A reliable Artificial Weathering Test for Wood Coatings

Accelerated weathering plays an important part in the development of new finishing systems. A study coordinated by CTBA, involving four wood coatings manufacturers and ten research institutes, has singled out a test that shows promise.

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Artificial weathering plays an important role in the development of improved coating systems by providing a means of obtaining performance assessments in much shorter time than it is possible using natural weathering. However, there exists at present no agreed artificial weathering test applicable to wood substrates.

At the end of 1996 the European Community has approved an extensive European research project called "Arwood." This project involved ten wood research institutes (CTBA, BRE, WKI, VTT, TRAETEK, EMPA, CC, NIT and RUG) and four industrial partners (Tikkurila Oy, Gori-Dyrup, ICI Paints and Cecil) between 1996 and 2000. The project was co-ordinated by CTBA.

The principal aim of the project was to develop an artificial weathering method to assess the durability of exterior wood coatings in a short period of time and consequently to speed up the industrial development of new types of coatings systems required to meet increasingly demanding environmental regulations.

The development of the test itself had to comply with a particular economic criterion—to wit, the use of a device that is accessible to small and medium-sized companies. This is why the studies have been directed at cycles using fluorescent lights which have, moreover, turned out to be effective in other industrial sectors (steel, plastics).

The work of this project had to be the basis for a new CEN standard within the frame of EN 927 "Paints and varnishes-Coating materials and coating systems for exterior wood" describing an artificial weathering test for exterior wood coatings. This standard should complement several existing standards which are addressing the artificial exposure with fluorescent UV, but which are not specific regarding the exposure on a wood substrate.[1,2,3]

Within this research project several natural and artificial round-robin exposure trials with different coating systems and wood substrates were carried out. This paper mainly reports the findings of two subsequent series of tests which were especially designed to develop and test an "optimized" exposure cycle for the fluorescent UV devices for the artificial weathering of exterior wood coating systems.

Materials and Methods

Substrates: Exposure tests were carried out on coated wood panels following the specifications of the natural exposure test as described in prEN 927-3[4]. Test panels consisted of planed defect-free pine (Pinus silvestris) sapwood with a growth ring orientation to the exposed face of zero to 45°. Panel sizes were adapted to fit the device specific sample holders: in the evaluation test series the sample size was 300x75x15mm. Some laboratories used samples with a 150x75x15 mm panel size to accommodate a higher number of samples in one device and the same test run; for the "optimized" test series a slightly thicker sample with an uniform size of 150x74x18 mm was used.

Three replicate samples per coating system were tested in each laboratory and a set of unexposed samples was kept as reference controls. To ensure "identical" sample material the sample preparation was done in each test series centrally by one of the participating laboratories.

Coatings systems: The greater part of this research project was performed with one species: Scots pine (Silvestris pine) and six different coatings systems: two white paints—one solvent-based paint and one water-based one; two high-built wood stains—one solvent-based (the ICP which is used in the EN927 part 3: natural weathering test) and one water-based; one low-built solvent wood stain; and uncoated wood to have a control of the weathering of the wood itself.

Uncoated samples were also included to study the weathering effects on bare wood. For the sake of simplicity the uncoated samples are referred to as coating system F in Table 1 and in further text. Table 1 gives an overview of the selected coatings. For each series of tests coating application was done by brushing. Deviating from the natural exposure test in prEN 927-3 the back side of the panels were coated.

Weathering device: Seven weathering devices of the fluorescent UV condensation type were available in the two test series, each modified with a spraying system.

Most of the devices were fitted with a programmable microprocessor to control the exposure cycle. Several devices were equipped with an automatic irradiance control while others had to rotate and change the lamps according to the manufacturers recommendations. Samples were also rotated periodically within the chamber to ensure a uniform exposure.

Performance assessments: The performance assessments were done according to prEN 927-3 including cracking, blistering, flaking, chalking, gloss and color measurements.

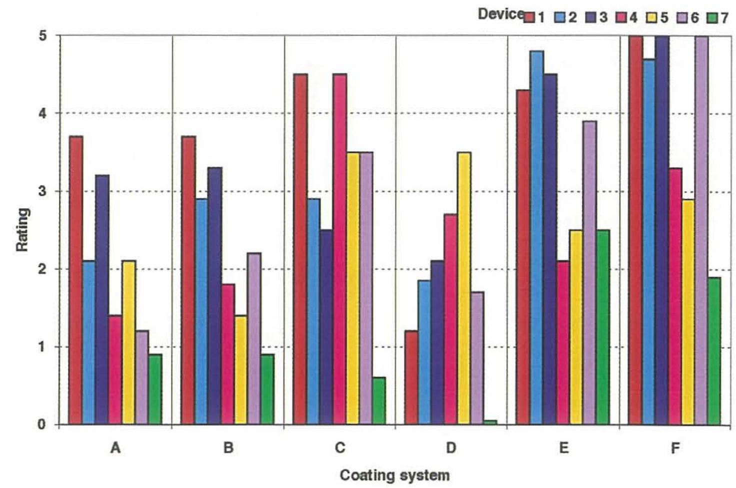

Figure 1: General appearance after 2,000 hours exposure for the seven tested cycles.

