Liquid Water Permeability of Exterior Wood Coatings–Testing According to a Proposed European Standard Method

Jan Ekstedt—Trätek – Swedish Institute for Wood Technology Research*
Gunilla Östberg— Alcro-Beckers AB†

The proposed European standard method for the assessment of liquid water permeability, prEN 927–5, gives significant differences in water absorption values for different types of paints on wood. The proposed limits in the performance standard for the water absorption values for coatings to be used in different types of construction seem to be at acceptable levels. There is a good correlation between the level of water absorption and outdoor experience of the performance of the paints. Aging can drastically influence the water protection properties of the coating. Some sort of aging of the samples is needed in the assessment of the water absorption properties of coatings. An artificial aging procedure is proposed in this paper.

INTRODUCTION

Coatings for exterior wood have two basic functions. One is to give an aesthetically acceptable surface appearance and color. The other is to provide protection against wood degradation by microbiological or physical attack. In humid areas, protection against liquid water and moisture is extremely important. Ingress of water or moisture into wood causes dimensional changes which may result in cracking and checking of the film and, hence, a loss of durability.

The transport of water through coatings on wood can be explained by three different mechanisms[1]: (1) liquid water transport through the coating into the wood substrate (water absorption), (2) water vapor transport through the coating into the wood substrate (water vapor absorption), and (3) water vapor transport through the coating from the wood substrate (water vapor desorption).

In Scandinavia, many buildings have painted wooden facades. Large seasonal variations in climate (temperature and humidity) place high demands on the water protecting capacity of a wood coating.

In a wooden construction, a balance between the absorption of water or moisture and the desorption of moisture is extremely important. If the absorption is higher than the desorption over an extended period of time, a continuous accumulation of water will occur in the wood. If this accumulation reaches a high level, there is a risk of physical failure from blistering or cracking of the paint film and/or biological failure as a result of attack by blue stain or rot fungi. Therefore, one of the most important functions of a coating is to keep the moisture content in the wood construction at a safe level.

Extensive work has been reported in the literature regarding moisture transport through paint films.[2-8] To quantify the efficiency of a coating to protect wood from water, different tests have been developed.[9-11] Within the European Committee for Standardization (CEN), a standard procedure has been developed for the assessment of liquid water permeability. The proposed test procedure, prEN 927-5, has been prepared by CEN/TC 139, paint and varnishes. A summary of the development of the EN 927 standard has been published by Miller.[12] A recent review of major difficulties in moisture absorption measurements has been published by Graystone.[13]

The water transmission properties of coatings and coating systems can be expressed in different ways, for example, as the moisture-excluding effectiveness (MEE),[9] as the water uptake coefficient, w_t[10], or as the water absorption value. The latter approach has been proposed by CEN TC 139/WG 2 in prEN 927-5.

Ahola et al.[8] reported on the testing of the water protection capacity of 11 different model coatings by three different methods, including the proposed European standard method. They found that the water absorption values obtained by the different methods were highly consistent. In this paper, their results will be compared with the results from the present study.

*P.O. Box 5609, SE-114 86 Stockholm, Sweden, email jan.ekstedt@tratek.se
†117 83 Stockholm, Sweden, email gunilla.ostberg@alcro-beckers.com

