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INVESTIGATIONS ON THE DRYING BEHAVIOUR OF ADHESIVES ON PLASMA-TREATED WOOD MATERIALS

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ABSTRACT

In this study, the drying behaviour of a polyvinyl acetate (PVAc) adhesive and an emulsion polymer isocyanate adhesive on particle board and heat-treated beech wood in untreated and plasma-treated (by a dielectric barrier discharge at standard atmospheric pressure) state was investigated. Shear strength tests were performed to monitor the increase in bonding strength during the drying process. The results show an accelerated increase in bonding strength of PVAc-glued particle boards after plasma treatment, but no change in the drying characteristics of heat-treated beech wood was found.

KEY WORDS: drying, adhesive, heat-treated wood, particle board, plasma (dielectric barrier discharge)

INTRODUCTION

The increase in throughput and therewith an increase in productivity is an incessant ambition in industrial production. One limiting factor in the wood processing industry is the drying time of adhesives, which necessitates a specific pressing time of glued wood products before they can be processed further. A previous study investigated the effect of plasma treatment on particle boards, finding an increased surface energy (Wolkenhauer et al. 2007a). Particle boards were shown to have an almost nonpolar character in the untreated state, but after plasma treatment, a distinct increase of surface energy, primary the polar part, is apparent. This increased surface polarity increases the wetting by water, which might accelerate the hardening of water-based coating systems such as adhesives owing to the accelerated penetration of water into the bulk material (Wolkenhauer et al. 2007b). Therefore, pressing times of glued particle boards might be reduced and the throughput in industrial applications increased. Recently, several processes to modify wood by heat treatment have been developed (Militz 2008). Notwithstanding unfavourable properties, such as increased brittleness, the dimensional stability and durability of the wood is improved through heat treatment. This increased dimensional stability and durability can be ascribed to the loss of hydroxyl groups, which entails reduced hygroscopicity and increased hydrophobicity of the wood surface (Tjeerdsma and Militz 2005, Petric et al. 2007). However, reduced hygroscopicity and increased hydrophobicity entail decreased wetting and penetration of water, which generally makes the deposition of waterborne finishes more difficult (Petrissans et al. 2003) and increases drying times, respectively. Prolonged drying times of, for example, adhesives reduce throughput in industrial applications by increasing the pressing times and are thus unfavourable consequences of heat treatment. Previous studies investigated the effect of plasma treatment on heat-treated wood and showed a distinct change in surface energy characteristics and improved wetting behaviour of water (Podgorski et al. 2000, Wolkenhauer et al. 2008a). According to these results, plasma treatment might be able to partly compensate for the undesired effects of the heat treatment by promoting adhesion and drying of water-based coatings because of an increased penetration rate of water. To investigate whether plasma treatment with a dielectric barrier discharge (DBD) at standard atmospheric pressure accelerates the drying of water-based adhesives on particle board and heat-treated beech wood, untreated and plasma-treated samples were glued and tested with a shear strength test. A poly-vinyl acetate (PVAc) adhesive (D3) was used for both materials because of its practical relevance. Because heat-treated wood has excellent properties for outdoor applications, two D4 adhesives, a PVAc and an emulsion polymer isocyanate (EPI) were also tested.

MATERIAL AND METHODS

Plasma Setup

For the plasma treatment, a dielectric barrier discharge at atmospheric pressure was used. The plasma setup consists of two fused silica tubes as a dielectric, filled with a metal powder and sealed with silicone (Fig. 1). The specimens are positioned on the lower, grounded electrode so that a discharge gap of 2 mm is obtained between specimen and upper electrode, which is connected to a high-voltage generator (34-kV peak). In this unsealed setup, ambient air at atmospheric pressure is blown through the discharge gap of 2 mm between the sample and the high-voltage electrode. During plasma treatment, gas temperatures of approximately 40°C are measured. The plasma treatment duration is 60 s for particle board and 5 s for the heat-treated beech wood.