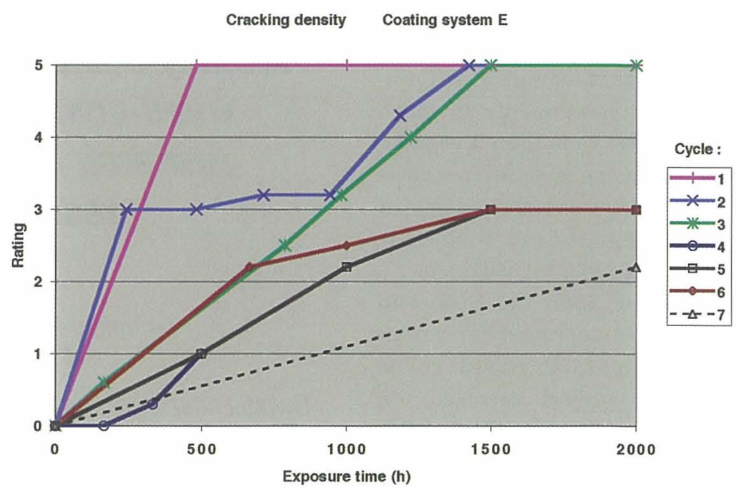

Figure 2: Cracking density with coating system E during 2,000 hours of exposure for the seven tested cycles.

Coating System	A	B	C	D	E	F
Coating type 1)	wb acrylic paint	sb alkyd paint (high-solid)	sb alkyd stain (ICP)	wb acrylic stain	sb low-build stain	uncoated
Blue stain primer	X	-	-	X	-	-
Number of coats	2 (1pr+1top)	2	3	2	2	-
Color	white	white	red-brown	red-brown	brown	-
Classification (EN 927-1)						
End-use category	stable	stable	semi-stable	semi-stable	non-stable	-
Build	high	high	medium	medium	minimal	-
Hiding power	opaque	opaque	semi-transparent	semi-transparent	semi-transparent	-
Gloss	semi-matte	high gloss	high gloss	gloss	matte	-

Table 1: Description of the selected coating system Notes: 1) wb = waterborne, sb = solventborne.

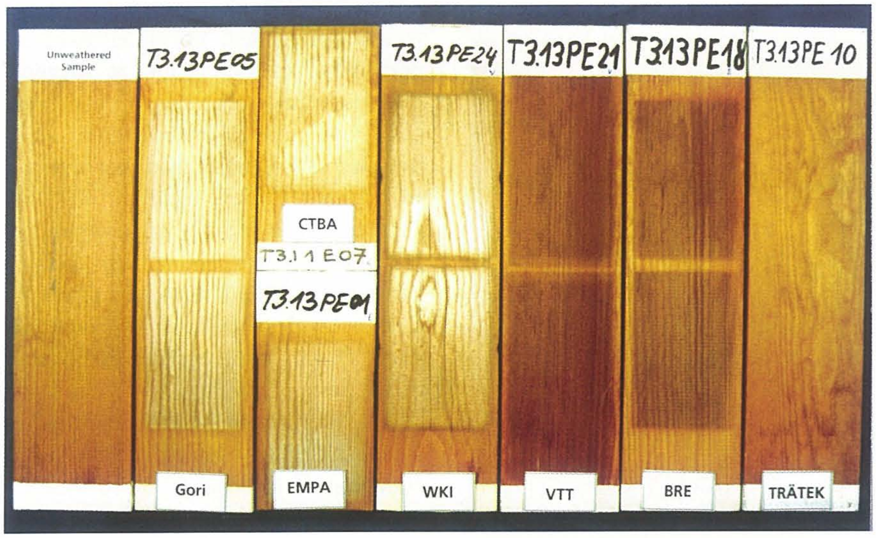

Photo 1: System E at the end of the seven exposure cycles.