Table 1—Coating Systems

System	Paints	Classfication According to EN 927-1	Non-volatile Content (vol%)	PVC (%)	Total Dry Film Thickness (μm)	Commercial Name	Supplier
Decorative Coatings							
1	Alkyd primer (SB)[a]	High build, opaque,semi matt	54	38	80	Expo Trägrund	Alcro-Beckers AB
2	Alkyd primer (SB)	High build, opaque, semi matt	54	38	38	Expo Trägrund	Alcro-Beckers AB
	Alkyd paint 1 (SB)	High build, opaque, semi gloss	64	21	66	Expo Villafärg	Alcro-Beckers AB
3	Alkyd primer (SB)	High build, opaque, semi matt	54	38	38	Expo Trägrund	Alcro-Beckers AB
	Acrylic paint (WB)	High build, opaque, semi matt	39	32	46	Expo Fasadakrylat	Alcro-Beckers AB
4	2x alkyd paint 2 (SB)[b]	High build, opaque, semi gloss	40	20	110	Exponyl Täcklasyr	Alcro-Beckers AB
5	2x alkyd paint 3 (WB)	High build, opaque, semi gloss	35	21	90	Exponyl Elit Täcklasyr	Alcro-Beckers AB
6	2x acrylic paint (WB)	High build, opaque, semi matt	39	32	135	Expo Fasadakrylat	Alcro-Beckers AB
7	2x alkyd emulsion paint (WB)	High build, opaque, semi gloss	45	31	116	Skärgård	Laatumaalit OY
8	3x linseed oil paint (SB)	High build, opaque, semi gloss	87	34	100	Tradition Linoljefärg	Alcro-Beckers AB
9	2x alkyd stain (SB)	High build, transparent	28	1	80	Exponyl Utomhuslasyr	Alcro-Beckers AB
10	Polyurethane dispersion paint (WB)	Medium build, transparent	n.a.[c]	n.a.	(194 g/m²)	Zeneca Formulation C-1309	Zeneca resins bv
	Polyurethane dispersion paint (WB)	High build, opaque, semi matt	n.a.	n.a.	(291 g/m²)	Zeneca Formulation C-1283	Zeneca resins bv
11	Swedish red paint (WB)	Medium build, opaque, matt	20	26	40	Äkta Falu Rödfärg	Stora Enso
Industrial Coatings							
12	Polyurethane coating (SB)	High build, opaque, semi matt	45	46	70	Reafen	Becker Acroma
	Polyurethane coating (SB)	High build, opaque, semi gloss	45	26	80	Reafen	Becker Acroma
13	2x PU/Acrylic dispersion paint (WB)	High build, opaque, semi matt	38	15	130	Laqvin	Becker Acroma
Reference Coating							
14	2x ICP (SB)	High build, transparent	37	2	82	—	—

(a) (SB) = solventborne; (WB) = waterborne.
(b) 2x (3x) means the coatings were applied in two layers (three layers) with intermediate drying.
(c) n.a. = not available.

Within the standard EN 927, there is a performance standard ENV 927-2 that proposes "limit values for performance criteria" for coatings intended for different end uses, for example, coatings for windows (stable substrate), for cladding (semi-stable substrate), or for fences (non-stable substrate). The proposed maximum accepted water absorption value for coatings or coating systems intended for "stable constructions" is 175 g/m^2 and for "semi-stable constructions" 250 g/m^2. These values refer to the water uptake through the coating after 72 hr of exposure to liquid water.

This paper reports the water permeability properties of a number of commercial decorative and industrial coatings measured as water absorption values according to the proposed EN standard. Its purpose is to give publicity to the standard, to consider the results for coatings in relation to their performance in practice, to discuss the proposed limits for classification, and to discuss and exemplify the need to standardize a method for artificial aging.

EXPERIMENTAL

Materials

Test Panels: Test samples of Norway spruce (*Picea abies*) were used. Freshly cut boards were kiln-dried (at Trätek). The dimensions of the test samples were 150 × 70 × 20 mm (longitudinal, tangential, and radial directions, respectively). All faces were planed. The test samples were manufactured in accordance with the specifications in prEN 927-5.

The test samples were free from knots and cracks, straight-grained and with between three and eight annual rings per 10 mm. The inclination of the growth rings to the test face was 45° ± 10°. The densities of the test samples were between 0.4 and 0.5 g/cm^3, measured at a moisture content of 12%.

Prior to coating, the test samples for Systems 2–9 (see *Table* 1), were conditioned to constant weight at 23°C and 50% relative humidity (RH). This climate is normally used in standard methods for coatings, but it is not in accordance with the climate recommended in prEN 927-5, which is 20°C and 65% RH and normally used when testing wood. The initial moisture content in panels for Systems 2-9 was thus approximately 9%.[1]

The test samples to be used for System 1 and Systems 10-14 were conditioned in accordance with prEN 927-5 (20°C and 65% RH). The initial moisture content in panels for System 1 and Systems 10–14 was thus approximately 12%.[1] The discrepancy in conditioning for the different systems will be discussed later.

