood morphology of pit membrane is studied in this research.

2 Materials and methods

Subalpine fir tree containing normal (healthy) wood and wetwood were selected in Northern BC and a disk of 5 cm thickness was cut from the subalpine fir log. Specimens were sliced into about 25 μm in the radial and tangential directions from the wet zone and the normal zone in the disk with a microtome. They were mounted on the specimen-holders. A layer of golden film (150–200Å) was sprayed onto the surfaces of the specimens in a high-vacuum chamber by a Hummer Ⅲ ion sputter coating device. Observations were carried out with a Cambridge Stereo 260 scanning electron microscope at 12–20 kV.

Following the existing method (Jiang et al., 1993), proportions of aspirated pits were observed and calculated from 200 earlywood bordered pits and 100 latewood bordered pits in normal wood and wetwood by SEM.

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3 Results and analysis

3.1 Aspirated pits and their proportions

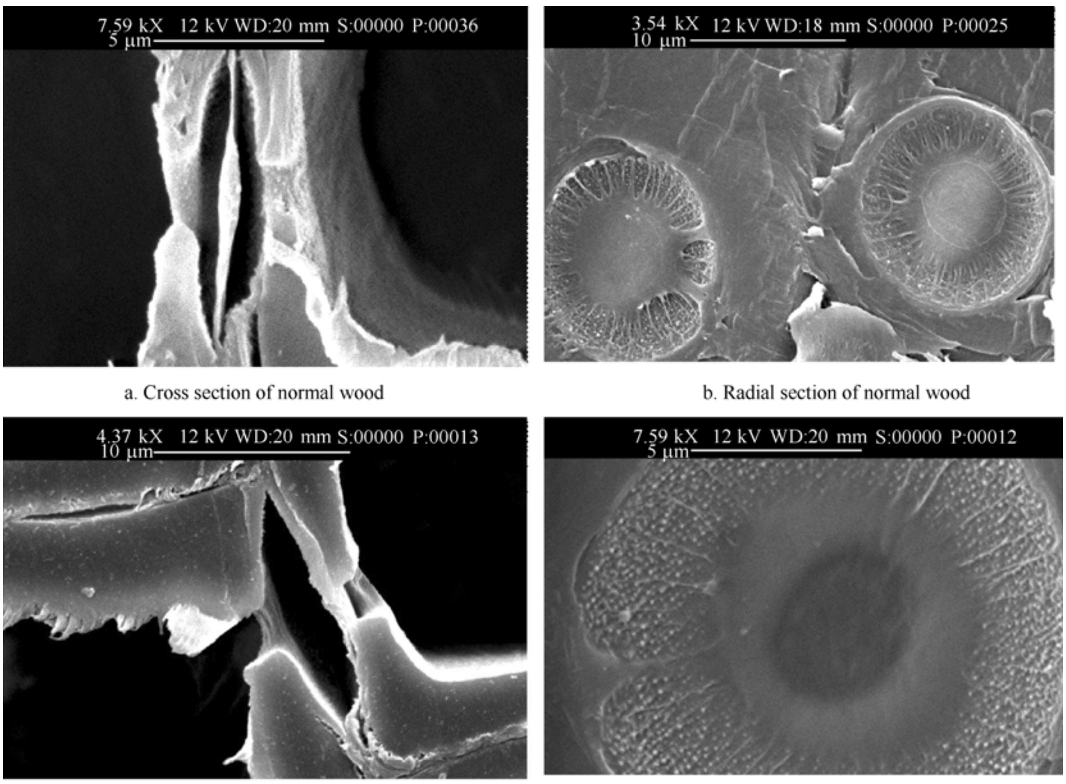
Bordered pit pair between tracheids in the cross section of normal subalpine fir earlywood is shown in Fig. 1a. The pit membrane is slightly thinner than that in latewood tracheids. The torus located in the center position of bordered pit pair is flexible. Neither are the pit borders thickened nor are the pit canals obvious. SEM (Fig. 1b) reveals that the pit membranes consist of the circular torus and the radial fibrils of margo in radial section. The pit membrane in normal earlywood has relatively wider interspaces in margo. A warty layer is obvious in the interior wall of the pit borders.

The margo is completely covered by amorphous substances. Fig. 1b also shows the unaspirated pits in normal wood. Bordered pit pairs in normal latewood have smaller diameter, longer pit canals, and thicker torus.

Figure 1c shows the latewood bordered pit pair between tracheids in the cross section of wetwood. The pit aperture was blocked because the torus was dished, drawn, and held tightly to the pit border. Thus, the pit was aspirated. There are more aspirated and encrusted pit membranes on trachied cell walls in wetwood (Fig. 1d) than those in normal wood (Fig. 1b). Figure 1d also displays that the dished torus is observable in wetwood.

