Application Report

Free surface energy of pressure-impregnated wood

Application report: AR263e
Industry: Building Materials
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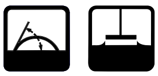
Date: December 2008

Drop Shape Analyzer – DSA100

Force Tensiometer – K100

Methods:


Keywords: surface free energy, wood, contact angle, interfacial tension, weathering

No chance for wetness!

Surface science for optimal wood protection

Abstract

About 80 years ago Dr. Karl Wolman developed the pressure impregnation method for preserving wood. Thanks to this technique the active agents penetrate the wood deeply and uniformly, which gives it long-term protection against wood pests and fungal infection and makes it fit for outdoor use. Pressure-treated wood is on the market in different classes based on the amount of active agent absorbed per cubic meter; this determines the field of use for the wood depending on ambient conditions such as soil contact or wetness.

In order to protect the wood surface against weathering the pressure-treated wood is frequently additionally coated – hundreds of products for final treatment are currently on the market. Our Application Department cooperates with various manufacturers to investigate the influence of the pressure-impregnation and active agent content on the long-term stability of such a coating. The determination of the interfacial tensions in the coating, water and wood triangle provides useful information.

Treated wood leaving a pressure container (photo: Dr. Wolman GmbH)

Problem

By studying weathering influences one of our customers found that when his oil-based wood lacquer (Coating A in the following text) was used on ACQ[1] pressure-impregnated wood it was apparently inferior to the product of one of his competitors (Coating B) – particularly when the wood had a low ACQ content. Although the customer had a relatively high share of the market for intensively treated shipbuilding wood, he lagged behind his competitor is the far larger market for house construction wood. Investigations of the surface and interfacial tensions of the participating components should determine the reasons for this.

1 "Alkaline Copper Quat"; an aqueous mixture of an alkaline copper complex and a quaternary ammonium compound

The wood samples were selected according to an English classification for pressure-impregnated wood (pine) based on the active agent content in kg/m^3:

Active agent content	*Field of application*
4.0 kg/m^3	Above-ground use
6.4 kg/m^3	Soil contact
9.6 kg/m^3	Permanent wood foundations
40.0 kg/m^3	Salt water contact

For long-term weather protection of the wood surface two quantities are of primary importance: the contact angle of water on the coating and the interfacial tension ("IFT" in the text) between the coating and the wood. The first indicates how the wood is wetted by the water – a large contact angle indicates a good water-repellant effect. The latter, in a comparison of the IFT between water and uncoated wood, describes the tendency to phase exchange, i.e. to breaking adhesion between the coating and wood by water contact. The ratio of the two IFTs (coating/wood and water/wood) expresses whether and to what extent the bond between coating and wood is thermodynamically favored in comparison to the breakage of this bond by water. This relationship is explained in detail in Application Note AN232 [1].

Measurements and results

Contact angle on coated wood

Poor wettability with water, i.e. the formation of a large contact angle, is essential for the long-term stability of a coating.

Water contact angles on the coated wood samples were measured with the DSA100. A full week was allowed to elapse between coating application and measurement; this means that the coatings were fully hardened.

Active agent content	*Water contact angle*	
	with Coating A	*with Coating B*
0.0 kg/m^3	106.5°	101.1°
4.0 kg/m^3	106.3°	101.2°
6.4 kg/m^3	106.9°	101.6°
9.6 kg/m^3	107.4°	101.4°
40.0 kg/m^3	107.1°	101.9°

In comparison to Coating B, Coating A formed a contact angle that was 5° to 6° larger. However, both coatings lay above the limiting wetting value of 90°, so that both could be regarded as being non-wettable. This means that the degree of pressure impregnation has no apparent effect on the short-term water-repellent effect of a coating.

This also means that the knowledge of the wettability is not enough to evaluate the quality of a coating. In order to determine how stable a coating bond is against wetness, additional observations of the surface and interfacial free energies must be included.

Determining the surface free energies and tensions

We first determined the surface free energies of wood sample strips for each of the four treatment classes as well as untreated pinewood. On the outside of the strips we determined the surface free energy with a DSA100 from KRÜSS using the sessile drop method with water and ethylene glycol as the test liquids. We took care that the drops formed a stable contact angle after the contact time without being significantly absorbed by the sample. Our criterion was that 98% of the initial volume still had to be visible. The calculation for this forms part of the DSA software. The following contact angles (means values for 10 drops) were measured for the untreated wood samples:

Active agent content	*Contact angle on outer surface*	
	Water	*Ethylene glycol*
0.0 kg/m^3	73.1°	42.8°
4.0 kg/m^3	75.1°	46.0°
6.4 kg/m^3	76.2°	47.7°
9.6 kg/m^3	77.5°	55.4°
40.0 kg/m^3	82.7°	60.3°

According to the Fowkes theory, the following values for the surface free energy of the wood samples were calculated from this contact angle data (see [2]):

Active agent content	*Total surface free energy (mJ/m^2)*	*Polar fraction (mJ/m^2)*	*Disperse fraction (mJ/m^2)*	*Surface polarity (%)*
0.0 kg/m^3	39.56	6.58	32.98	16.63
4.0 kg/m^3	38.17	5.93	32.24	15.54
6.4 kg/m^3	37.42	5.58	31.84	14.91
9.6 kg/m^3	36.37	5.26	31.11	14.46
40.0 kg/m^3	32.42	4.01	28.41	12.37

As can be seen, the total surface free energy and the polarity of the uncoated wood surfaces decrease as the active agent content increases.