Coatings*:* The tested coatings are listed in *Table* 1. The decorative coatings represent normal coatings used in Scandinavia. The industrial coatings are special coatings for windows, and they represent products for applications defined as "Stable constructions" according to the classification in EN 927-1. Also included is the internal comparison product (ICP), a transparent wood stain. The ICP is defined in prEN 927-3 and is used as a reference coating in testing according to the standard EN 927.

Methods

Coating Application: The tested coating systems are listed in *Table* 1. The test samples for all of these systems, except Systems 12 and 13, were coated by brush on one tangential surface. Systems 12 and 13 were spray applied. The different coating systems were applied according to the manufacturer's recommended spreading rate. For each system, five replicates were coated. The amount of paint applied was weighed, and the dry film thickness was calculated. After drying, the end grains and the sides were coated with a solventborne alkyd primer followed by an impermeable, flexible sealant. The uncoated faces were sealed with two layers of a moisture-impermeable coating. After sealing, the test samples for Systems 2-9 were conditioned to constant weight at 23°C and 50% RH and the test samples for System 1 and Systems 10–14 were conditioned in accordance with ISO 554:1976 (20°C and 65% RH).

Water Absorption Measurements*:* After conditioning, each test sample was exposed to deionized water for 72 hr according to the prEN 927-5, clause 6.2. This exposure was achieved by floating the panels on the surface of the water in a filled container with the coating under test facing downwards. This test procedure was carried out in a controlled environment: for Systems 2–9 in a conditioning room at 23°C and 50% RH and for System 1 and Systems 10–14 at 20°C and 65% RH. The weight increase of the test samples was recorded after 72 hr floating.

Pre-Conditioning*:* In prEN 927-5, it is required that all coatings shall be subjected to a leaching procedure before testing, which shall be carried out twice as follows:

- 24 hr floating face down in deionized water.
- 3 hr drying at 20°C and 65% RH
- 3 hr drying at 50°C
- 18 hr drying at 20°C and 65% RH

In this study, the effect of pre-conditioning was examined in an alternative test on two of the coatings (Systems 2 and 6).

Artificial Weathering*:* The European draft standard, prEN 927-5, clause 6.3 "Optional testing of weathered panels" provides that: "If required, coatings may be subjected to a weathering test before or after measurement of liquid water permeability." The proposed standard does not specify any defined weathering procedure. The procedure used in this study has been developed at Trätek.[6]

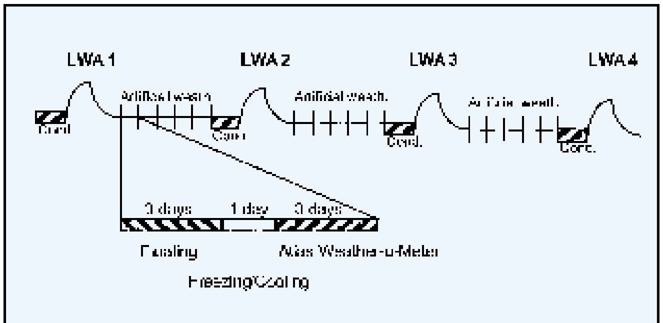

Figure 1—Artificial weathering schedule. Cond. = conditioning. LWA 1–4, see text.

The test procedure outlined in *Figure* 1 involves four determinations of the liquid water absorption (LWA) value on four different occasions, which are LWA 1, LWA 2, LWA 3, and LWA 4, respectively. Between these water absorption measurements, the samples are aged according to the artificial weathering schedule outlined in *Figure* 1.

After the first water absorption value of the unweathered test samples has been measured, at LWA 1, the test samples are subjected to artificial weathering. The artificial weathering cycle, which is one week long, consists of:

- Floating the test panels for 72 hr on the surface of the water in a filled container with the coating under test facing downwards.
- Freezing at –18°C or cooling at +3°C for 24 hr.
- Exposure to light and water spray in an Atlas Weather-Ometer Ci65 (WoM) with a 6500 W Xenon arc lamp for 72 hr. The WoM was programmed for 102 min UV radiation, followed by 18 min of UV radiation and water spray.

This cycle is repeated five times. In the first cycle, the test samples are subjected to freezing at -18°C. In the subsequent four cycles, the test samples are subjected to cooling at +3°C. After five cycles, the samples are conditioned to 20°C and 65% RH, and the water absorption value is measured a second time at LWA 2. The water absorption values at LWA 3 and LWA 4 are measured in the same way.