The proportions of aspirated pits in normal earlywood and latewood in green conditions accounted for only 6.8% and 13.4%, respectively. Nevertheless, the proportions of aspirated pits in wetwood accounted for 77.7% and 72.1%, respectively. It indicates that most of the bordered-pit membranes in normal wood are unaspirated in green conditions while most of them in wetwood are aspirated. Similar conclusions were obtained by Schneider et al. (1989) when they observed pit membranes of wetwood in balsam fir.

Bordered pit pairs between trachieds provide important pathways for flow in subalpine fir. The flow path is controlled by pit membranes. All factors, such as pit aperture, openings in the margo, deposits on pit membranes, and departure from the central position of pit membranes, affect the flow path. Most of the water is unable to migrate from one cell to another through the margo of the pit membrane if the pit membrane shifts from its normal central position to the pit aperture and forms aspirated pits during the growth of the tree. The problem of hard-to-dry for subalpine fir could be reasoned from the considerable amounts of aspirated pit membranes in wetwood.



a. Cross section of normal wood b. Radial section of normal wood

c. Cross section of wetwood d. Radial section of wetwood

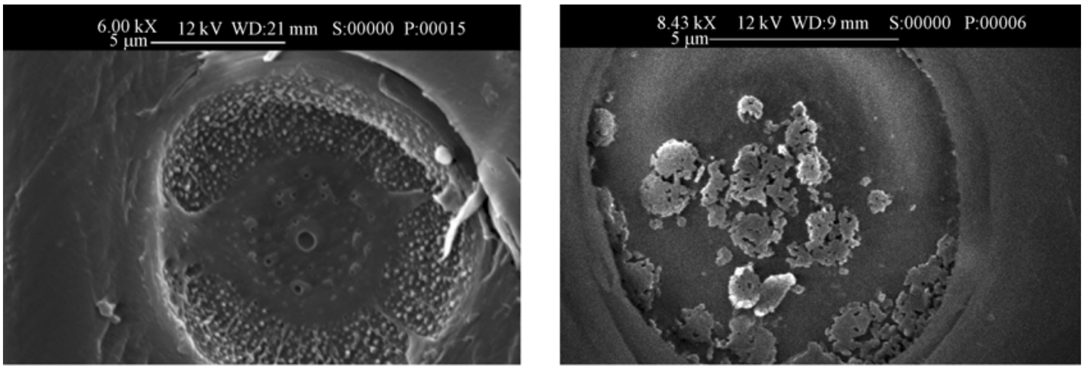
Fig. 1 Unaspirated pits in normal wood and aspirated pits in wetwood

3.2 Bacterium in wetwood and microbial degradation

Deposits, like water drop, orbicular shape, and flaky shape, were observed on the torus and membrane in wetwood (Figs.2a and 2b), but not in normal wood. Similar deposits on pit membranes were found by Ward (1986), Schneider and Zhou (1989), Eriksson et al. (1990), and Lihra et al. (2000) when they investigated pit structures in wetwood. Broken pit membranes in wetwood were not found and the characteristic of the deposits was not determined by Schneider and Zhou (1989) and Lihra et al. (2000). Schneider and Zhou (1989) pointed out that these deposits may increase permeability. Similar deposits on pit membranes, which were identified as bacteria, were reported by Ward (1986) and Eriksson et al. (1990). Sakamoto and Kato (2002) described that wetwood is always associated with bacteria. Shapes of deposits on pit membranes in wetwood are different as shown in Figs. 2a and 2b. The difference in the shape of deposits, i.e., whether it is water drop or orbicular or flaky, could be caused by the type of bacteria.

Microbial populations in wetwood are still unclear. However, the research by Schink and Ward (1984) and Jiang and Zhang (1993) indicated that the populations must contain a lot of bacterial species, which are more anaerobic and less aerobic. Part of an anaerobic bacteria can provide pectic enzymes, lead to pit membranes were degraded. Zu (2000) described that hemicellulose was degraded due to certain bacterial species that can grow in starch and saccharides in wetwood. The structure of wetwood changed correspondingly in subalpine fir and was attributed to the activity of microbial metabolism. An amount of bacteria accumulated in ray parenchyma cells in wetwood (Fig. 3a). The presence of bacteria appears to be due to decomposition of storage material in the rays. Then the ray parenchyma cells in wetwood disappeared (Fig. 3b, arrow c) and the wall of ray parenchyma cells was partially degraded by bacterial attacks.