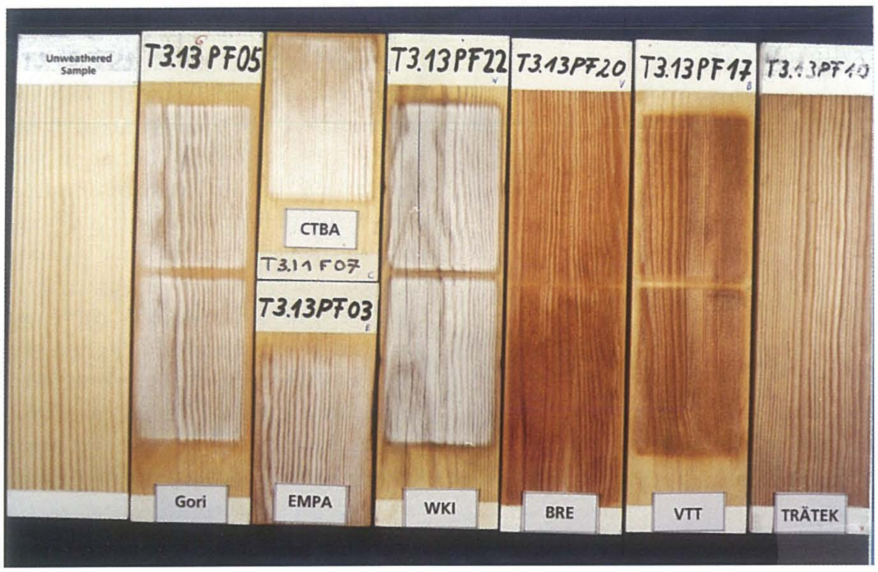

Photo 2: System F at the end of the seven exposure cycles.

A further assessment called "general appearance" was introduced. General appearance is the human eye's impression of the overall condition of the tested coating system. It was rated on a visual scale from zero (no change) to five (severe changes) in comparison to the unexposed reference samples. Assessments during the exposure were done by each laboratory ("on-site assessments") while the final assessments were also repeated centrally by one operator in one of the participating laboratories ("common assessments").

In the following graphs time-series data always represent on-site assessments containing some possible operator bias. Final condition data are based on a common assessment and reflect differences due to exposure effects.

Evaluation Test Series

The testing procedures were based on existing standards [1,2,3] and the experience of the different laboratories.

In this evaluation test series, seven exposure cycles were established and tested as listed in Table 2. Cycles one to three are variations of exposure cycles from earlier development work on the fluorescent UV devices of some partners using both condensation and water spray. The main focus of these three cycles is on different timing options. Cycles four and five are based on recommendations in existing standards using only UV irradiation and condensation. Only the type of UV lamps is different (UVA-340nm and UVA-351nm). Cycles six and seven are using different treatment (soaking, freezing) to increase exposure stresses.

Fig. 1 shows the general appearance after 2,000 hours of exposure for the seven tested cycles. As expected the opaque coating systems A and B show only small to moderate changes while the most severe changes are observed for the uncoated wood (F). The acrylic stain D clearly performs better than the alkyd stain C and even slightly better than the two opaque coatings A and B.

Considerable differences between the different exposure cycles are observed and there is no clear ranking over all coating systems. An example of the appearance of the samples at the end of the seven exposure cycles is presented in Photo 1 for coating system E and in Photo 2 for coating system F. Only limited cracking (up to a rating of two) was observed after 2,000 hours for all the exposure cycles with the film forming coatings (system A to D). No cracking at all was present in any of the samples with the acrylic paint A. There was however a rapid crack development with the low build stain (system E) and the uncoated wood (system F) as shown in Fig. 2 and Fig. 3 respectively.

Cycles one to three clearly cause the fastest and most severe cracking of all the tested cycles. Cycles five to seven reach only medium cracking scores. An example of gloss changes with the different cycles is shown in Fig. 4 for the alkyd paint (coating system B). This paint shows a rapid loss of gloss. As for cracking the exposure cycles one to three lead to the most severe weathering effects of all the tested cycles. The different results obtained in this research project lead to the following conclusions:

- special treatments like freezing or soaking do not appear to improve the severity of the weathering effects;
- fluorescent UV lamps UVA-340nm are well suited to simulate the degradation effects of the sunlight; and
- condensation and water spray must both be included in an artificial

