PERFORMANCE OF WOOD PRESERVING AND WOOD FINISHING SYSTEMS FOR EXTERNAL JOINERY EXPOSED TO NATURAL WEATHERING

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CONTENTS

INTRODUCTION

MATERIALS AND METHODS

Selection of wood species
Product and system types
Application methods
Exposure conditions

RESULTS AND DISCUSSION

Film thickness and penetration
Physico-chemical performance

Action by water

Influence of natural weathering on the diffusivity resistance coefficient
Influence of natural weathering on the water repellency
Influence of weathering on the overall moisture content

Action by light

Blue stain-in-service resistance
Weathering performance

GENERAL CONCLUSIONS
TABLES AND FIGURES
REFERENCES

INTRODUCTION

Wood exposed out-of-doors will undergo a complex combination of chemical, physical, mechanical and biological influences, which finally will lead to the degradation of the wood substrate. The deterioration of the wood surface under this unfavourable environment is generally referred to as the weathering. Weathering is not to be confused with decay, which results from the presence of excessive moisture for an extended period of time.

The preservation, finishing and maintenance of external joinery and timber assume the extension of the classical preservation against biological deterioration towards a physico-chemical protection against atmospheric influences.

According to the Belgian technical specification STS 52 (1973) external joinery is defined as "wooden parts which are completely or partly exposed to the natural weather conditions". However, wood should also give the mechanical strength to these elements. In the STS 52 windows, doors and wooden fronts are described under exterior joinery. Feist (1982) defines exterior wood surfaces as e.g. siding, decking, millwork. The wooden elements referred to in this paper are specified in the BWPA Manual (1986) under commodity specifications :

- C5: Preservative treatment of non-load-bearing external softwood joinery and external fittings (excluding cladding) not in ground contact.
- C6: Preservative treatment of external timber cladding.

Wood exposed out-of-doors may be protected either in a non-chemical or a chemical way.

Non-chemical protection is often also called constructional protection. This includes all preventive measures of architectural, constructional and material-technical nature.

Chemical protection involves the pretreatment, finishing and recoating with "wood preserving and wood finishing products". In the literature, these products are given different names such as: exterior wood stains (Hilditch 1983), pigmented stains, penetrating stains (Feist 1978), surface finishes (BWPA Manual 1986), coloured organic solvent wood preservatives (Hilditch 1983), wood-preserving stain, transparent wood finish, stain, topcoat product, preventive preservative (Anon 1982).

In this paper these products will be called 'exterior wood stains'. They form the point of contact between two different industrial approaches: on the one hand, the wood preserving industry which lays the accent on a biological preservation against fungi and/or insect attack and, on the other hand, the paint manufacturers who put the main emphasis on the physico-chemical performance of the products.

In a small country like Belgium about 100 of such products are currently available on the market. For many years this diversity has provoked a confusion with the official organizations, the professional users and not at least with the do-it-yourself consumers.

Therefore it was decided to start in 1980 with a research project which should investigate the efficacy of exterior wood stains under weather conditions when applied to wood species which are normally used for external joinery in Belgium.

The STS 52 specifies the type of wood preservatives for external joinery and the methods by which timbers may be protected. The Belgian homologation system is based on a classification of products in relation to the type of structural elements, taking into consideration the conditions of exposure and the timber species used. Products for external joinery are classified in homologation class C and are defined in Table 1 (Stevens and Cockroft 1981). Recently (1988) this table has been modified. C3-products have been deleted from the list. C1-products should now always provide an insecticidal protection. One group of products, generally referred to as "TOP-products" could not and still cannot obtain a homologation under the existing Belgian homologation scheme, although these products have known an increasing popularity among the do-it-yourself public. A major objective of our study was to investigate the performance of this product group.

It was also a general feeling at the start of this project that thinking in terms of products was no longer an appropriate approach to the treatment of external joinery. In Belgium it is common practice that external joinery receives different treatments which are dispersed in time. Therefore, combinations of products or different coats of single products were evaluated.

Each combination forms a so-called "external joinery preserving and finishing system". Our research aimed at finding out which "systems" would have the best life-expectancy.

A selection of the investigated parameters will be reviewed in this paper. Special attention will be paid to physico-chemical characteristics of the "systems" such as the thickness of the coats, the penetration depth, the influence of natural weathering, the blue stain-in-service resistance and the degradation patterns. Finally, some general conclusions on the performance of the investigated wood preserving and wood finishing systems will be discussed.