Calculations

The liquid water permeability was determined as the increase in weight of the test samples after 72 hr of floating on water as specified in prEN 927-5. For each set of five replicates, the arithmetic mean value of the weight increase and the 95% confidence interval were calculated. The arithmetic mean value of the weight increase after 72 hr of floating is reported as the water absorption value and is expressed as g/m^2,72 hr.

RESULTS AND DISCUSSION

The different paint systems were conditioned in different climates, 23°C/50% RH or 20°C/65% RH, as described in

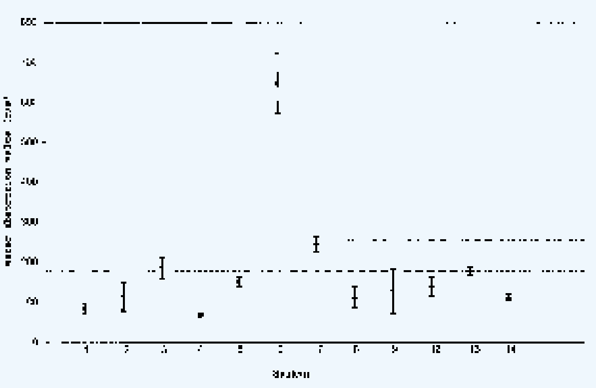

Figure 2—Water absorption for different types of coatings. Mean values for five replicates and the 95% confidence intervals are shown. The water absorption value for the untreated wood was 1101 g/m^2. The horizontal lines show the proposed limits in prEN 927-5 for coatings used on wood for "stable construction," 175 g/m^2, 72 hr and for "semi-stable" constructions, 250 g/m^2, 72 hr.

the Methods section. This gave equilibrium moisture contents in the test samples of 9% and 12% respectively.[1] The ingress of water through the coating into the wood substrate is determined largely by the permeability of the coating and to a lesser extent by the properties of the substrate. This has been demonstrated by Ahola et al.[8] They found that the water absorption value for a certain coating differed very little regardless of whether it was coated on a spruce or a pine test panel, although the water absorption values for the uncoated pine panels were approximately three times larger than the values for the spruce panels. On the basis of these results, we have reason to believe that the difference in conditioning and, thus, in water absorption of wood, has only a minor effect on the water penetration through the coatings. For that reason, the water absorption values for the different coatings can be compared, despite the difference in conditioning.

Permeability of Different Types of Coatings

The results from the water absorption tests of different paints are shown in *Figure* 2. The distribution in the water absorption values measured for a coating is shown as the 95% confidence interval of the mean. The mean value and the 95% confidence interval are calculated from five replicates. The horizontal lines in *Figure* 2 are the classification limits proposed in ENV 927-2, Performance specifications. The lower line, at a water absorption value of 175 g/m^2, shows the proposed maximum accepted water absorption value for coatings on wood for "stable constructions," for example, windows. The upper line, at a water absorption value of 250 g/m^2, shows the proposed maximum accepted water absorption value for coatings on wood for "semi-stable constructions," for example, wooden facades.

To relate the measured water absorption values for painted samples to the water absorption values for untreated wood samples, the mean water absorption values for 40 untreated samples of Norway spruce were determined. The mean water absorption value was 1101 g/m^2 with a 95% confidence interval of ± 84 g/m^2. Ahola et al.[8] found a similar water absorption value for untreated spruce, 1032 g/m^2.

Alkyd Paints: The results for the traditional solventborne alkyd paints, Systems 1, 2, and 4, clearly show a good protection against liquid water. All these paint systems fall well into the proposed category for use on stable and semi-stable constructions. This agrees well with many years of practical experience with these types of paints on wooden facades in Scandinavia. They are also often used on window frames. The waterborne alkyd paint, System 5, also shows good protection against water and falls into the category for use on stable constructions.