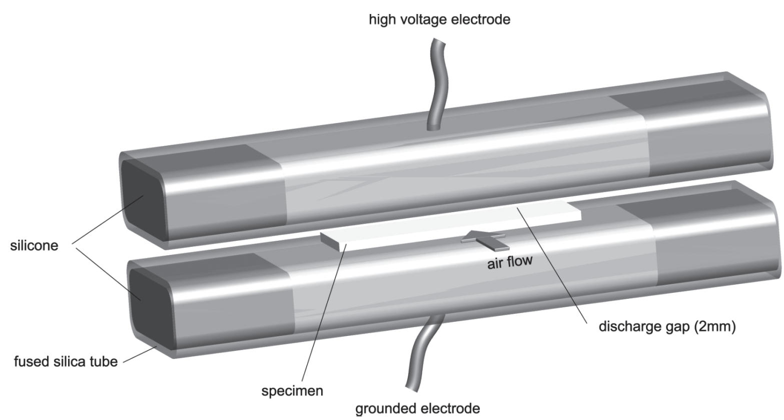

Fig. 1: Plasma setup

Material

The heat-treated beech wood was taken from a commercial process (delivered by Hagensieker, Detmold-Germany). All samples were stored for 5 days in a climate-controlled chamber at 20°C and 65% relative humidity. The heat-treated beech wood samples were planned before storage in the climate chamber. Ponal Super 3 PVAc adhesive from Henkel was used as the D3 adhesive. The same PVAc adhesive and D4 hardener from Henkel and the EPI adhesive Jowacoll 14 102.49 with hardener 195.60 from Jowat were used as the D4 adhesives for the shear strength tests.

Shear Test

Fig. 2 shows a schematic sketch of the samples for the shear test. The adhesive was applied to one side on the samples (100 × 20 × 5 mm^3) with a 20-mm overlap, so that a glued area of 400 mm^2 is obtained. After the adhesive was applied, the untreated and plasma-treated samples were pressed with a pressure of approximately 1 N/mm^2 until directly before the shear test, so that the pressing time is tantamount to the drying time. The shear tests were conducted with the tensile testing machine Zwick Z010 with a traverse speed of 20 mm/min. Each test was repeated 10 times.

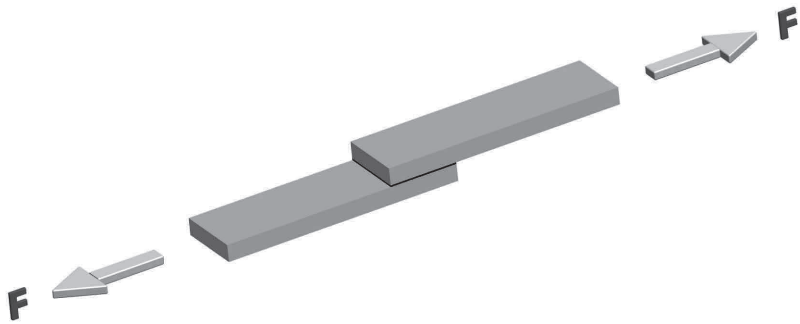

Fig. 2: Samples for the shear strength test

RESULTS AND DISCUSSION

Figs. 3–6 show the shear strength of untreated and plasma-treated samples plotted against drying time. Fig. 3 depicts the result for the particle boards with PVAc adhesive (D3) without hardener. A distinct difference in shear strength between untreated and plasma-treated particle boards is apparent. Up to 90 min, the plasma-treated samples possess a significantly higher shear strength than that of the untreated samples. After a drying time of 40 min, the plasma-treated samples show no further increase in shear strength. From this point on, the adhesive is cured so far, that a cohesive fracture within the samples occurs, and no further increase in shear strength is detectable. The untreated samples, however, do not approximate these values until 120 min of drying time.