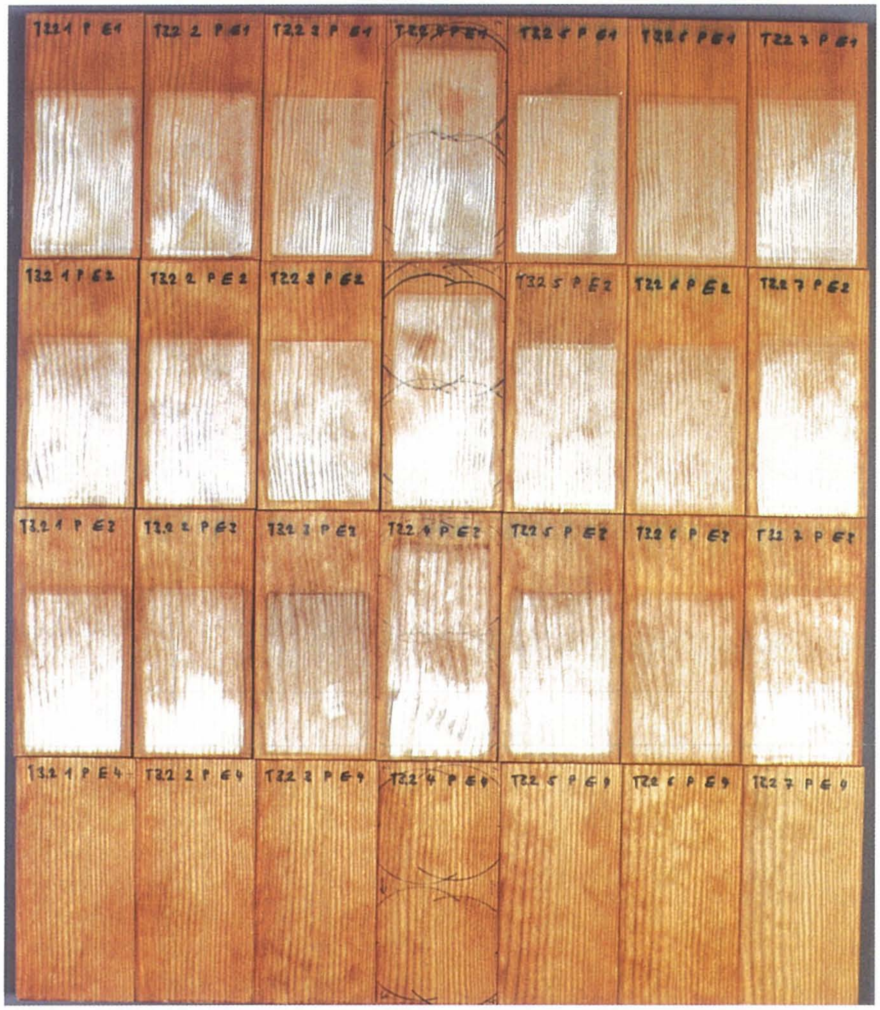

Photo 3: System E at the end of the optimized cycle.

weathering cycle to simulate the different aspects of moisture during the weathering. The moisture content of the wood substrate can be increased with condensation. The water spraying system is useful to produce the characteristic surface erosion of uncoated wood observed during natural weathering and to remove degraded material from the surface.

Development and Study of An Optimized Test Cycle (Reproducibility)

The results of the evaluation test series showed the most severe weathering effects for cycles one to three. Since a satisfactory artificial weathering has to produce a good correlation to natural weathering and a sufficient acceleration these three cycles were used as the basis for the development of an optimized exposure cycle.

The optimized cycle meets the main conclusions obtained from the evaluation test and presents the following characteristics: use fluorescent UV lamps with a peak emission at 340nm; use both condensation and water spray; use periodic extended periods of condensation to increase the moisture content of the wood substrate; use high frequency alternations of UV light and water spray to achieve a high number of short-term changes mainly on the surface. (The water spray is mainly used to remove degraded material from the surface and to produce frequent cold shocks); and total testing duration of 2,000 hours.

The optimized cycle is defined in Table 3. It consists of a long initial condensation phase, followed by short intervals of UV-light and water spray. It is rather simple and has the advantage of not requiring any special treatment outside the weathering devices. A new set of samples prepared by one laboratory was distributed to the different partners in order to test the reproducibility of the optimized cycle.

The first visual examination and comparison of the exposed samples from the different weathering devices gave the overall impression of a generally good agreement of appearance. Compared to earlier results, there was a markedly more uniform degradation effect with the different devices. After 2,000 hours of artificial exposure defects of various degree and types were present and the expected differences of the performance level of the used coating systems could clearly be seen. The general appearance of the samples after 2,000 hours of exposure

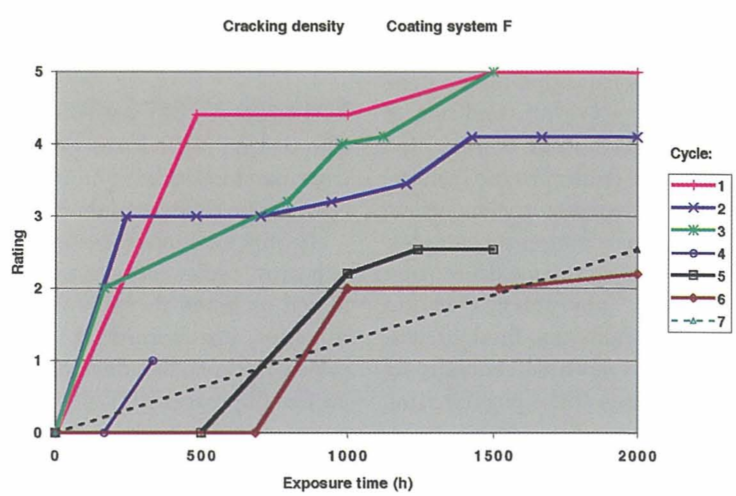

Figure 3: Cracking density with coating system F during 2,000 hours of exposure for the seven tested cycles.

