High-Performance Envelopes for Wood.

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ABSTRACT

Wood can be coated with a clear finish, stained or painted to provide protection from water and ultra violet energy. In this case the coating and wood are two different phases that coexist. Another approach is to provide protection by “coating” **in** the surface not on the surface. Such an approach is referred to as an envelop rather than a coating. This can be done in several ways including cold plasma surface functionalization, monomer-polymer surface impregnation, surface chemical modification, combination of polymer-chemical modification, high temperature surface chemical conversions, nano whiskers in surface polymers, control release of chemicals when needed, self-cleaning envelopes, surface densification, inorganic surface envelopes (such as aluminum), modified veneers over junk, and finishes that are in the surface not on the surface

INTRODUCTION

Many view coatings on wood as a surface layer of either a colored paint or a clear coating. Paints are used to change the color of the wood, to protect the wood from ultraviolet radiation and to provide a certain degree of water repellency. A clear coating is used to enhance the beauty of the wood and also to provide a degree of water repellency. In both of these cases, there is a visible film on the surface of the wood.

Figure 1 – Coating failure on wood.

There is another approach to protecting the surface of wood. When you write a letter, you place it in an envelope to protect the letter against what ever it will encounter in transit. Looking to protect wood using the idea of envelops provides a much wider array of new technologies that can be developed to protect the surface of wood in an outdoor environment. For example: 1. cold plasma surface functionalization, 2. monomer-polymer surface impregnation, 3. surface chemical modification, 4.

combination of polymer-chemical modification, 5. high temperature surface chemical conversions, 6. nano whiskers in surface polymers, 7. control release of chemicals when needed, 8. self-cleaning envelopes, 9. surface densification, 10. inorganic surface envelopes (such as aluminum), 11. modified veneers over junk, and 12. finishes that are in the surface not on the surface.

ENVELOPE TECHNOLOGIES

1. Cold plasma surface functionalization

Cold plasmas are produced in matter with low energy contents; the degrees of ionization are small, the atomic and molecular charged and neutral species have low energies while the electrons have relatively high energies. These electrical discharges are non equilibrium plasmas and, owing to the low energy levels of the species composing the plasma, they alone are suitable for modifying organic matter (Denes et al. 2005).

Cold plasma surface functionalization can be done under high vacuum or at atmospheric pressure. The objective is to activate the wood surface and react it with a chemical that penetrate the outer few microns of the wood. The resulting chemically modified surface can be tailored for water repellency, UV protection, color change or fire retardancy. Figure 1 shows southern pine control and one that has been treated with an oil and then plasma treated to anchor the oil in the outer surface.

Figure 1 – Southern pine control (left) and plasma treated (right).

Figure 2 – Drop of water on a plasma treated surface.

Figure 2 shows a drop of water on the plasma treated surface providing a high level of water repellency to the wood. The plasma layer is less than 10 µm into the wood surface.

2. Monomer-polymer surface impregnation

Another approach to a in-surface treatment is to impregnate the wood with a monomer that will polymerize. The monomer is only allowed to penetrate a few millimeters into the wood surface and then heated to form a stable polymer in the outer surface. Figure 3 shows a control and acrylic monomer-polymer treatment in the surface of wood used for furniture and flowering. The large vessels of the oak are filled with the polymer providing a high level of water repellency to the wood. This type of treatment also greatly improves hardness and strength (Ibach and Ellis 2005).

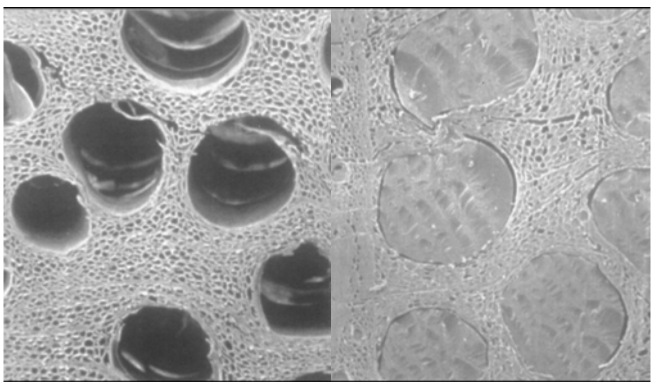

Figure 3 – Oak control (left) and polymer filled (right).

