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Wood carbonization as a protective treatment on resistance to wood destroying fungi

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ABSTRACT

Wood, as a typical natural material, is crucial to extend its service lifetime through preservative treatments against both biological and abiotic processes. Conventional wood protective treatment methods have major disadvantages by utilization of toxic chemicals. In this study, a physical treatment approach against wood biodeterioration was tested via the carbonization treatment technique. Both *Pinus sylvestris* and poplar were systematically prepared under different conditions of carbonization treatments to analyze the mechanism of carbonization protective treatment and then the performance against biodeterioration. Variations of nitrogen contents, thiamine (Vitamin B1), inorganic salts, pH, moisture content and the mass loss of wood were investigated after the different carbonization treatments. Indigenous wood decay fungi were destroyed by the carbonization treatments to decrease the opportunity for initiation of destruction from inside the wood. The results also illustrated that significant change of pH and moisture content in wood were also remarkable, but the wood nitrogen contents, thiamine (Vitamin B1) and inorganic salt were not influenced much after carbonization treatments. Since the indigenous microflora and also their favourable conditions for growth were eliminated or further restricted, further protection can be extended for the service life of wood against fungal colonization and biodeterioration under selective conditions.

1. Introduction

Wood, as a renewable resource, is in high demand in construction and building, but serious issues are often encountered under humid conditions. For example, the moisture content of wood vary with the changes of temperature and humidity of the surrounding environment, resulting in the deformation of wood products, even cracking and also susceptibility to attack by wood decay fungi. As wood is attacked by fungi or insects, biodeterioration of wood and colonization by microorganisms mainly by fungi would immediately occur to change the chemical composition in wood (Karim et al., 2016), thus dramatically shortening the service life and value of wood products (Salem et al., 2016; Schmidt et al., 2016; Yang et al., 2017). With the economic development, a large amount of wood has been exploited and consumed, leading to the big challenge to against environmental conditions and the wood colonizing microorganisms. From the point of view of sustainable development, it is indispensable to explore effective approaches for wood processing and functional improvement to against microbial colonization and degradation (Bao and Jiang, 1998; Huang and Gao, 2004).

At present, methods for wood processing and functional improvement include preservative (Arunasekera et al., 2017), e.g., chemical preservative treatment (Tiralovd and Reinprecht, 2004) and natural products treatment (Zhang et al., 2016; de Medeiros et al., 2016; Adedeji et al., 2017), dimension stability (Liu and Wang, 2004), color (Duan and Bao, 2001) and strengthen treatments (Furuno et al., 2004). Wood functional improvement is mainly based on the treatment of chemical reagents and most of them are toxic, such as copper, arsenic, chromium, and other chemical reagents. Although some chemical reagents are not toxic by themselves, they can be transformed to toxic substances after released into the environment. Chemical preservatives play a significant role in wood protection, but they pose a serious issue to ecological quality and environmental health when used. In rainy seasons, chemical preservatives can be leached out and released from wood and be carried by rainwater into soil, river and eventually coastal and oceans to cause water and sediment pollution. In order to compensate these shortcomings of chemicals used in treatment of wood, wood carbonization at high temperature has been explored to promote innovations in wood processing industry in Germany, the Netherlands, Finland, Canada and Japan.

Carbonization treatment as a protective treatment of wood is a typical pyrolysis process in which lumber is placed under high humidity

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and high temperature or hypoxia environment. The pyrolysis process can reduce the hydroxyl groups in wood components, leading to a decline in ability of wood moisture absorption and the internal stress would decrease subsequently (Bekhta and Niemz, 2003). At the same time, the pyrolysis process can degrade the hydrophilic hydroxyl groups of wood matrices, increase the hydrophobic groups, so that the dimensional stability of lumber could be highly improved. Furthermore, carbonization of wood components at high temperature significantly reduces nutrients in wood, which strongly inhibit subsequently fungal growth in wood to achieve resistance to biodeterioration performance (Yuan et al., 2009).

The well-designed process of carbonized and preservative-treated wood only involves a modification of physical and chemical properties of the wood without introducing any chemicals so that there is no harmful impact to the environment and human health. In addition, the carbonization and preservative-treated wood enhance some advantageous properties such as excellent durability, weather resistance, dimensional stability, environmental friendly (Pertti et al., 1995; Blmiyan and Hirai, 2005; Wang and Cooper, 2005). Moreover, the contents of available nutrients in wood would be reduced greatly with the optimizationing of carbonization conditions, e.g., treatment time duration and carbonization temperature. As a result, the microbial nutrients and the mass loss from wood are influenced by varying the carbonization time and temperature to eliminate microbial population and survival, and to achieve wood resistance to biodeterioration.

Theoretically, the chemical composition of wood varies after carbonization protective treatment, and the nutrients in wood can be reduced to improve the decay resistance of lumber. In this study, experiments with different treatment procedures were conducted on poplar and *Pinus sylvestris* by carbonization at temperature of 180 °C, 200 °C and 220 °C, and the carbonization time for 2, 4 and 6 h. The processing procedure was optimized subsequently according to investigations on nutrients, the pH value, moisture content and the wood decay resistance of treated poplar and *P. sylvestris* was analyzed during the carbonization protective treatments, and the relationship among nutrients, the pH value and the mass loss of wood was systematically summarized to provide a better understanding on wood resistance mechanism to biodeterioration after carbonization treatment.