Partner	Cycle	Exposure cycle	Duration of 1 Cycle	Total Exposure Time
WKI	1	[-24h condensation (45°C)][1] -(3h UV-340nm then 1h spray) during 120h -48h stored outside device (ambient conditions)	7 days	1860 hours
EMPA	2	-24h condensation (45°C) -(5h UV-340nm then 1h spray) during 96h	5 days	2033 hours
GORI	3	-24h condensation (45°C) -(5h UV-340nm then 1h spray) during 144h	7 days	2016 hours
BRE	4	-4h condensation (40°C) -4h UV-351nm	8 hours	2000 hours
Tikkurila and VTT	5	-4h condensation (40°C) -4h UV-340nm	8 hours	1500 hours
CTBA	6	-48h freezing (-20°C) -24h condensation (45°C) -(3h UV-340nm then 1h spray) during 96h	7 days	2016 hours
Traetek	7	-24h freezing/soaking in water [2] -(4h condensation (40°C) then UV-340nm) during 72 hours -72h soaking in water	7 days	2016 hours

Table 2: Evaluation test cycles.
Notes: 1—24 hours condensation only once at start of exposure. 2—2 hours freezing + 2 hours soaking + 2 hours freezing + 18 hours soaking.

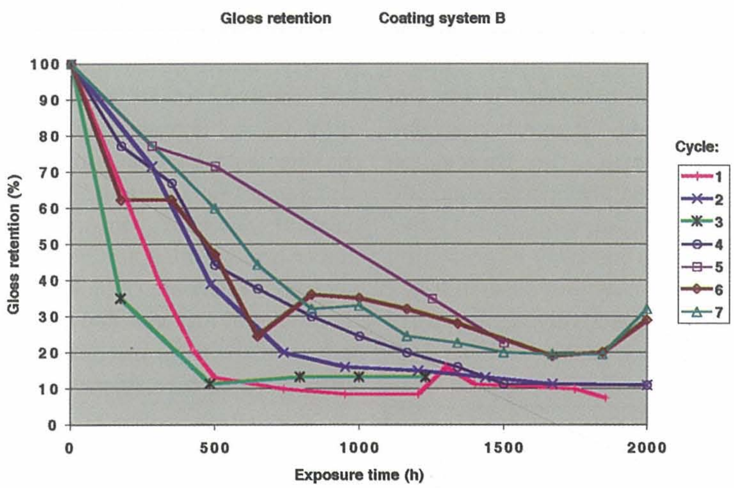

Figure 4: Gloss retention of coating system B during 2,000 hours of exposure for the different tested cycles.

Step	Function	Temperature	Duration	Remark
1	condensation	45°C	24 h	
2	subcycle step 3+4		48x	
3	UV	60°	2.5 h	UVA-340nm
4	spray		0.5 h	6-7 liters/min, UV light off
5	Go to step 1			
Total (1 cycle) 168h • Repetition of cycle = 12 x (i.e.12 weeks) • Total Duration Exposure = 2016 h				

Table 3: Optimized test cycle

with the optimized cycle in seven devices can be seen in Fig. 5.

As expected, in terms of general appearance the film-forming coating systems A to D show only small to moderate changes after 2,000 hours of exposure, while systems E (low-build stain) and F (uncoated wood) show intense changes compared to the unexposed control sample. The coating system A (acrylic paint) clearly shows the best overall performance. The acrylic stain D appears to perform better than the alkyd stain C (ICP). Agreement between the devices appears to be especially good with the coating system C (alkyd stain, ICP), while with systems A (acrylic paint), B (high-solid paint) and D (acrylic stain) some inter-device variation can be observed.

With systems E (see Photo 3) and F there are some obvious differences between the devices in terms of surface erosion, which do not reflect in the general appearance score. With some devices there is clearly an insufficient removal of degraded material from the sample surface probably coming from a non-uniform spraying pattern (severe erosion right in front of the spray nozzles, insufficient washing effect on the peripheral areas of the sample). This observation demonstrates the importance of a regular cleaning of the spray nozzles. This non-uniformity of the spraying pattern may not be as apparent with the film-forming coatings, but may still have undesired effects on the coatings degradation.

