Pretreatments of Wood to Enhance the Performance of Outdoor Coatings

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Summary: The wet adhesion of water borne acrylic dispersions is a crucial factor on the performance of outdoor coatings on wood. Pine sapwood was treated with several methods for surface activation to increase the wet adhesion of water borne acrylic dispersions. The wet adhesion was measured by pull-off tests as well as with a modified cross-cut test. Atmospheric plasma, corona treatment and fluorination increased the wet adhesion of the coating which is attributed to the increasing polar portion of the surface free energy. Other ways of improving the wet adhesion are the addition of promotors, the use of primers and organisational improvements.

Keywords: coatings, wood; adhesion; dispersions; cold plasma

Introduction

The performance of outdoor coatings on wood is strongly influenced by the presence of liquid water that penetrates the substrate and the interface wood – coating. Changing moisture levels cause the wood to swell and shrink. These movements of the substrate may cause cracks in the coating as soon as the maximum in elasticity of the coating is exceeded. The deposition of water molecules in the interfacial zone reduces the bonding strength (wet adhesion) between the coating and the wood as well [1,2]. Especially, for water borne acrylic dispersions the wet adhesion is occasionally so critical that blistering, adhesive failure and other damages might occur (Figure 1).

The wet adhesion of coatings on wood depends on several factors. Therefore, an improvement can be achieved with several different methods that are highlighted in the paper.

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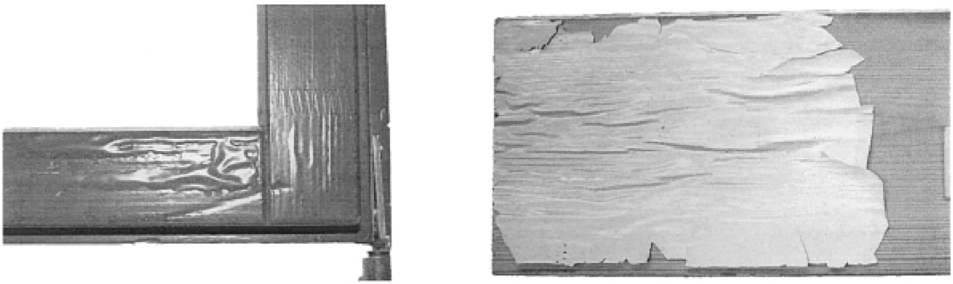

Figure 1. Damages of coated wood due to the insufficient wet adhesion of the coating

Experimental

Scots Pine (*Pinus sylvestris*) sapwood was preatreated with several methods and afterwards coated with 3 layers of a transparent or stained waterborne acrylic dispersions. After distinct time intervals, the wet adhesion was measured by one of the following methods with at least 3 replicates for each parameter:

The cross-cut test was a modified test in relation to ASTM D 3359[3] – 93 and EN ISO 2409[4]. Eleven parallel cuts were performed under an angle of 0° and 90° to the grain direction of the wood – resulting in 100 squares of 2 mm x 2 mm. The cuts were made with sharp scalpel knives using either a template and cutting by hand or using an apparatus that produced 11 cuts at the same time.

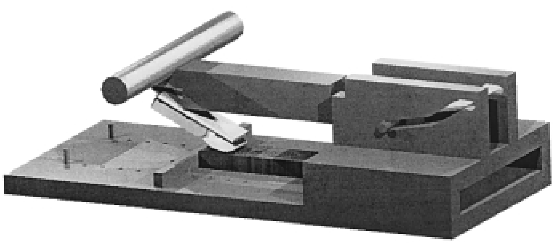

Figure 2. Aparatus for cutting 11 parallel cuts with scalpell blades at the same time.

Four layers of paper-towel were placed on the cut and intensively wetted with deionisised water. After two hours the towels were removed and the surface rubbed dry. 5 Minutes later a tape (Baiersdorf tesa® 4122) was rubbed firmly on the surface. The tape was then removed by hand at constant speed in an angle of about 60°. The classification of the cross-cut area was made according to EN ISO 2409 using the area of the flaking as classification system. A cross-cut classification of 0 represents a very good adhesion without flaking on the cross-cuts after the removal of the tape. A cross-cut classification of 5 represents a very poor adhesion with more than 65% flaking of the cross-cut area.