3. Surface chemical modification

Properties of the surface of wood can be modified by reacting simple chemicals with the cell wall polymers. Water repellency, dimensional stability and biological resistance can be greatly improved by reacting the surface with acetic anhydride. The reaction chemistry is shown below (Rowell 2005).

WOOD-OH + $CH_3C(=O)$-O-C(=O)-CH_3 → WOOD-O-C(=O)-CH_3 + $CH_3C(=O)$-OH

Acetic Anhydride — Acetylated Wood — Acetic Acid

There is only a slight color change in the modified wood. In most cases, light woods come out slightly darker and dark woods come out slightly lighter. The surface is still porous and can be stained or oiled if desired.

4. Combination of polymer-chemical modification

If the surface of wood is first acetylated and then impregnated with an acrylic monomer and polymerized, a hard, water repellent and UV resistant surface results. Figure 4 shows a graph of pine that has been acetylated, treated with methyl methacrylate, and acetylated followed by impregnation with methyl methacrylate Feist et al. 1991). Acetylation or acrylic impregnation alone give some degree of UV resistance but the combination results in a very high degree of UV stability as shown in the reduced weight loss due to accelerated weathing in a weatherometer.

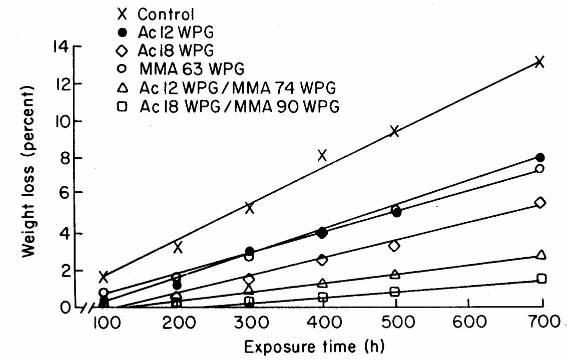

Figure 4 – Control, acetylated, methyl methacrylate treated, and acetylated plus methyl methacrylate treated pine.

The increase in UV protection of the duel treated specimens is probably due to the acrylic polymer acting as binder after the lignin is degraded by the UV energy.

5. High temperature surface chemical conversions

It has long been known that heating wood greatly increases its water repellency and resistance to biological attack. The treatment of wood with heat has been done by one of several methods. In the present case, the surface of the wood would be contacted by a metal plate heated to a high temperature. Heating wood at high temperatures causes the wood to undergo pyrolysis converting some of the hemicelluloses and cellulose sugars to furan resins and some of the wood substance to charcoal like material (Rowell et al. 2002). Removing the moisture sensitive hemicelluloses reduces the moisture sorption and increases dimensional stability. Resistance to biological attack is also improved. The process is done quickly so only the surface is modified.

Figure 5 – Heat treated wood showing a darkening and slight cell wall shrinkage.

6. Nano whiskers in surface polymers

It is possible to isolate nano-crystalline cellulose and use its strength and properties to improve the surface layers of wood. Bacterial cellulose has been isolated by Yano (2004) and used as a reinforcing fiber matrix in polymers that can penetrate the surface layers of wood. Figure 6 shows a scanning electron microscope image of bacterial cellulose.

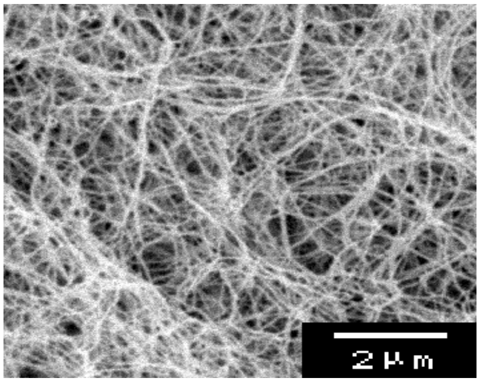

Figure 6 – SEM of bacterial cellulose.