Fig. 6 shows the cracking density at the end of exposure with the optimized cycle in the seven devices. Cracking density and size show a similar performance pattern like the general appearance rating. As opposed to results obtained in the evaluation test series cracking is present now also with system A, which is still performing best. Cracking with systems B, C and D is slight to moderate. Systems E and F consistently show a dense pattern of fairly large cracks. In general the scores for cracking density and size are positively correlated. Interdevice variation is present with all the film-forming coating systems.

Considering the usually high variation of test results obtained with wood samples, the available preliminary results indicate that the reproducibility of the artificial weathering test is "acceptable." Reproducibility varies with the different assessment parameters and coating systems. The detected device effect can probably be attributed primarily to differences in the operation characteristics of the weathering chamber. Possible sources for differences in the operation characteristics are: UV output of the fluorescent lamps (ageing of the lamps); level and /or fluctuations of the room climate with a possible influence on the effectiveness of the condensation and/or the spray water temperature; water spray pattern and pressure (clogged spray nozzles); schedule of the sample rotation.

An improvement of the reproducibility of this artificial test method seems possible mainly by the definition and observance of a very strict test procedure. One of the most important goals in this regard would be the identification and elimination/limitation of the observed device effects.

An improved test procedure should mainly include precise specifications for: the wood substrate (e.g. growth ring angles); the sampling plan (e.g. uniformity of sample sets); the room climate (definition of bandwidth for temperature, relative humidity); the water spray (water quality, use of recycling system, filters, pressure, cleaning of nozzles); the maintenance during the exposure (e.g. control of lamp output, water spray, sample rotation); and the assessment methodology (e.g. color measurements).

Correlation to Natural Weathering

To verify any artificial weathering test method the correlation to natural weathering is still a key issue and the basis to estimate an acceleration factor. Correlation of performance data in artificial and natural weathering can be demonstrated by overlaying and visually comparing the time-series curves of selected performance parameters from artificial and natural exposure tests. This analysis is presented for cracking density and gloss in Fig. 7 and in Fig. 8 respectively in the case of device/laboratory #2. The time axis for natural exposure (up to 21 months) has been scaled down empirically to give the best overall correspondence for all coating systems.

Development of cracking agrees quite well for all the coating systems, with the possible exception of the alkyd stain (system C) which shows much more cracking in the artificial exposure. The empirically estimated overall acceleration factor is roughly five, but may need some individual adjustment for the different coating types. The characteristic course of the loss of gloss curves seems to be reproduced also quite well, but apparently with a considerably higher acceleration factor of about 10. Again the alkyd stain is degraded much more in the artificial exposure.

Another important issue of correlation to natural weathering is the moisture content of the wood substrate (MC) during the exposure. Moisture is closely linked to chemical changes of the coating and to cracking due to dimensional changes of the substrate. Earlier tests have shown that the MC during artificial exposure in the fluorescent device is on average much lower and shows a smaller range than observed outdoors. This has led to the inclusion of an extended condensation phase at the beginning of each cycle to increase moisture stress.

System	Solvent	Binder	Opacity	Variable	Expected Response
1	S	Alkyd	Opaque	Long oil	Long durable Gloss retention
2	S	Alkyd	Opaque	Medium oil	Short durable cracking
3	S	Alkyd	Translucent	Long oil	Long durable Gloss reduction
4	S	Alkyd	Translucent	Medium oil	Short durable cracking/flaking
5	S	Alkyd (as 3)	Translucent	Long oil + UV Abs	Long durable Good color retention
6	S	Alkyd (as 3)	Colorless	Long oil	Short durable/cracking/flaking
7	S	Alkyd (as 3)	Translucent	long oil 1 coat	Short durable/poor color retention/flaking
8	W	Acrylic	Opaque	High PVC	Good durable/cracking
9	W	Acrylic	Opaque	Low PVC	Long durable
10	W	Acrylic	Opaque	Low PVC Change extender	Long durable/ poor gloss retention
11	W	Acrylic	Translucent	High Tg	Short durable/cracking
12	W	Acrylic	Translucent	Low Tg	Long durable

Table 4: Coating systems tested with the optimized cycle.

Response of Different Coating Systems & Different Wood Substrates Tested With the Optimized Cycle

The optimized cycle was developed by testing six coating systems (A to F). In order to obtain more information concerning the optimized cycle various formulations of coatings were tested where single parameters are changed. This has been focused on parameters where a response in the outdoor performance is known from earlier experience.