The more traditional waterborne alkyd paint, based on an alkyd emulsion, System 7, however, shows a higher water absorption value than the other alkyd paints, both waterborne and solventborne. The alkyd emulsion paint is at the limit to be accepted for use on semi-stable constructions. The higher water permeability of the alkyd emulsion paint than of the other alkyd paints is probably due to the presence of surfactants, which are used to stabilize the emulsion droplets and can cause bad film formation. The new type of waterborne alkyd used in System 5 is based on another technology without any free surfactant. The transparent alkyd stain, System 9, falls into the category to be used on semi-stable constructions, which is the main area on which they are used (wooden facades). The linseed oil paint, System 8, shows a similar water absorption value as the solventborne alkyd paints. The reference coating, the ICP, System 14, shows a low water absorption value.

Acrylic Paint: The waterborne acrylic paint, System 6, shows a high water absorption value, as seen in *Figure* 2, despite a considerable film thickness. This is the reason why, at least in Scandinavia, it is always recommended that these paints should be used together with an alkyd primer to obtain a satisfactory protection against water. Fundamental studies[14] on the film formation of latex dispersions have shown that high water permeability is usually caused by defects in the paint film. During the physical drying of a latex film, the latex particles dispersed in water should coalesce together and form a smooth film. In practice, however, non-uniform films with defects are often obtained. Bad film formation can be caused by insufficient stabilization by the surfactants during film formation. Another possible cause is that hydrophilic anionic surfactants may migrate out from the film during coalescence and leave pores in the paint film where water can enter.

When the acrylic paint was used as a topcoat on a solventborne alkyd primer, System 3, the water absorption value was of the same order as the water absorption value for the solventborne alkyd paint used both as primer and topcoat, System 2. The water protection property of the system with the acrylic topcoat is therefore mainly given by the primer. This can be explained by reference to the results for the alkyd primer alone, System 1. The film thickness for the alkyd primer alone was 80 µm, resulting in a water absorption value of about 100 g/m^2. The alkyd primer + acrylic topcoat system, System 3, has a primer film thickness of 38 µm, and a water absorption value was about 200 g/m^2. Halving the film thickness of the primer thus results in a doubling of the water absorption value. Since both the solventborne alkyd system and the alkyd primer and acrylic topcoat perform similarly with regard to water protection, the choice often depends on aesthetic properties of the coating. The acrylic paints have excellent resistance against chalking, while the alkyd paints often chalk within a few years.

It should be noticed that this test method requires that the samples have planed surfaces. At least in Scandinavia, the main types of wooden facades are made from sawn wood. The recommended amount of paint is usually different for application to planed wood from that for application to sawn wood. The dry film thickness also influences the water absorption and should, therefore, always be considered when evaluating the results.

Table 2—Comparison of Water Absorption Values from Different Studies

Type of Coating	Water Absorption Values (g/m^2, 72 hr) This Study	Ahola et al.[8]	PVC (%)[a]
Alkyd Emulsion Coatings			
Alkyd emulsion primer + alkyd emulsion topcoat		206.7	n.a.[b]
2x alkyd emulsion paint, System 7	244		31
Acrylics			
Acrylic(A) primer + acrylic(A) topcoat		255.8	25+15
Acrylic(A) primer + acrylic(A) topcoat		408.8	25+25
2x acrylic, System 6	647		32+32
Alkyd Coatings, Solventborne			
Alkyd primer + alkyd topcoat		111.8	n.a.
Alkyd primer + alkyd topcoat, System 2	114		38+21

(a) PVC(%): 25+15 means that the PVC for the first coat was 25% and for the second coat 15%.
(b) n.a. = not available

Industrial Coatings*:* The industrial coatings tested in this study are mainly used in stable constructions such as windows. The solventborne polyurethane coating, System 12, falls well into the category of paints for "stable constructions," whereas the waterborne PU/acrylic coating, System 13, falls on the proposed limit. These two paints have shown very good outdoor performance during the last 15 years of commercial use. Field tests with painted window sills at Trätek´s test site show excellent performance for both coatings. The test on the coatings commenced in 1987 and the coatings still perform well.

Swedish Red Paint: The test result for the Swedish red paint (SRP), System 11, is not included in *Figure* 2. The water absorption value for SRP is of the same order, 1034 g/m^2, as that for untreated wood. The SRP has been used with excellent results since the 17th century as a durable coating on sawn wood. One of the advantages of the paint is that it contains a pigment that is supposed to protect the wood against biological degradation. It is completely open for water to be absorbed into the wood, but the water can also easily be desorbed.