The total surface tensions of the liquid products A and B were determined with a Tensiometer K100 from KRÜSS using the Wilhelmy plate method. The contact angles of the two coatings were also measured on PTFE. The following data represent the mean values of 5 measurements:

	Surface tension (mN/m)	*Contact angle on PTFE*
Coating A	34.24	68.6°
Coating B	36.19	73.6°

Using this as a basis, the polar and disperse fractions of the surface tension were calculated according to Fowkes (see TN306 [2]):

Active agent content	*Total surface free energy (mJ/m^2)*	*Polar fraction (mJ/m^2)*	*Disperse fraction (mJ/m^2)*	*Surface polarity (%)*
Coating A	34.24	3.91	30.33	11.41
Coating B	36.19	6.28	29.91	17.35

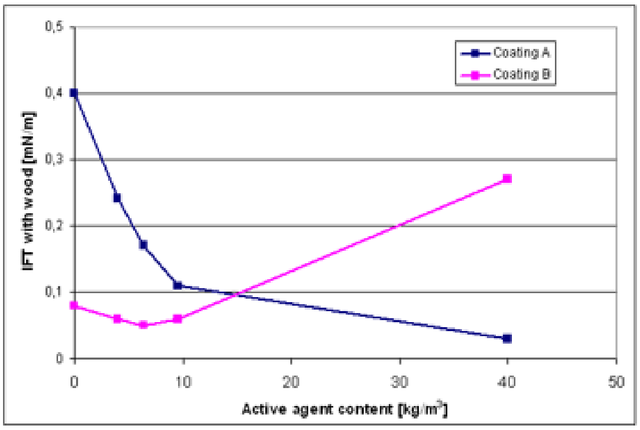
It can be seen that the surface polarity of Coating B is larger and that of Coating A is smaller than the surface polarity of all wood samples. Accordingly the compatibility of Coating A becomes better as the active agent content increases; i.e. the expected IFT (see below) will decrease. For Coating B the IFT will increase as the active agent content increases, i.e. the coating becomes less compatible with the wood surface. This estimation is confirmed below by the calculation of the interfacial tension according to Fowkes.

Calculation and interpretation of the interfacial tension

The IFT expresses the tension that remains after the adhesive contact between the coating and the surface. For long-term bonding this value should be as small as possible. For many applications values below 1 mN/m are acceptable for long-term adhesion; values above this mean that in the long term instable bonding can be expected. The IFT values calculated according to Fowkes for the two coating wood samples are compared below:

Active agent content	*IFT with Coating A (mN/m)*	*IFT with Coating B (mN/m)*	*IFT with water (mN/m)*
0.0 kg/m^3	0.40	0.08	18.40
4.0 kg/m^3	0.24	0.05	19.45
6.4 kg/m^3	0.17	0.05	20.05
9.6 kg/m^3	0.11	0.06	20.61
40.0 kg/m^3	0.03	0.27	23.17

For Coating A the IFT decreases as the active agent content increases, this is associated with the low surface polarity of the coating. The opposite is the case with the very polar liquid water, as the polarity of the wood surface decreases as the active agent content increases.



Coating B shows the smallest IFT for the lowest active agent content, as the surface polarity of this coating and wood has similar values at 4.0 and 6.4 kg/m^3. Measured against the guideline value of 1 mN/m it appears that both coatings are suitable for all treatment classes.

However, more stringent criteria apply for coating applications in very rough, moist surroundings: the IFT between substrate and coating should be at the most one hundredth of the IFT between the substrate and water (surrounding moisture and rain). Only then the risk that the bond can be broken by weather influences can be clearly reduced.

Active agent content	*Ratio between IFS water/wood and Coating A/wood*	*Ratio between IFS water/wood and Coating B/wood*
0.0 kg/m^3	45.8	234.5
4.0 kg/m^3	81.2	399.8
6.4 kg/m^3	120.1	395.1
9.6 kg/m^3	195.6	362.4
40.0 kg/m^3	720.2	85.0

The limit of 100 is undercut by Coating A for untreated and slightly treated wood; for Coating B it is clearly exceeded throughout almost the whole range; the ratio IFT water to IFT Coating is two to five times higher for Coating B than for Coating A. Only for shipbuilding wood with the highest active agent content is Coating A more efficient (by a factor of about 8) than Coating B; in this case the value for Coating B is below the limit of 100. The findings of the weathering tests clearly correlate with the interfacial tension data.

On the basis of these results our customer developed a coating with a higher surface polarity in order to increase his share of the market for less intensively treated wood.

Summary

We studied the surface properties of five wood samples with different degrees of pressure treatment (impregnation with wood protection agents). We found that as the active agent content of the wood increases, the surface free energy and polarity decrease. We then determined the surface tension and its components for two oil-based wood protection lacquers and used classical theories to calculate the IFT between the coating and the wood. It was found that the results of the IFT calculations correlated well with the differences in quality found in weathering tests and the differing suitability of the coatings for various wood qualities.

Future prospects

Up till now only the surface free energy aspects of the quality of the coating and wood have been considered. However, wood is porous, and it is known that the penetration of the coating into the wood influences its working life. We are currently investigating the surface free energy of the inner pores of various types of wood.

Literature

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