Twelve coatings were tested including alkyd, acrylic, opaque or transparent systems with or without UV absorber, with high or low glass transition temperature, etc. Table 4 shows the 12 coating systems tested on pine with the optimized cycle. The performance for the alkyd systems follow the

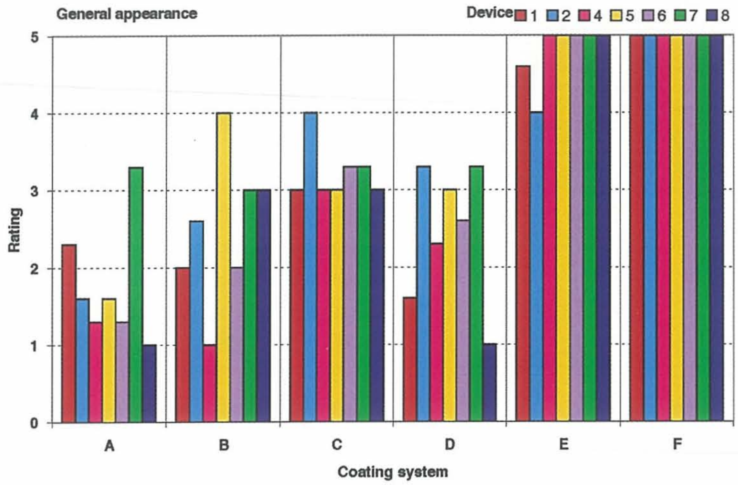

Figure 5: General appearance of the samples after 2,000 hours of exposure with the optimized cycle in seven devices.

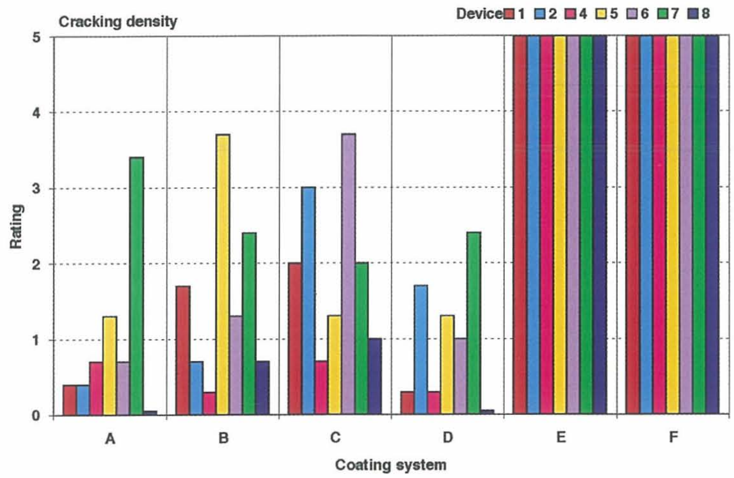

Figure 6: Cracking density after 2,000 hours of exposure with the optimized cycle in the 7 devices.

general trend which is observed at outdoor exposures on pine panels but also the experience obtained from exposures at joineries, facades etc.

For the acrylic systems the performance compared to outdoor exposures is very dependent on the pigmentation. The opaque systems did not follow the experiences from exterior conditions. It is known that opaque acrylic systems in general can result in very long durabilities. A consequence can be that these systems may need longer exposures with the optimized cycle than 2,000 hours. It is therefore recommended to investigate this further.

For the translucent acrylic systems there was a good correspondence with the outdoor performance. As for the alkyd systems this is however only based on one acrylic formulation and further experiments may be needed to investigate the performance of other formulations using the optimized cycle. The trend was very clear and there is a potential to use the optimized cycle.

The optimized cycle was developed by testing six coating systems (A to F) on pine only. It was important to determine whether the optimized cycle can be used to evaluate the performance of coating systems on different wood substrates.

In this exercise the six coating system (A to F) have been investigated on five wood substrates: beech, oak, spruce, meranti and exterior plywood. This evaluation involved an assessment of the comparability of the results obtained following the artificial weathering cycle with those obtained from the natural weathering test carried out according to prEN927 –3.

The results indicate that the cycle enables differentiation between the performance of different coating systems and differentiation between coating performance on different wood substrates. The amount of cracking found was dependent upon the wood substrate. Most cracking was found on pine, oak and plywood. The performance on one wood species should not be used to indicate performance on different wood substrates. Performance on other wood substrates would need to be evaluated.

Conclusion

The principal aim of this European research project was to develop an artificial weathering method to assess the durability of exterior wood coatings in a short time period.

The objective was to base the method on the modern and relatively low-cost fluorescent lamp apparatus originally developed for coated steel and plastics substrates, adapting equipment and operating cycles to meet the needs of wood substrates. Several cycles were defined from the experience of the 14 partners involved in this project. They included different types of UV radiations, condensation, spray, high and low temperature, freezing and soaking. These cycles were tested on six coatings systems.

