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Thermal Aging's Effects on the Adhesion Forces of Wood Cell Wall

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Abstract

The most significant renewable resource on Earth for industrial usage is wood, yet little is known about how biopolymers on cell walls age. In the case of wood and many other lignocellulosic materials, adhesion qualities are crucial. To investigate the adhesion force phenomenon and the effects of heat treatments, we used atomic force microscopy and defined the jump-off force ratio in the retract force-displacement curve. Here, we found two sigmoidal curves that described the change in the adhesion force and the jump-off force ratio. The first curve was assigned to the movement of extractives, while the second was related to the breakdown of the hemicellulose-lignin matrix. By examining the cell wall surface topography and performing a Fourier analysis on the treated samples, we were able to confirm the theory presented in this study.

Keywords: Wood; Adhesion; Biopolymers

Introduction

When qualities of interest undergo irreversible changes as a result of different influences over time, such as temperature, moisture, loading, UV light, or chemical solutions, the term "ageing" is used. We are interested in how temperature-related ageing factors affect the surface of wood cell walls. We research wood because to the material's growing significance as a structural component and the paucity of knowledge on in situ ageing processes. Almost every ageing process in the production and use of wood, from the creation of wood composites to the usage of wood in construction, is influenced by temperature. Heat is frequently employed to speed up the ageing processes of polymers, such as when time-temperature superposition is applied. 1., 2, 3, 4, 5, 6. Ageing affects the wood's composition.

Biopolymers including cellulose, hemicelluloses, lignin, and trace amounts of other materials like extractives make up the cellular structure of wood, which is made of biopolymers [1,2,3]. In a number of investigations, the atomic force microscope (AFM) was utilised to view the cell wall ultrastructure on transverse cross sections. 17., 18, 19, 20, 21. In several investigations, adhesion forces from force-displacement curves were used to characterise the fine structure of wood from a Nano mechanical standpoint17, 22, 23 and to determine if the adhesion forces on wood surfaces changed in response to UV radiation or heat. 24., 25, 26. 27. The adhesion force measurements' ability to be interpreted, however, is at best restricted [4]. The structural and chemical variety of natural wood surfaces, the dearth of trustworthy repositioning methods, and the limited sample numbers all contribute to this gap and make it impossible to draw findings that are statistically significant.

Materials and Method

Temperature of Treatment is Chosen

The temperature of 150°C was chosen as the ageing acceleration factor based on the literature review, 9., 10., and 11. It was anticipated that this temperature would result in measurable changes in the main chemical components of wood within a reasonable amount of time. Measurements of the characteristics of wood surfaces invariably take extractives into account. As a result, the thermal treatment was also carried out at 70°C, which caused extractives to migrate to the surface.

Treatment

Three samples were subjected to an oven treatment for AFM measurements at 150°C for a total of 6, 24, 51, 72, 144, 240, 384, and 624 hours. Three other samples received the same treatment time at 70°C. The wood samples were desiccated for at least 24 hours after each treatment to reach equilibrium (RH 10%, 21 2°C), and then their AFM properties were assessed. The wood slices were heated to 150 and 70°C for a total of 6, 72, 144, 240, 384, and 624 hours in order to perform Fourier transform infrared (FTIR) spectroscopic observations. Following each treatment, the wood samples were allowed to acclimate for 24 hours at 20°C and 50% RH before being analysed using FTIR spectroscopy. Evaluations of the adhesion force [5].

A rectangular area measuring 0.65 m x 1.3 m on the secondary cell wall was chosen from the topographical image of the cell wall that was acquired by scanning in the contact mode (256 256 pixels). The chosen area was subjected to a 256 512 pixel contact-mode scan. With 8 measurement points on each line and a total of 16 lines, the adhesion force measurements were performed in the force-volume mode. On each chosen cell wall portion, one hundred twenty-eight adhesion force curves were gathered.

Discussion

In this study, we assessed more than 8000 points on cell walls of untreated wood and more than 2000 points on each of two heat-treated cell walls, at 150 and 70°C. We carried out pairwise comparisons using the repositioning method. We think that the jump-off force ratio is defined by the force gradient in the retract force-displacement curve, which depicts the nature of the interactions between the tip and the material. We were able to quantify the AFM tip separation mechanism as a result. In the adhesion force magnitudes and jump-off force ratios, we discovered two sigmoidal curves: (1) the first curve represented the transportation and oxidation of extractives during heat treatments, and (2) the second curve represented the degradation process.

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We suggest a qualitative model to describe how cell walls age thermally as a result of high temperatures (Figure 7). The surface layer of the wood cell wall is made up of extractives, hemicellulose-lignin matrix, and cellulose aggregates from the outside in; the combination of these materials had an impact on the adhesion force magnitude and jump-off force ratio in the force-displacement curve (Figure 2). The first sigmoidal curve shows that heat treatments speed up the transport of extractives to the surface and their oxidation process; the transportation process is predominant at 70°C and the oxidation process is predominant at 150°C. A layer of amorphous hemicellulose-lignin is degraded by prolonged heating at 150°C, exposing a layer of cellulose aggregate with a parallel-lined pattern [6,7].

Conclusion

Our research demonstrates that AFM can be used to accurately determine how temperatures affect lignocellulosic materials. The main ideas are: (1) a reliable repositioning technique to reduce the spatial variability of natural materials; (2) a combined interpretation of adhesion force magnitude, jump-off force ratio, and topography; and (3) taking into account [8].

The relationship between the adhesion force and jump-off force ratio in the thermal ageing of wood surfaces can be described, according to our research, by the Boltzmann sigmoidal equation. The movement of extractives and their oxidation on the surface are described by the first sigmoidal curve of the connection between adhesion force-jump-off force ratio. The hemicellulose-lignin matrix may be degrading, as indicated by the second sigmoidal curve, which also shows that cellulose aggregates may be becoming more visible. The thermal ageing of wood cell walls and the adhesion force measurements can both be understood using the jump-off force ratio and the adhesion force magnitude. In accordance with the Graduiertenkolleg 2075, this study received a portion of its funding from the German Research Foundation (DFG). AFM and FTIR equipment was made available by the Fraunhofer Wilhelm-Klauditz-Institut. Martina's support [9,10].

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Potential Conflicts of Interest

The authors disclaim any financial conflicts of interest.

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