When the refractive index of the bacterial cellulose is matched with that of a polymer such as an acrylic or an epoxy, the resulting composite becomes clear. Before this polymer impregnated micro-crystalline cellulose film is cured, it can be pressed partially onto and into the surface of wood. Figure 7 shows the polymer impregnated nano-cellulose film and a wood veneer that has had the film impregnated in and on a wood surface. The wood surface is very hard and water repellent.

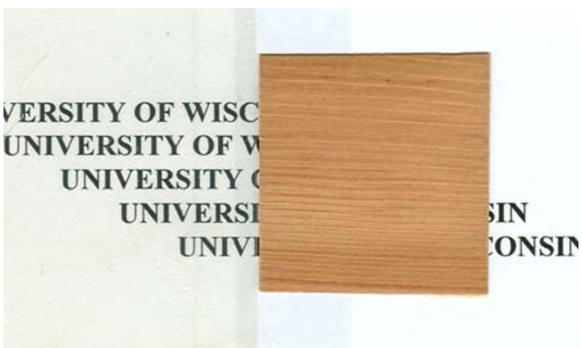

Figure 7 – Clear nano-cellulose impregnated polymer composite film (left) and the impregnation of this polymer composite into the surface of a wood veneer (right).

7. Control release of chemicals for self healing envelopes

It is possible to form micro-capsules that contain chemicals that can partially penetrate the wood surface. The micro-capsules can be composed of a moisture sensitive polymer that will release, for example, a water repellent when the capsule becomes wet. The capsules can also contain an antifungal chemical that is released when the capsules become wet. It is also possible for the capsules to contain a reactive monomer that will rebuild lost strength.

It is also possible to use a hydrolyzing polymer network that is impregnated into the surface that releases desired chemicals when the polymer gets wet.

It is also possible to use micro encapsulation that contain the desired chemistry to change the surface chemistry when the wood gets wet or attacked by microorganisms.

8. Self-cleaning and self-detecting envelops

It is well known that the lotus leaf cleans itself. The surface of the lotus leaf consists of nano-fibrils that do not allow dust and other surface contaminates to stick to the surface when a drop of water runs down the leaf (Figure 8). The simple mechanism

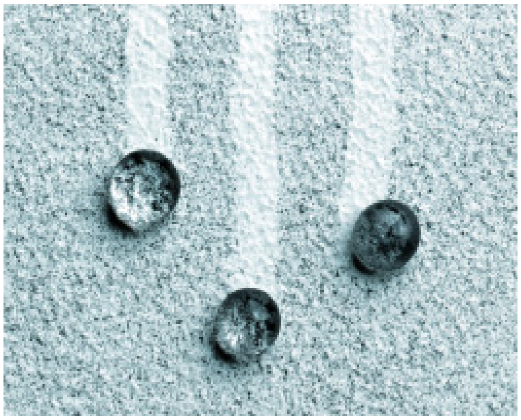

Figure 8 – Drops of water on a self-cleaning surface (The lotus effect).

of this effect is shown in Figure 9. The contaminate is displaced from the surface of the leaf to the water. This same principal has been demonstrated on a wood surface and can be used to clean a contaminated wood surface envelop.

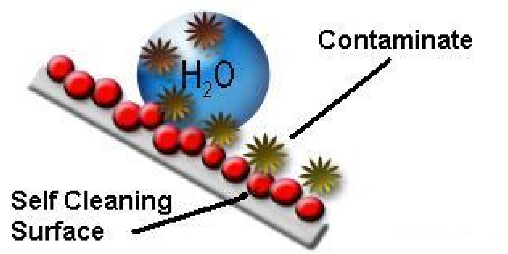

Figure 9 – Contaminate on the wood surface removed by a self cleaning surface.

Quantum dots can be inserted onto or into the surface to detect different types of invaders. The quantum dots can detect moisture, stress, various chemicals and many other factors. While these dots are very expensive, they can provide a gateway to information on changes in surface chemistry and that can lead to systems of self correction.