From the results obtained with these cycles it has been possible to define an optimized cycle. This cycle is made of 24 hours of condensation followed by a sub-cycle of 2.5 hours of UVA-340nm and 0.5 hours of water spray. The reproducibility of this cycle has been studied: eight partners tested this cycle with the same six coatings using a detailed test procedure. The reproducibility was correct even if some sources of variation have been identified.

Then this optimized cycle has been tested on several coatings. The purpose of this task was to investigate if further variations in systems and products used on exterior wood compared to the first six systems used in the main experiments would follow the performance known when the optimized cycle is used. The performance for the alkyd systems followed the general trend which was observed at

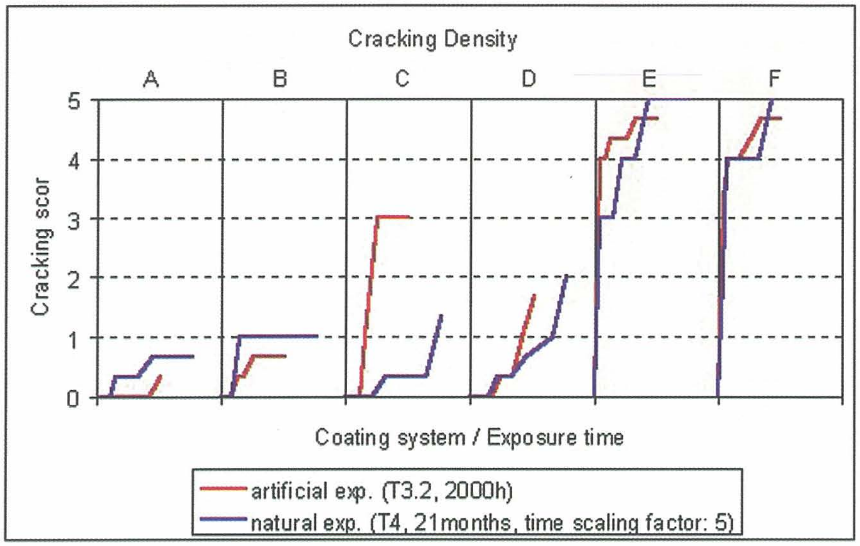

Figure 7: Cracking density—correlation of artificial (optimized cycle) and natural weathering (example from device/laboratory #2).

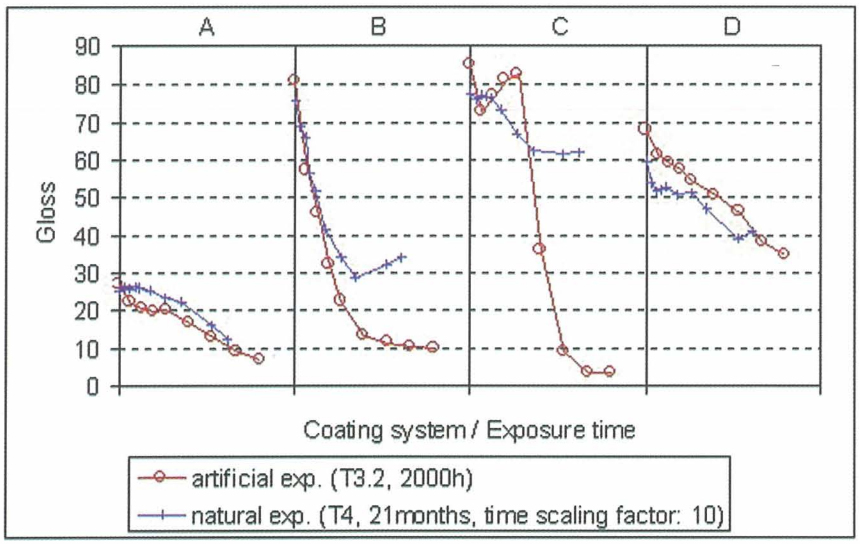

Figure 8: Loss of Gloss—correlation of artificial (optimized cycle) and natural weathering (example from device/laboratory #2).

outdoor exposures on pine panels but also the experience obtained from exposures at joineries, facades, etc. For the acrylic systems the performance compared to outdoor exposures is very depending on the pigmentation.

The optimized cycle has been tested on different wooden substrate to determine whether it can be used to evaluate the performance of coating systems on different wood substrates. The six main coating systems were tested on oak, beech, spruce, meranti and exterior plywood. The results have indicated that the optimized cycle enables differentiation between coating performance on different wood substrates.

At the end of the project guidelines for a draft standard have been defined. Considering that the artificial weathering test method should be refined, the consortium agreed to suggest to CEN/TC139/WG2 a draft for a European Prestandard: prENV927-6: coating materials and coating systems for exterior wood. Part 6: Method, assessment and evaluation for an artificial weathering test for wood coatings based on fluorescent lamp apparatus.

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