Comparison of the Results with Other Investigations: Ahola et al.[8] report on the testing of model coatings with regard to water protection capacity by the same method as used in this study. *Table* 2 shows a comparison between water absorption values obtained in this study and values reported by Ahola et al.[8] for similar coating systems. Although the model coatings used by Ahola et al.[8] are characterized only by generic type and not by chemical composition, some comparisons between the results can be made.

The agreement between the studies with regard to the test results for alkyd emulsion coatings is fairly good. There is a slight difference between the dry film thickness of the alkyd emulsion paint in this study (116 µm) and that of the alkyd emulsion paint in Ahola et al.[8] (80 µm).

The water absorption values for waterborne acrylics, used both as primer and topcoat, differ between the studies. The higher pigment volume concentration in System 6 in this study gives a more permeable film with a higher water absorption value than the corresponding paint with a lower pigment volume concentration (PVC) in the study by Ahola et al.[8]

The very similar water absorption values for the solventborne alkyd coatings are interesting, since the compositions and the PVCs are probably not the same.

Repeatability of the Method

In *Figure* 3, water absorption values are shown for four coating systems, tested on different occasions. The acrylic paint, System 6, was tested on three occasions and the other three paints, Systems 2, 4, and 5, on two occasions. New test samples were used in each test. The repeatability is quite good, although there is a statistically significant difference between the two sets of data for Systems 4 and 5. For System 5, the results fall into different user categories for the different measurements, but the performance in practice would probably be very similar.

Influence of Aging on the Water Permeability

Pre-Conditioning*:* In prEN 927-5, a pre-conditioning procedure is included before the measurement of water

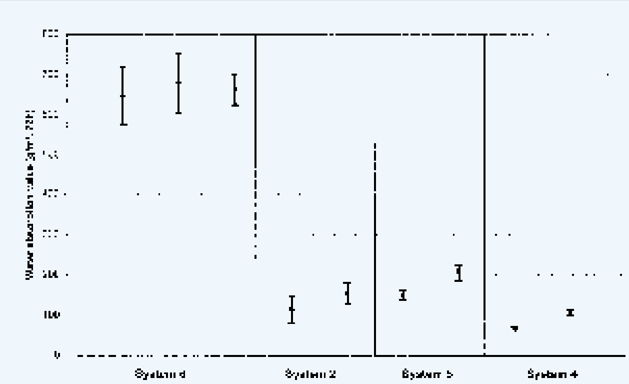

Figure 3—Repeatability of the method. The figure shows the results obtained with the same coatings measured on different occasions. Mean values for five replicates and the 95% confidence intervals on each occasion are shown.

absorption. The pre-conditioning procedure consists of two cycles of soaking in water with intermediate drying at an elevated temperature (see the Methods section). The reason why the pre-conditioning procedure is included in the standard is that some coatings, for example, acrylic paints, may drastically change with regard to their water absorption properties after exposure to water. In *Figure* 4, the water absorption values for two different types of coating systems are shown, both pre-conditioned and not pre-conditioned. The coating systems tested are two coats of waterborne acrylic paint, System 6, with a high water absorption value and two coats of alkyd paint, System 2, with a low water absorption value. For these coatings, there was no difference in the measured water absorption values between samples that were pre-conditioned and those that were not. The reason for this could be that the pre-conditioning process is too mild.

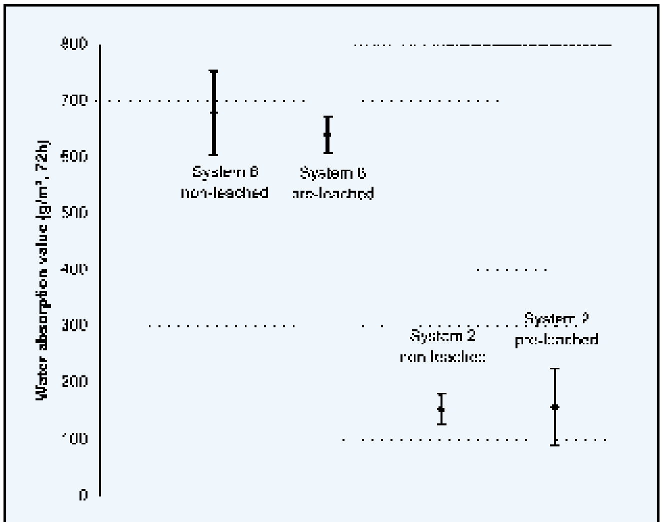

Figure 4—Effect of pre-leaching of the coated test samples before the water absorption measurements according to the procedure in prEN 927-5. Mean values for five replicates and the 95% confidence intervals are shown.