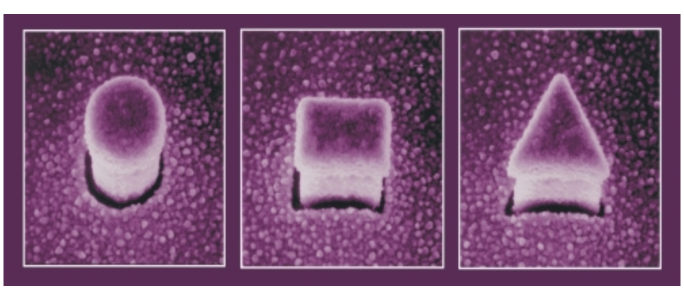

Figure 10 - Quantum Dots – Self Detecting envelopes

9. Surface densification

The surface layers of wood can be densified by first softening the outer layers with steam or microwaves, followed by compression and drying (Inoue et al. 1993). The compressed surface has a much higher density and is much harder and stabilized. Figure 11 shows normal wood surface layer cells and the same cells after compression.

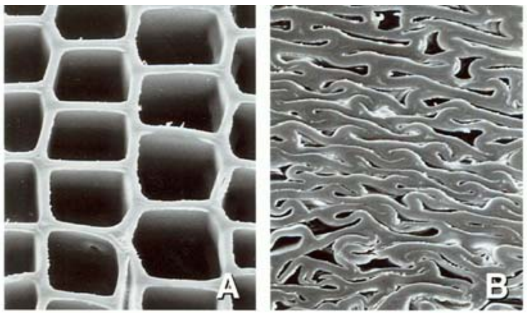

Figure 11 – Normal wood surface layer cells (A) and the same cells compressed (B).

This process is reversible, however, and if the surface gets wet, the surface layers will swell back to almost their normal thickness.

10. Inorganic surfaces

It is possible to sputter a metal onto the surface of wood that is reflective to UV energy and water repellent. Figure 12 shows a normal fiberboard surface and one that has had aluminum sputtered on it using plasma. The aluminum layer is very thin and not continuous but the metallic surface does not allow water to penetrate. Other metals can also be used in this process depending on the surface chemistry desired.

Figure 12 – Normal fiberboard surface (left) same fiberboard surface sputtered with aluminum (right).

11. Modified veneers over junk

One of the oldest approaches to a nice surface covering a not-so-nice core is the process of veneering. In the case in point, the veneer carries all of the surface chemistry desired and it is then placed on the material used in the core. The process would be to produce the value-added veneer in advance and then place it on the surface of what ever core material is provided. This allows a lot of technology to be put into a very thin exterior shell without a lot of added cost to the bulk of the composite.

Figure 13 – Property enhanced surface veneer over low value core.

12. Finishes that are in the surface not on the surface

A thin veneer or the top layer of a wood surface can be impregnated with a polymer that provides a high level of water repellency.. It can also provide a biological shield preventing attack by molds and fungi. The polymer is in contact with the cell wall polymers as well as filling voids so the surface becomes semi-transparent as seen in Figure 14. The properties of the impregnating polymer will determine the properties of the combined wood-polymer surface. Hardness, toughness, color, water repellency and other properties can be built into this system.

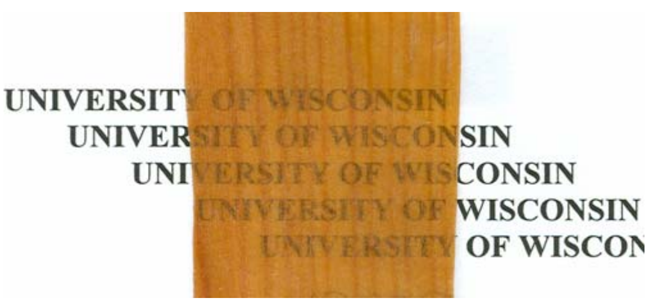

Figure 14 – Wood veneer impregnated with a polymer that results in a semi-transparent veneer.

CONCLUSIONS

This paper presented a new approach to the protection and performance improvements of a wood surface. The idea is to approach this technology by providing coatings that are in the surface not on it. The envelop approach attempts to stabilize and interact with the wood surface chemistry. The added chemistry becomes part of a new wood surface that is designed to provide the properties and protection desired. The question is, what do you want the surface to do and what technology is needed to get you there? From the wisdom of Pogo: WE ARE SURROUNDED BY INSURMOUNTABLE OPPORTUNITIES

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