The pull-off strength was determined according to EN 311[5] fourteen days after the application of the coating. A circular groove of 0.2 mm depth with an inside diameter of 35.7 mm was milled into the surface and a metal dolly was glued in the center with a 2-k metal adhesive Metallon E 2082 (hardening time 12 hours) under pressure. With a laboratory syringe water was deposited into the groove and the pull-off strength was tested after 3 hours.

Results

Despite the inhomogeneity of wood and the inherent subjectiveness of the cross-cut test, both the cross-cut test and the pull-off test showed rather reliable correlation and reproducible values of the wet adhesion. The values correlated with the occurrence of adhesion problems in practice. When performing the cross-cut test on wood, very thin and sharp blades have to be used to avoid the squeezing of the substrate. It is also essential to wait 5 minutes after rubbing the wet surface dry before the application of the tape. Otherwise the adhesion of the tape may be too poor to achieve reliable results. Unfortunately the EN ISO 2409 classification of the flaking lacks of consistence as qualitative (kind of flaking) and quantitative parameters (area of flaking) have to be combined in the evaluation exercise without further specifications. Especially, as the image analysis of cross-cuts is one goal for the future, qualitative parameters should be removed from the standard or defined more precisely in relation to the flaking area.

The 60 seconds pretreatment of scots pine with 1% effective concentration of fluorine at 500 mb increased the wet adhesion of two acrylic dispersions (Figure 4).

The fluorine content in the wood was measured by Electron Probe Microanalysis (EPMA). At the very surface 0.25 atomic percent fluorine were present, in a depth of 0.4 mm following the grain direction about 0.1 atomic percent and in 1 mm depth the wood was fluorine free.

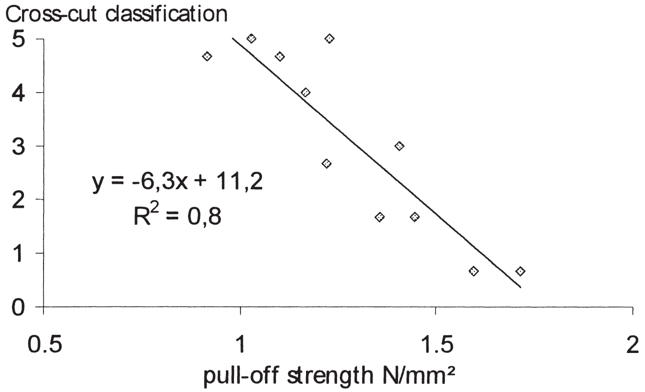

Figure 3. Correlation between the cross-cut test and the pull-off test

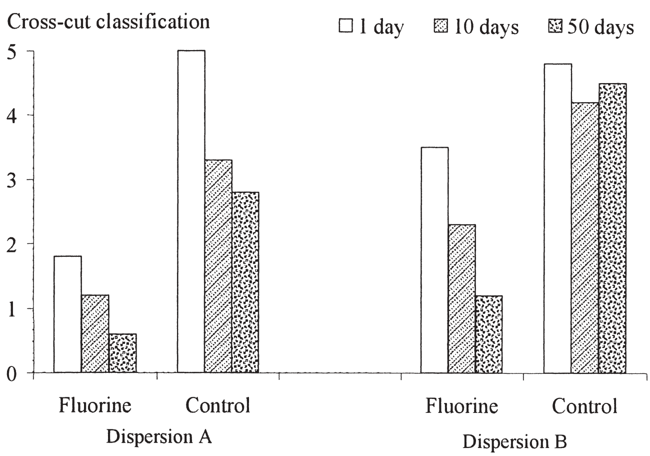

Figure 4. Cross-cut classification of two acrylic dispersions with and without a preatretment with fluorine in dependance of the timelag between coating and the cross-cut test. (Cross-cut classification of 0 = optimum adhesion)

The corona-treatment was performed with 100 V, 45 kHz, 100 µs pulses at a 2 kHz frequence and a movement of the substrate of 5 cm/sec. The cross-cut classification improved from 3,7 (untreated) to 0,7 after the corona treatment.

