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Sanding vs. plasma treatment of aged wood: A comparison with respect to surface energy

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Abstract

To compare sanding and plasma treatment by dielectric barrier discharge (DBD) with respect to their effects on wood surface characteristics, beech, oak, spruce, and Oregon pine were investigated. For this purpose, the surface energy of aged, freshly sanded or plasma-treated surfaces was examined by contact angle measurement and calculation of work of adhesion. For both methods, sanding and plasma treatment, an increase in surface energy caused by a heavily increased polar part was found. Plasma treatment turned out to be superior to sanding. To see whether a combined treatment amplified this effect, a combination of sanding and plasma treatment was also investigated.

Keywords: Surface treatment by exited gases (plasma); Wood; Aging; Contact angles; Surface energy

1. Introduction

During aging of wood, hydrophobic extractives migrate to the surface and decrease the surface energy [1]. As a result, wetting of glues and coatings is adversely affected, and bonding results deteriorate. Common methods to ensure adhesion of coatings or glues on wood are, quick processing after machining (e.g., sawing or planning) to avoid the effects of aging, or the refreshing of aged surfaces by sanding. A freshly sanded wooden surface shows a distinct increase in surface energy and work of adhesion between water and wood, predominantly the polar part, compared to an aged wood surface [2]. Gindl et al. [2] and Gardner et al. [3] have found by means of X-ray photoelectron spectroscopy (XPS) data, a reduction of the oxygen/carbon (O/C) ratio on aged surfaces compared to freshly sanded surfaces, which points to a greater hydrophobicity and a reduction of the polar part of surface energy. Polymer-processing industries are using plasma treatment techniques to improve wettability and adhesion on hydrophobic polymer surfaces [4–6]. By using plasma treatment, for example, polyethylene and polyethylene terephthalate, the O/C ratio is increased by the formation of functional groups such as hydroxyls and carboxyls, which bring about an increase in surface polarity [7,8]. Several publications deal with plasma treatment of wood or wooden materials, yet no study exists where sanding and plasma treatment of wood materials are compared with respect to surface energy [9–16]. In this study, the surface energy increase due to sanding is compared with the surface energy increase due to plasma treatment with a dielectric barrier discharge at atmospheric pressure. The fundamental difference between sanding and plasma treatment is that sanding generates a new and fresh surface by removing the material, whereas plasma treatment affects primarily the chemical composition. Since both methods increase the surface energy, it might be possible that a combination of sanding and plasma treatment would lead to an additional increase in the surface energy. To see whether a combined treatment would lead to an additional increase in surface energy, freshly sanded surfaces which received a subsequent plasma treatment were also investigated. For this purpose, the surface energy of beech, oak, spruce, and Oregon pine samples was determined by contact angle measurements. It is important to note that

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the measured contact angle values are influenced, not only by surface chemistry, but also by surface topography, which is changed by sanding but not by plasma treatment and impedes comparison of the two treatments. To minimize errors and to enable comparison, all specimens were sanded prior to aging. In this way, all measured surfaces, sanded surfaces and plasma-treated surfaces, possess similar surface roughness. The surface energy of aged, freshly sanded, plasma-treated and freshly sanded + -plasma-treated samples was divided into dispersive and polar part. It should be noted that the absolute values of the surface energy data obtained should be regarded with caution because, the surface energy calculations are based on the Young's equation which assumes thermodynamic equilibrium. This condition is not fulfilled on wood surfaces because of e.g., chemical heterogeneity, roughness, and porosity. However, surface energy determination through contact angle measurement seems to be a suitable method for demonstrating and comparing the efficiency of the surface modification by sanding and by plasma treatment.

2. Materials and methods

2.1. Configuration of the plasma experiment

The samples are positioned between two insulated (fused silica) electrodes (copper) and placed onto the lower grounded electrode (Fig. 1). An alternating high-voltage pulse generator with pulse duration $t_p = 2\,\mu s$ and a frequency of $f = 17\,kHz$ is connected to the upper electrode. During plasma treatment, a voltage of $u = 34\,kV$ (peak) and a power dissipation of $P \approx 60\,W$ were measured. In this unsealed setup, ambient air at room temperature is blown through the discharge gap of $d = 2\,mm$ between the sample and the high-voltage electrode. To minimize thermal influence which could alter the surface characteristics, a treatment duration of $t_t = 2\,s$ is followed by a break of $t_b = 2\,s$. Gas temperatures $T < 40\,^{\circ}C$ as measured with a fiber-optic thermometer (Soliton FOT-L) are not likely to cause thermal damage to heat-sensitive timber surfaces [15].