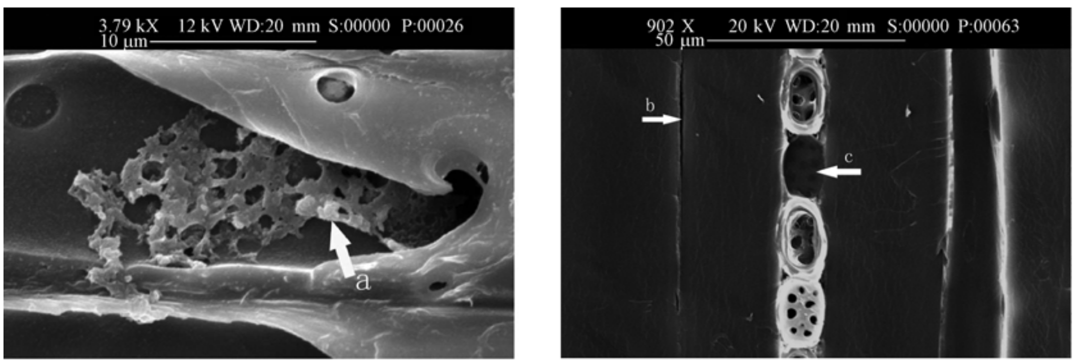
Greaves (1969, 1971) pointed out that the three major types of damages in bordered pits can be produced by bacteria. The first type occurs when the bacteria invade cells and randomly scatter over the borders, both outside and inside of the pit chamber. Many discrete pockets of lysis result, which in extreme cases may coalesce, and thus too often give rise to a complete loss of border. The second type of attack appears to be limited to aspirated pits, in which the bacteria, having failed to gain entry into the pit chamber,



a. Deposits of water drop or orbicular shapes on torus

b. Deposits of flaky shape on the pit membrane

Fig. 2 Deposits on the torus and the pit membrane in wetwood



a. Bacteria in the ray parenchyma cells

b. Missing a ray parenchyma (c) and separation in middle lamella of trachieds (b)

Fig. 3 Bacteria in the ray parenchyma cells of wetwood and micromorphology of bacterial attack on wood accumulate around the sealed aperture and decay only this area. Deaspiration can occur in this way. The third type of border attack is the result of bacteria inside the pit chamber, which have been "washed" in or have found their way towards the regain of the annulus. The small decay pockets thus formed around the circumference of borders may eventually coalesce, just as in the first type of attack, and circumcise the entire border. Loss of pit border in subalpine fir wetwood was not observed, but the first type of bordered pit damage occurred. The margo strands of the pit membrane is susceptible to bacterial enzymes. Destruction of margo somewhat resulted in part detachment of the torus (Fig. 4). Meanwhile, bacteria passed from cell to cell via the pits easily and caused a certain amount of degradation, which increased the damages in bordered pits.

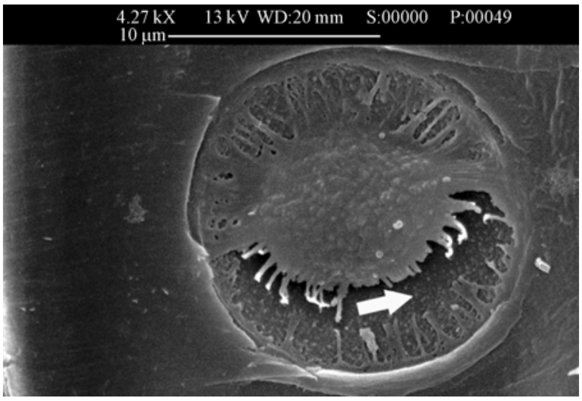


Fig. 4 Partially damaged margo strands in pit membrane by bacterial activity

Greaves (1969, 1971) reported a preferential breakdown of the middle lamella region and subsequent separation of tracheids and fibers occurred in bacteria-attacked wood. Similar results were observed as shown in Fig. 3b (arrow b). Bacteria attacked the middle lamella between cell walls; therefore separation and weakening of the bonds in middle lamella occurred.

4 Conclusions

1. Differentiating from normal wood, bacteria of water drop shape or orbicular shape, and flaky shape are observed in the pit membranes in wetwood of subalpine fir. Not only are ray parenchyma cells in wetwood partially degraded but also margo strands in pit membranes and the middle lamella between cell walls are somewhat degraded by bacterial activities.

2. Most of the bordered-pit membranes in normal wood are unaspirated in green conditions and the proportions of aspirated pits in earlywood and latewood account for only 6.8% and 13.4%, respectively. Nevertheless, most of the bordered-pit membranes in wetwood are aspirated in green conditions and the proportions of aspirated pits account for 77.7% and 72.1%, respectively.

3. The problem of hard-to-dry for subalpine fir could be reasoned from the considerable amount of aspirated pit membranes in wetwood.

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