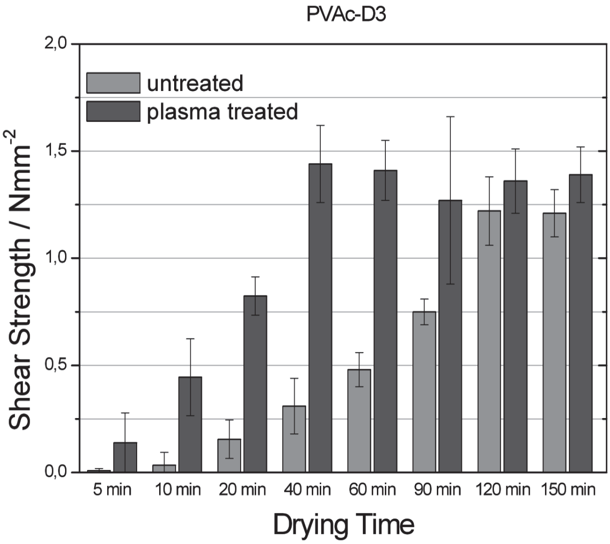

Fig. 3: Shear strength of untreated and plasma-treated particle board, glued with PVAc glue (D3), plotted against drying time. Error bars, standard deviation

The outer right bars in Figs. 4–6 represent the shear strength after 7 days of drying. At this stage, a cohesion fracture within the wood occurs, so that no conclusions about the final bonding strength or differences among untreated and plasma-treated samples can be drawn. Fig. 4 shows the result of PVAc adhesive (D3) without hardener on heat-treated beech wood. The shear strength of untreated and plasma-treated samples increases with drying time, but no distinct differences in shear strength between untreated and plasma-treated samples are observable over the course of several drying times. A similar result is obtained for the D4 PVAc adhesive mixed with hardener on heat-treated beech wood (Fig. 5). Similar to the D3 PVAc adhesive, no significant differences in shear strength are obtained, but the D4 PVAc adhesive shows a slightly faster increase in shear strength than does the D3 PVAc adhesive. Fig. 6 depicts the result for the EPI adhesive (D4) on heat-treated beech wood. As for the PVAc adhesives (D3, D4), the shear strength increases with drying time, and similar to the PVAc adhesives, no significant difference in drying behaviour after plasma treatment is detectable. Yet the EPI adhesive shows a faster increase in shear strength than that of the PVAc adhesives on heat-treated beech wood. Contrary to the results of the plasma-treated particle boards, where the drying (and consequently the increase in bonding strength of the PVAc adhesive) is accelerated, none of the three tested adhesive systems on heat-treated beech wood show significantly altered drying characteristics after plasma treatment. The results for the particle board might be attributed to a hydrophilic bulk material and a hydrophobic surface that acts as a penetration barrier by impeding wetting and penetration of water. Plasma treatment changes this hydrophobic surface into a more hydrophilic surface by increasing the surface energy (Wolkenhauer et al. 2007a). Therefore, wetting improves and the penetration rate increases, entailing faster hardening of PVAc adhesive. In contrast to particle board, where the limiting factor of the penetration rate is the hydrophobic surface, the limiting factor for the heat-treated beech wood seems to be the bulk material. Therefore, the penetration rate of the heat-treated wood is determined more by the bulk material than by the surface alone, and a plasma treatment, which affects surface characteristics, has no influence on the hardening of the tested glues. Yet this does not necessarily mean that the plasma treatment has no effect on the final bonding strength, which was shown to be increased on plasma-treated particle boards (Wolkenhauer et al. 2008b), because plasma treatment strongly affects surface characteristics such as surface energy and wetting (Wolkenhauer et al. 2008a).

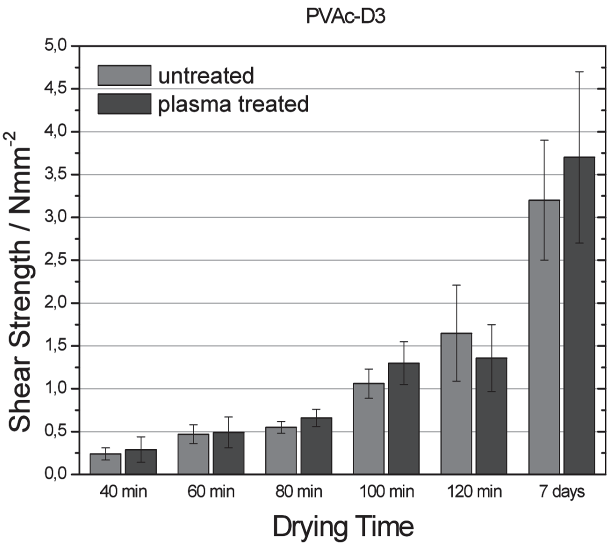

Fig. 4: Shear strength of heat-treated beech wood, untreated and plasma-treated, glued with PVAc glue (D3), plotted against drying time. Error bars, standard deviation

