Influence of atmospheric pressure plasma on wood surfaces

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Abstract

- Plasma treatment has been used lately in order to alter some wood surface properties, such as surface energy, wettability, water repellence or coating adhesion. Among the various designs of plasma reactors, atmospheric reactors present the advantages that they operate at very low cost and they can treat samples very rapidly. Such reactors could be transferred to industry at very low cost, allowing the development of a new generation of wood products.

- In the present study, the influence of several plasma gases on sugar maple (*Acer saccharum*) and black spruce (*Epicea mariana*) was evaluated by contact angle analysis and coating pull-off tests. According to experimental results, it turned out that the wettability of maple can be highly influenced by plasma gas and exposure time. Following plasma treatment, coating adhesion was improved for both species. Repetition of contact angle measurements after 1 and 2 weeks revealed that the effect of atmospheric plasma on wood surfaces is not permanent. It is important to highlight the effect of normal pressure air plasma on maple, which possibly leads to the development of industrial plasma reactors at atmospheric pressure for wood industry.
Introduction

• Thus in this talk we will present new research on adhesion of coatings on wood. It is possible to enhance this adhesion with plasma treatments, which could be termed a ‘nanocoating’. As follows, effect depends critically on what kind of gas is used and on which kind of wood... Thus wood is not an ideal substrate for coatings and its performance with regards to the coating can be enhanced, not necessarily with plasma.
Presentation plan

• Introduction
• Introduction to adhesion testing of coatings
• Plasma Treatments
• Adhesion measurements on treated wood
• Surface energies
• A bit of spectroscopy
• Conclusions
With time the paint will be attacked by UV light and weathering: could this be slowed down by better adhesion?
Paint adhesion

STRUCTURE DE BOIS RÉSINEUX
Figure 1: Schematic view of dielectric barrier atmospheric pressure linear plasma source used.
Plasma Unit
Figure shows difference between a nontreated and treated surface with low pressure plasma (other work, H₂O-based). The surface is not degraded-burned. This was done at UBC by group of professor P. Evans.
Plasma Treatment Conditions

- Dielectric discharge type,
- 9 kHz Frequency,
- Peak-to-Peak 30 kV,
- Gases: O$_2$, CO$_2$, N$_2$, Ar,
- Gas Volume: 50 L/min
- Speed of movable belt conveyor: 1.5 cm/s
Plasma Treatments- coatings

Plasma treated surface was coated with a Polyurethane –acrylate paint, UV curing type. Thus dried paint was cured with UV, emitted with strong UVA (53 j/m²) source: it is a free-radical polymerisation, very fast (seconds).

Adhesion is measured, by gluing with epoxy, aluminium Stubs on painted surface and measuring adhesion strength Following ASTM D4541-02; stubs are broken away from surface.

For each value, in following data, 28 measurements were done.
Wood surface after plasma treatment (Maple)
Adhesion on Maple
relative values to those of the untreated wood (sanded F Busnel)

Figure 4: Mechanical properties of interface between wood and waterbone polyurethane acrylate coating according to plasma treatment for sugar maple

Sugar Maple
Load cell = 5 kN
Tensile speed = 7 mm.min⁻¹
Adhesion on Black Spruce

values relative to those of the untreated wood

Figure 3: Mechanical properties of interface between wood and waterbone polyurethane acrylate coating according to plasma treatment for black spruce

Conclusion: effect is very dependent on nature of wood and gases used, it is not only an elimination of extractives /water on the surface. We have not measured other coatings...
Wetting

- Measurement of contact angle with water were done, before and after treatment, at t=0 and as a function of time, over hours. For some treatments, contact angle was high, which means a highly hydrophobic surface and there was little drift with time. If contact angle is low, the drift is high due to water sorption.
- These values also decrease with time, over days; that is, if treated samples are stored for days and contact angle measurement is repeated; which means part of the effect is not permanent, thus plasma may create reactive moieties on surface which are unstable, such as, maybe, free radicals.
- It is possible also the increased quality of wetting makes the paint penetrate farther into the wood... Confocal studies would confirm that...
Contact angles (water)

Figure 2: Camera view of sessile drop according to wood fiber direction.
Best wetting conditions

Formation of hydrophobic surfaces, with best conditions at 15% O₂ in N₂+O₂.
Maple wettability

Wettability with water for sugar maple

Contact angle (degrees)

Time (s)
Stability of air plasma treatments on Sugar Maple, evaluated by contact angle analysis. C. Anghel)
$\gamma_D$ remains fairly constant after plasma treatment in N$_2$/O$_2$ plasmas.
- Increase of $\gamma_P$ with the addition of O$_2$ due to surface re-oxidation.
Plasma characterization

![Graph showing plasma characteristics with varying oxygen percentages and wavelength intensity.]

- Intensity (arb. units)
- Wavelength (nm)
- NO($\text{A}^2\Sigma^+ - \text{X}^2\Pi$)
- N$_2$ second positive system
- 0% O$_2$, 25%, 50%, 75%, 98%, 100%
XPS et FTIR for Maple after treatment with $\text{N}_2/\text{O}_2$
- No N incorporation was detected by XPS and FTIR (consistent with low % dissociation).
- “Homogenization” of C-H bonds after plasma treatment.
- Decrease of the O-to-C ratio in pure N₂ plasmas and surface re-oxidation with O₂ addition.
Conclusion

Thus treatment of wood which made surface more hydrophobic gave best adhesion even though paint was ‘water-based’. We do not know to what extent it is due to better wetting, molecular adhesion (covalent bonds) or extractive elimination. This may have industrial applications.
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