The plasma treatment was performed with a round nozzle under a distance of 3 cm and a movement of the substrate of 5 cm/sec. The results show in principle the suitability of the plasma pretreatment for acrylic dispersions. The wet adhesion of the two aqueous acrylate dispersions was improved by this treatment. Following the plasma treatment the wet adhesion after one day was not yet optimal, but improved gradually within the subsequent 9 days. Opposite to the observations made for the acrylate dispersions, the wet adhesion of the solvent based internal comparison product (ICP) according to EN 927-3[6] was reduced by the plasma treatment. The cause for the poor wet adhesion of the solvent-based ICP following the plasma pretreatment is not yet known. It was stated by microscopic investigations that the penetration of the ICP into the wood structure was not changed by the plasma pretreatment. It might be due to an incompatibility of the solvent or the functional groups of the ICP with the wood surface activated by the plasma treatment. In each case this is a clear reference to the fact that the plasma treatment has to be carefully fine-tuned to the coating material.

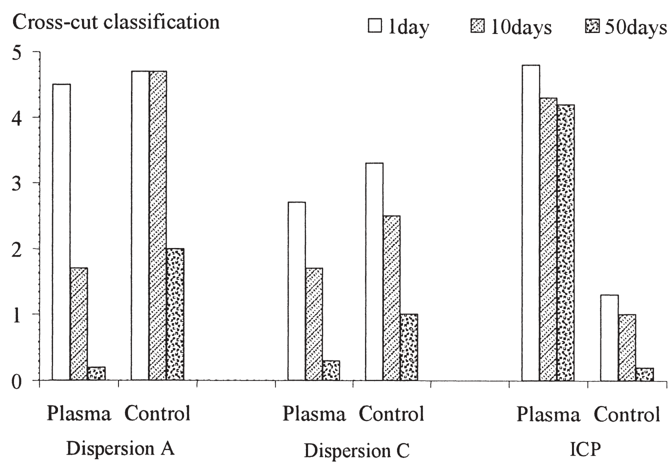

Figure 5. Cross-cut classification of two acrylic dispersions and ICP with and without a plasma preatretment in dependance of the timelag between coating and the cross-cut test.

The surface free energy of plasma treated pine and its respective disperse and polar portions where measured by the dynamic contact angle measurement according to Wilhelmy with water and methyleniodid. Except for the measurement immediately after the plasma treatment, both the surface free energy and its polar portion where increased by the pretreatment.

Table 1. Dependence of the surface energy and its disperse and polar portions at plasma-modified pine sapwood as a function of the time after the treatment compared with untreated samples

	Controls	Plasma treated				
		0 d	1 d	4 d	7 d	14 d
Surface tension N/mm²	45	37	52	51	47	52
Disperse portion N/mm²	40	24	44	40	39	42
Polar portion N/mm²	5	13	8	11	8	10

The wet adhesion can also be substantially improved by adequate primers (**Table 2**).It just turns out to be clear that the kind of primer is to be fine-tuned carefully with the selected final coating, since otherwise a degradation of the wet adhesion may occur. The temporal development of the wet adhesion proves that the positive effect of the primer is effective already briefly after the final coating.

Table 2. Cross-cut classifications of two coatings as a function of the pretreatment with different impregnations

	solvent[a)]	solids[b)]	Dispersion A		Dispersion B	
		%	cc1[c)]	cc50[d)]	cc1	cc50
Primer A	o	13	1.5	0.2	4.7	0.0
Primer B	o	15	4.7	1.2	5.0	1.7
Primer C	w	6	0.8	1.0	0.3	2.2
Primer D	w	18	0.7	0.0	0.5	0.0
Water (Controls)	w	0	4.7	1.2	1.3	0.0

[a)] o= organic; w = water
[b)] Solids content determined at 80 °C for 12 h
[c)] Cross-cut classification one day after the coating
[d)] Cross-cut classification 50 days after the coating

Numerous trials on the time dependence of the wet adhesion at room temperature after the drying of the film resulted in 3 typical features (Figure 6). Type A performs a poor wet adhesion without any mentionable change during the storage. Type B, the most common one, shows a rather poor wet adhesion after the drying of the film. Thus, within the first 10 days after coating a strong improvement occurs. Type C shows a good initial wet adhesion with little changes over the time.