MATERIALS AND METHODS

In this section the general methodology of the exposure studies is described. Specific methods investigating the influence of individual parameters will be dealt with in relation to the discussion of the individual results.

Selection of wood species

In Belgium about 50 % of the wood for external joinery consists of meranti (*Shorea species*). For this study, meranti of a common commercial quality as well as DRM (Dark Red Meranti) and LRM (Light Red Meranti) were selected.

Another tropical hardwood species retained was merbau (*Intsia spp.*).

Softwoods were represented by both Scotch pine (*Pinus sylvestris*) and spruce (*Picea abies*). The former one is only allowed for external joinery when treated with a C3-product (nowadays replaced by a C1-product).

Spruce (*Picea abies*) is one of the main softwood species grown in the Southern part of Belgium. However, it does not figure in the STS 52 list of timber allowed for external joinery. Nevertheless, it seemed worthwhile to determine its potential use for external joinery.

Planed flat sawn test samples free of any visible defects, measuring 40 x 8 x 2 cm, were used. For meranti and merbau only heartwood was selected, for spruce and red pine in addition also sapwood boards were tested.

Product and system types

Forty-two (42) different products, 35 of which were commercially available, were studied and are listed in Table 2.

It appeared from the literature that the solid content is an appropriate criterion to divide exterior wood stains into groups (CTB 1983, Hambling 1976, Hilditch and Crookes 1981, Janotta 1975, Klug 1976). Each group was further subdivided on the basis of active ingredients, i.e. fungicides against decay (D), blue stain-in-service (B) or insecticides (I).

In Table 2 the Belgian classification is compared with the classification proposed by Hilditch and Crookes (1981). The presence of 18 "Top-products" reflects their popularity on the Belgian market. However, 6 of these high-build stains did not contain a biocide. This is the main reason why the Belgian Wood Preservation Association has not yet included this group in their classification.

The group of 42 products was combined to 77 systems. Each system consisted of products originating from the same manufacturer to avoid incompatibilities and premature failures. The 77 combinations may be grouped in 10 "Treatment Types", which are presented in Table 3.

Application methods

Each sample underwent a pretreatment on all sides during the first application. Application techniques prescribed by the various manufacturers were: brushing, short immersion and vacuum-pressure for the CCA type products. The subsequent finishing coats were always applied by brushing.

Exposure conditions

All samples were placed on aluminium racks under a 45° angle facing the south-west on the roof of the faculty for agricultural sciences of the State University of Ghent.

RESULTS AND DISCUSSION

FILM THICKNESS AND PENETRATION

An efficient coating system should leave a surface film on the wood substrate to protect it from atmospheric influences, but at the same time a good penetration should be achieved to ensure a good biological protection.

For the determination of the thickness of the surface film, Scotch pine samples (10 x 4 x 1 cm) were treated with different systems at a coverage rate of 210 g/m^2. The thickness was measured on 25 µm slides by means of a digitizer.

Results are presented in Figure 1. It appears from this figure that the treatment types can be divided into two main groups, i.e. non-film-forming (C-systems of types I & II) and semi-film-forming (Top-systems of types III-X). Product systems with a waterborne acrylic or alkyd-acrylic resin formed a layer of 100-140 µm.

The various statistical analyses revealed that the primer coating and the final coating were the most important for the film thickness. Consequently, treatments with types I and II require at least 3 coats to assure a good weathering resistance.

For the protection against blue stain and decay fungi the fungicides should also penetrate in the wood substrate. It is generally accepted that at least 1.5 to 2 mm penetration is needed for blue stain-in-service control. For protection against decay a deeper penetration is required. Normally exterior wood stains are only applied by brushing, spraying or short immersions. The effect of superficial treatment techniques on their fungicidal effectiveness forms still today in many countries the topic of a wide debate. It is not the purpose of this paper to enter this debate.

The penetration depth was determined according to DIN 52162 (1980). Penetration varied substantially within each treatment type. Certain systems showed no penetration front at all, due to the blockage of the Ceresblue dye by the binders at the surface. This was mostly the case with high-build stains with a solid content of 40-60 %. Systems with a C1/C3-pretreatment showed penetrations of 2.3 to 4.5 mm, whereas C2-systems varied between 1.0 to 2.9 mm penetration. Top-systems showed only a limited penetration of 1.0 mm at the most. Statistical analysis on all penetration data revealed a very significant relation between the penetration depth of the first coat and the total system. This means that the first application should be carried out with great care, since it determines both the formation of the film and the penetration into the wood substrate. It was also noted that pigmented products showed a significantly lower penetration in comparison to the unpigmented types. This is illustrated in Table 4.