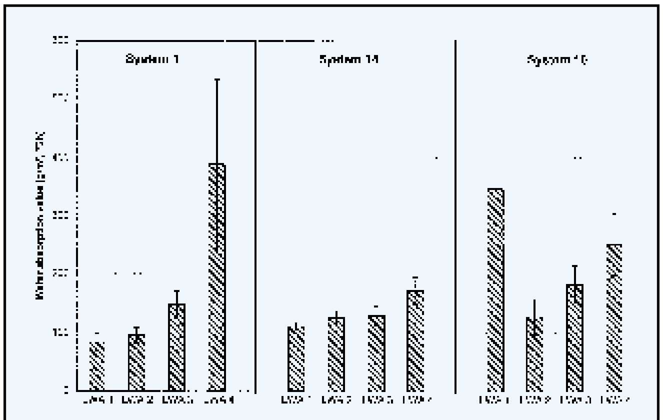

Figure 5—Influence of artificial aging on the water absorption property of the paints. The coated test samples have been aged between the water absorption measurements (see Figure 1). Mean values for five replicates and the 95% confidence intervals are shown.

Artificial Aging: In *Figure* 5, the water absorption values and 95% confidence intervals are reported for two primers, Systems 1 and 10, and the ICP, System 14, initially and after artificial weathering. The samples were artificially weathered as described in the Methods section, and the liquid water absorption values were measured before aging and after 5, 10, and 15 aging cycles. The value for the alkyd primer, System 1, starts to increase after 10 weeks of artificial weathering. Subsequently, the 95% confidence intervals are considerably broader. This is in agreement with outdoor experience with this type of primer. During aging, the paint film starts to show cracks due to more complete oxidation and subsequent brittleness.

The PU dispersion primer, System 10, shows a relatively high water absorption value before the artificial weathering at LWA 1. During the first five cycles of artificial weathering, the coating film seems to become less permeable and to show a low water absorption value at LWA 2. The explanation of this may be that leaching of water-soluble material from the coating makes the coating less permeable to water transport. Perera[15] found that leaching of water-soluble substances from a coating led to a decrease in the diffusion coefficient (δ_p). The same decrease in the diffusion coefficient after weathering has been reported by Holsworth et al.[16] Additional weathering causes the water absorption value to increase again. This change in water absorption value after weathering has been shown to be common for waterborne coatings.[6]

The ICP, System 14, shows remarkably good performance. Even after 15 cycles of artificial weathering, the water absorption value is low and the 95% confidence interval is also quite small.

CONCLUSIONS

This work has shown that the proposed European standard method for measurement of the water absorption value for coatings gives significant differences in water absorption values for different types of coatings on wood. The proposed limits for the water absorption values for coatings to be used in different constructions seem to be set at acceptable levels, at least if the initial measurement is considered. There is a good correlation between the level of water absorption and practical experience of the performance of the paints in Scandinavia.

This work has shown, however, that aging can drastically influence the water protection properties of the coating. An obvious conclusion is that some sort of aging of the test samples is needed in the assessment of the water absorption properties of a coating. Measurement of the water absorption value before any aging has rather a limited usefulness for the prediction of long-term water-excluding efficiency. More work has to be done to find a proper aging procedure.

The repeatability seems to be satisfactory, although the wood material itself often exhibits large variations in its moisture absorption properties.

A limitation of the test method is that the test samples are made of planed wood. At least in Scandinavia and in the United States, most of the claddings have rough sawn surfaces. Testing of a coating on a sawn surface would give more realistic and useful water absorption values. By using test samples with sawn surfaces, one takes into account, for example, the influence of wood fibres from the sawn surface penetrating the paint film.