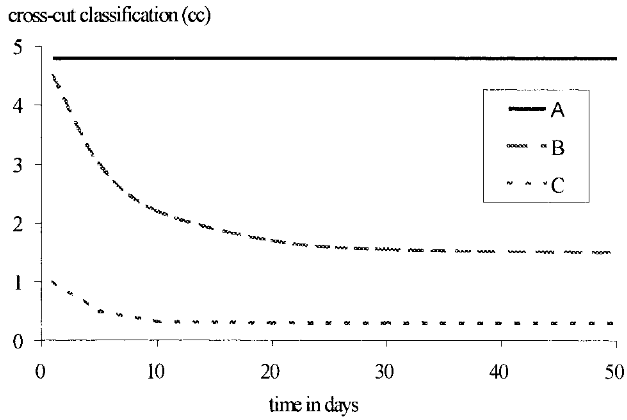

Figure 6. Idealised typical features of the time dependence of the wet adhesion of three aqueous acrylic dispersions

Discussion

The surface activation of wood is a promising approach to increase the wet adhesion of coatings. All three presented methods (corona, fluorination, plasma) are commonly used for the preatreatment of plastics to improve their coatablity. All three methods improved the wet adhesion of acrylic dispersions on wood, too. This can most likely be attributed to the increased polar portion of the surface free tension. As the corona technique is not appropriate for profiled timber, no further research was performed with this pretreatment technique. The fluorination of wood does have other disadvantages: The formerly halogen free wood is contaminated with fluorine and the price for the process is rather high for wood in practical dimensions. The vacuum steps, required in this process leads to an evaporation of terpenes from resinous softwoods, which might contaminate the reaction vessels.

For practical use, the pre-treatment with athmospheric plasma seems to be the most promising technique. A rough calculation of the preatreatment of one window unit resulted in approximately 0.3 Euro[7]. The continuous plasma treatment can be integrated into the existing production lines.

Nevertheless, in practice modern surface activation techniques will only be alternative, as long as other more conventional methods, listed in the following, for the improvement of the wet adhesion are not successful[7]:

- Reduction of the time lag between the last machining of the wooden surface and the first coating. (The wettability and the adhesion of coatings on resinous softwoods decreases rapidly after the last machining as a resin film develops on the surface[8])
- Increasing the time between the last coating and the exposure to weather
- Using an adequate functional primer[2]
- Improving the wet adhesion by adhesion promotors in the polymeric coating systems[1].

The optimum wet adhesion of coatings on wood depends on the expected moisture-conditions in use. Wooden constructions, that are regularly subjected to high moisture contents (fences, claddings) require a very high wet adhesion of the coatings. For wood, that should not become wet during its use (windows, doors) the optimum wet adhesion is more difficult to determine. On the one hand, a very good wet adhesion protects the coating from failure, especially when small defects are present. Little cracks, resulting from e.g. hail, will keep insignificant, as long as the wet adhesion is very high. On the other hand the wet adhesion of coatings should not exceed a certain value to allow an early visual detection of water that penetrates into the wood. From this point of view, it is advantageous if the coating shows blistering or flaking when the moisture content of the wood exceeds 30% for e.g. more than one week. If the wet adhesion is very high, the coating would appear defect free, even if the wood underneath is completely wet and e.g. decayed by fungi.

In any case, it is very important, that the wet adhesion has reached almost its final level when the wooden construction unit is installed especially in the cold months. As the development of the wet adhesion depends strongly on the temperature, it might take month to reach its final level at wintertime.

Acknowledgements

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References

[1] G. Hora (2002): Chemisch-physikalische Untersuchungen an wässrigen Holzaussenanstrichsystemen hinsichtlich Alterungsverhalten und Adhäsion. PhD-Thesis, Technical University Braunschweig.

[2] H. Turkulin; K. Richter; J. Sell (2000): Adhesion of waterborne acrylic and hybrid paint on wood treated with primers. Proceedings of the second woodcoatings congress, 23-25 October 2000, The Hague, Netherlands.

[3] ASTM-Standards, D 3359(1993): Standard test method for measuring adhesion by tape test.

[4] EN ISO 2409 (1994): Cross-cut test. Beuth Verlag GmbH, Berlin.

[5] EN 311(1992): Surface soundness of particleboards - Test methods. Beuth Verlag GmbH, Berlin.

[6] EN 927-3(2002): Natural weathering test. Beuth Verlag GmbH, Berlin.

[7] D. Lukowsky; G. Hora (2002): Final report 11739 N / 1 `Untersuchung der Ursachen einer verminderten Haftung von Anstrichfilmen auf Holzuntergründen im Außenbereich. DFO, Arnufstr. 25, 40545 Düsseldorf, Germany.

[8] R.M. Nussbaum (1999): Natural surface inactivation of Scots pine and Norway spruce evaluated by contact angle measurements. Holz als Roh- und Werkstoff 57, 419-424.