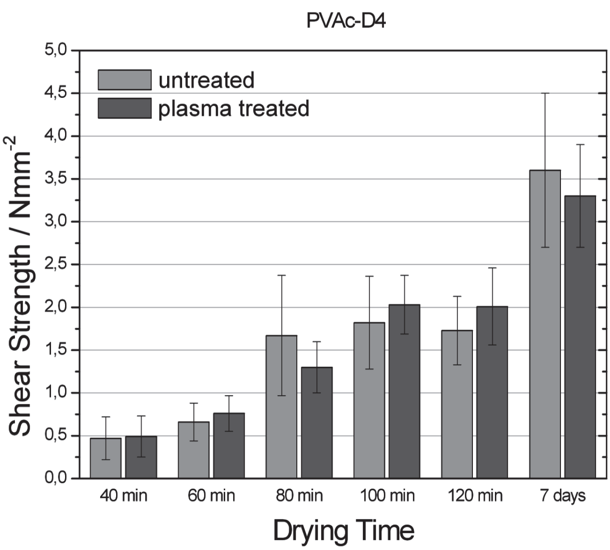

Fig. 5: Shear strength of heat-treated beech wood, untreated and plasma-treated, glued with PVAc glue (D4), plotted against drying time. Error bars, standard deviation

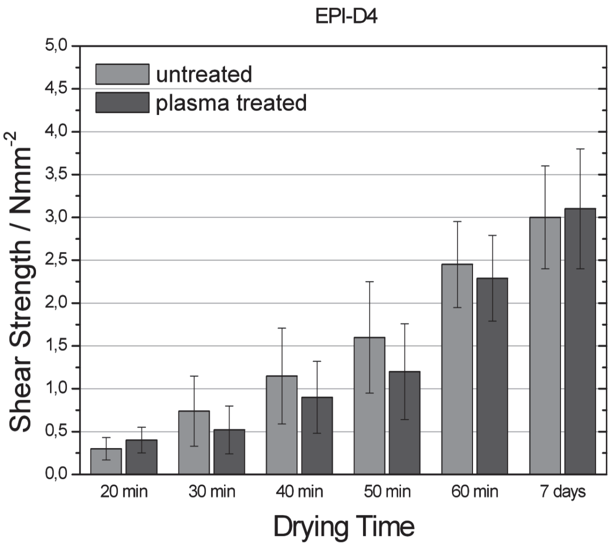

Fig. 6: Shear strength of heat-treated beech wood, untreated and plasma-treated, glued with EPI glue (D4), plotted against drying time. Error bars, standard deviation.

CONCLUSIONS

The increase in bonding strength of PVAc-glued particle board samples is considerably accelerated after plasma treatment. This result is ascribed to an increased surface energy and wettability, entailing faster penetration of water into the bulk material and hence an accelerated hardening of the adhesive. According to these results, it might be possible to reduce pressing times and increase throughput in industrial application. Despite increased surface energy and wettability of heat-treated beech wood by plasma treatment, this study found no significant effect on the drying behaviour of the tested adhesives (PVAc, EPI). This finding might be explained by the water penetration rate of the bulk material, which limits the water flow. A possible solution to increase the drying of adhesives may be reducing the water content of the adhesive. In this case, the deteriorated bonding caused by increased viscosity and decreased wetting of the adhesive may be compensated for by plasma pretreatment of the surface. Such a possibility needs to be investigated in further studies. A study is under way to evaluate whether plasma treatment of heat-treated beech wood affects final bonding strength.

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