The results showed that the tested waterborne acrylic paint alone is too permeable to liquid water to be used for stable and semi-stable constructions, according to the proposed standard. An alkyd-based primer was needed to give satisfactory protection against water. Also, the alkyd emulsion paint was too permeable to liquid water to be used alone. This is well in accordance with experience from outdoor exposure in Scandinavia.

ACKNOWLEDGMENTS

Mr. Gunnar Waldestedt, Ms. Elisabet Wallgren at Alcro-Beckers, and Ms. Katarina Nordman-Edberg at Trätek are kindly acknowledged for their skillful work in preparing the samples and performing the measurements. Dr. E. Roy Miller and Dr. Hillary Derbyshire at the Building Research Establishment, Watford, U.K., and Prof. Ove Söderström and Dr. Folke Björk at the Royal Institute of Technology, Stockholm, Sweden, are thanked for valuable comments on the manuscript. Part of this work has been financed by the Swedish National Board for Industrial and Technical Development (NUTEK) and by The Association for Swedish Wood Products Research.

References

(1) Siau, J.F., *Transport Processes in Wood*, Springer-Verlag, Berlin, 1984.

(2) Huldén, M. and Hansen, C.M., "Water Permeation in Coatings," *Prog. Org. Coat.*, *13*, 171 (1985).

(3) Holbrow, G.L., Sherwood, A.F., Dasgupta, D., Gardiner, D., Gibson, M.C., and Haines, M.J., "Wood Protection,"*J. Oil & Colour Chemists' Assoc.*, *55*, 35 (1972).

(4) Ahola, P., "Moisture Transport in Wood Coated with Joinery Paints," *Holz als Roh- und Werkstoff,* 49, 428-432 (1991).

(5) Hora, G., "The Dynamic Contact Angle-A Characteristic to Predict the Lifetime of a Wood Topcoat," JOURNAL OF COATINGS TECHNOLOGY, *66*, No. 832, 55 (1994).

(6) Ekstedt, J., "Moisture Dynamic Assessment of Coatings for Exterior Wood,". Licentiate Thesis, Royal Institute of Technology, Stockholm, TRITA-BYMA 1995:12 (1995).

(7) De Meijer, Mari, "Interactions Between Wood and Coatings with Low Organic Solvent Content," Ph.D. Thesis, Wageningen Universiteit, ISBN 90-5808-134-4 (1999).

(8) Ahola, P., Derbyshire, H., Hora, G., and de Meijer, M. "Water Protection of Wooden Window Joinery Painted with Low Organic Solvent Content Paints with Known Composition," *Holz als Roh- und Werkstoff*, *57*, 45-50 (1999).

(9) Feist, W.C., Little, J.K., and Wennesheimer, J.M., "Moisture-Excluding Effectiveness of Finishes on Wood Surfaces." Res. Pap. 462, U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, 1985.

(10) DIN 52617, "Determination of the Water-Uptake (water absorption) Coefficient of Building Material" (1987).

(11) Hjort, S., "Full-Scale Method for Testing Moisture Conditions in Painted Wood Panelling," JOURNAL OF COATINGS TECHNOLOGY, *68*, No. 856, 31 (1996).

(12) Miller, R., "The Development of EN 927 by CEN/TC 139 Working Group 2," Conference Paper No. 1, *Advances in Exterior Wood Coatings and CEN Standardization*, Brussels, Belgium, Oct. 19-21, 1998.

(13) Graystone, J., "Moisture Transport Through Wood Coatings: The Unanswered Questions." Conference Paper No. 6, *Advances in Exterior Wood Coatings and CEN Standardization*," Brussels, Belgium, Oct. 19-21, 1998.

(14) Hellgren, A.-C. and Li Tie-Qiang, "Surfactant Mobility During Film Formation of Acrylate Latexes and Its Impact on Mechanical Properties of the Dried Film," *Creative Advances in Coatings Technology, Paper No. 49*, 4th Nürnberg Congress, April 7-9, 1997.

(15) Perera, D.Y., "Hygric Aspects of Coated Porous Building Materials," *Prog. Org. Coat.*, 8, 183 (1980).

(16) Holsworth, R.M., Provder, T., and Ramig, Jr., A., "Physical Characterization Of Coatings Upon Aging," JOURNAL OF COATINGS TECHNOLOGY, *46*, No. 596, 76 (1974).