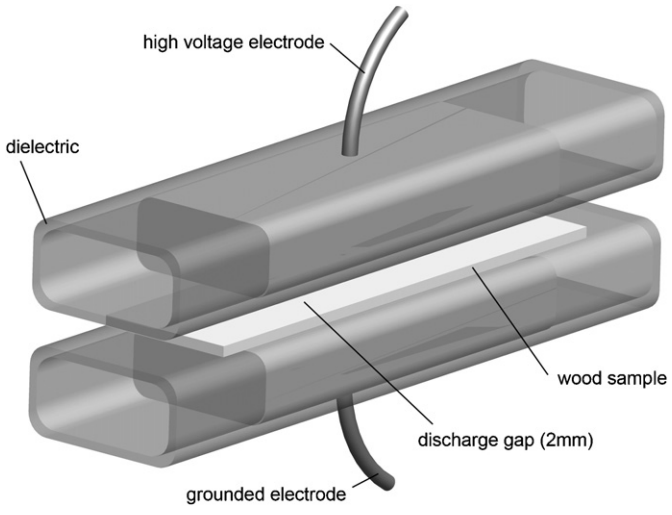

Fig. 1. Schematic sketch of the plasma experimental configuration.

2.2. Substrates

For contact angle measurement, beech (*Fagus sylvatica*), oak (*Quercus* spec.), spruce (*Picea abies*), and Oregon pine (*Pseudotsuga menziesii*) wood were sawn into samples of $60 \times 20 \times 4\,mm^3$ (radial cut), sanded with abrasive paper (P240), and stored in a climate chamber at $T = 20\,^{\circ}C$ and RH = 50% for 5 months. These aged samples were divided into four groups: aged (no further treatment), sanded (freshly sanded with P240), plasma (plasma treated for $t_t = 20\,s$) and sanded + plasma (freshly sanded with P240 and subsequently plasma treated for $t_t = 20\,s$).

2.3. Surface characterization

In recent years, surface energy determination by means of contact angle measurement has been frequently used to investigate the surface properties of wood [17–22]. These studies demonstrate that surface energy determination is an appropriate method to investigate wood surface characteristics such as wettability and adhesion properties. In this study, the geometric mean approach developed by Owens–Wendt (OW) was used to determine surface energy based on Young's equation:

$$\sigma_S = \gamma_{SL} + \sigma_L \cos\theta, \tag{1}$$

where σ_S is the total surface energy of the solid in $mN\,m^{-1}$ or $mJ\,m^{-2}$, γ_{SL} is the interfacial tension between solid and liquid, σ_L is the surface tension of the liquid, and θ is the contact angle [23]. In the OW approach, the total surface energy (σ_S) is divided into a dispersive (σ^D) or nonpolar part and a polar part (σ^P)

$$\sigma_S = \sigma^D + \sigma^P. \tag{2}$$

The interfacial tension between a solid and a liquid is evaluated by the geometric mean equation:

$$\gamma_{SL} = \sigma_S + \sigma_L - 2\left(\sqrt{\sigma_S^D \sigma_L^D} + \sqrt{\sigma_S^P \sigma_L^P}\right) \tag{3}$$

with dispersive (σ_L^D) and polar (σ_L^P) parts of liquid and dispersive (σ_S^D) and polar (σ_S^P) parts of solid. For optimum adhesion, the work of adhesion (W_{SL})

$$W_{SL} = \sigma_S + \sigma_L - \gamma_{SL} \tag{4}$$

must be maximized, which occurs if the interfacial tension (γ_{SL}) becomes zero. Good adhesion is obtained if the dispersive and polar parts of the solid and liquid phases are in the right ratios, because only dispersive–dispersive and polar–polar interactions occur. Therefore, the work of adhesion can be divided into a dispersive part and a polar part:

$$W_{SL} = W_{SL}^D + W_{SL}^P, \tag{5}$$