2. Materials and methods

2.1. Wood samples

Samples with dimensions of 20 mm × 20 mm × 10 mm (radial × tangential × longitudinal), 20 mm × 20 mm × 20 mm (radial × tangential × longitudinal) were prepared for decay and moisture content tests in accordance to Chinese Standard GB/T 13942.1–2009 (2009c) and Chinese Standard GB/T 1931-2009 (2009b). The trees were purchased in the Hohhot of Inner Mongolia. The poplar (*Populus beijingensis* W. Y. Hsu) and *Pinus sylvestris* (*Pinus sylvestris* var. mongolica) were treated under different conditions of carbonization treatments in carbonization treatment tank. The treated poplar wood blocks were dried at 103 °C for 24 h in drying oven and prepared into wood powder of 100 mesh, 40–60 mesh by high speed pulverizer.

2.2. Fungi and culturing medium

For the fungal decay test, white and brown rot fungi *Trametes versicolor* and *Gloeophyllum trabeum*, respectively, were purchased from China Forestry Culture Collection Center for the tests.

For the potato medium, potatoes (200 g) were washed and peeled into small pieces, which were boiled in distilled water (1000 ml) for 30 min, then, decanting and filtering the mixture through cheesecloth for making potato infusion. Distilled water was added so that the total volume of the suspension liquid reached to 1000 ml, agar (18 g) and glucose (15 g) were also added into the suspension liquid. The medium was autoclaved at 121 °C and 0.1 MPa for 30 min, before the medium was cooled and poured into glass Petri dishes in the sterile inoculation room. When the potato medium was solidified, the white rot fungi and brown rot fungi were inoculated into the medium with the inoculation needle. The agar plates after inoculation were incubated in the incubator at 28 °C and 80% relative humidity (RH) for 10 d.

2.3. Analytical methods

2.3.1. Amino acids as nitrogen sources

Nitrogen source is an important nutrient for microbial growth, however, wood has very poor N to support the microbial growth, but the proteins or amino acids in wood are a rich source of nitrogen. Microorganisms can utilize proteases to break down proteins into amino acids before assimilated by microorganisms. Therefore, amino acids in wood are very good nitrogen sources for microorganisms. Concentrations of available nitrogen source on biodeterioration were investigated by analyzing the available the amino acids in wood after carbonization protective treatments. According to the Chinese Standard GB/T 18246-2000 (2000), the contents of amino acids were measured using the automated amino acids analyzer after hydrolysis.

The wood powder sample (25 mg) and hydrochloric acid (6 mol l^{-1}, 10 ml) were added into an ampoule bottle (20 ml). The hydrolysis tube (ampoule bottle) was stored in liquid nitrogen or dry ice for cooled, then, the hydrolysis tube was evacuated to 7 Pa and sealed, which was dried in drying oven (100 °C) for 23 h. The hydrolysis tube was taken out, cooled, thoroughly mixed, and opened, and the mixed solution was filtered. The filtrate was transferred into a rotary evaporator and evaporated to dryness under conditions of vacuum at 60 °C. When needed, small quantities of water were added into the filtrate and repeated the drying process for 1 to 2 times. Finally, a buffer solution of sodium citrate (4 ml, pH = 2.2) was introduced into the sample solution and then shaken and centrifuged. The supernatant was tested on the amino acid analyzer for the contents of amino acids.

2.3.2. Thiamine (vitamin B1)

Fungi in wood cannot produce Vitamin B1 by themselves (Vitamin B1 is related to microorganisms growth), but only this Vitamin B1 (thiamine) is the essential growth factor for fungi survival. Wood contains the necessary Vitamins B1 for fungal growth. When the content of Vitamins B1 decreased, fungi will not grow well. Therefore, the availability of thiamine was investigated to analyze its role after carbonization protective treatments. According to the Chinese Standard GB/T 14700-2002 (2002), the fluorescence spectrophotometer was used to evaluate the thiamine contents in wood.

The wood powder sample (5–10 g) and hydrochloric acid (0.1 mol l^{-1}, 60 ml) were transferred into a volumetric flask (100 ml) and heated by thermostatic water bath (100 °C) for 30 min. After the volumetric flask was taken out and cooled to 50 °C, an amylase solution (5 ml) was added, and the pH value of mixed solution were maintained to about 4.0. Then, the volumetric flask was placed in a constant temperature humidity chamber at 45 °C-50 °C for 3 h, afterwards, the pH value was lowered to 3.5. After taking out, the solution was diluted with distilled water to 100 ml and the solution was filtered through ash-free filter paper and was cleaned with activated artificial zeolites (1.5 g, 60–80 mesh), acetic acid solution (3%, 10 times the volume of zeolite), acidic potassium chlorate (25 ml) and adsorption column. The eluent (25 ml) was fixed by the acidic potassium chlorate, and the standard solution of Vitamins B1 (0.1 mg ml^{-1}, 25 ml) was also run through repeated purification operation. The eluent (5 ml) was transferred into reaction tube A and reaction tube B in turn, followed by sodium hydroxide solution (3 ml) and n-butanol (15 ml) in order to tube A; alkaline potassium ferricyanide solution (3 ml) and n-butanol (15 ml) tube to B. Both tube A and B were shaken for 90 s and stood for separation. The lower layer of solution was siphoned out and anhydrous

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