In addition, a biological assessment of the penetration was also carried out. Therefore samples were exposed to a mixed culture of *Aureobasidium pullulans (DeBary) Arnaud P268* and *Sclerophoma pityophila (Corda) v. Höhn S231*. After six weeks' exposure the blocks were cut transversely and the Biological Effective Penetration Depth (BEPD) was measured.

Data are given in Figure 2 which compares the penetration values of some representative systems with the results obtained with the DIN 52162 standard. Almost all systems showed a larger BEPD as could be expected from the DIN 52162 test. This clearly emphasizes the different penetration of the Ceresblue dye to that of the biocides. In particular, this phenomenon was observed for the medium and high-build stains.

PHYSICO-CHEMICAL PERFORMANCE

During the natural weathering, treated samples are exposed to atmospheric influences such as water, light and heat. The ability of the systems to resist these detrimental effects has been examined by the resistance of the systems to the penetration of water. This resistance is greatly defined by the diffusivity resistance coefficient and the water repellency of the systems. These characteristics will also define the fluctuations in overall moisture content of the underlaying wood substrate.

ACTION BY WATER

Influence of natural weathering on the diffusivity resistance coefficient μs

The diffusivity resistance coefficient μs relates the water vapour permeability of the tested material to the water vapour permeability ~~to the permeability~~ of an air layer of the same thickness under equal test conditions i.e. temperature, barometric pressure and vapour pressure difference.

μs = $\lambda L / \lambda s$
λL = water vapour permeability in air (kg/m.h.Pa)
λs = water vapour permeability through system (kg/m.h.Pa)

The diffusivity resistance coefficient μs for the various systems was determined according to the method developed at EMPA - Switzerland (Kühne and Sell 1971 a and b, Sell and Leukens 1971, Kühne *et al* 1972, Sell 1975 and 1976). From μs the specific diffusivity resistance factor Us can be calculated. It expresses the thickness of an undisturbed air layer with the same μs of the tested system.

Us = μs x s (expressed in metres)
s = thickness of film in μm

In Table 5 μs en Us for different product systems before and after natural weathering are recorded. The weathering was performed on treated meranti cylinders which were exposed under a 45° angle facing the south-west for 6 months.

In practice, C-, C + TOP- and TOP-systems can be defined as non-film-forming, semi-film-forming and film-forming treatment types. It was also generally accepted that these systems were porous, semi-porous and non-porous. It appears from Table 5 that there was no such relationship. Our research demonstrated that the diffusivity resistance coefficient of the individual systems was significantly affected by the film thickness, the type of binder and the water-repellent characteristics.

The changes of the water vapour permeability λs of some systems due to natural weathering are pictured in Figure 3. Systems with a mean film thickness higher than 50 μm showed no increase in vapour permeability after 6 months' exposure. These systems possess a Us greater than 1.5 metres. According to Bagda *et al* (1981) a system showing a Us greater than 2 m can be defined as water vapour resistant. Therefore it is possible to determine a critical film thickness S which guarantees a Us above the minimum value. The Us was measured for different combinations of a certain type of a C2- and a Top-product.

From Figure 4 it can be seen that a product system with a mean thickness greater than 36 µm will protect the external joinery against an increase in water vapour permeability.

Types I and II may exhibit a decrease in diffusivity resistance coefficient after natural weathering. The other types (III-X) showed no increase in water vapour permeability under the weathering conditions of this test.

Influence of natural weathering on the water repellency

All exposed samples were visually inspected at regular intervals. With nearly all systems a decrease in water repellency was noted within 4 months from the start of the weathering. Samples which received a maintenance coat showed the same decrease after about 3-4 months.

In Table 6 the change of the contact angle due to weathering is illustrated. For each system independent of the treated wood species, a contact angle greater than 90° was measured prior to the weathering. After 3 years' exposure the contact angle had dropped to values below 90°. The maintenance had no significant influence on the permanence of the water repellency.

Influence of weathering on the overall moisture content

The movement of moisture in treated wood through the exposed surface coating is most important. The ability of the systems to monitor the moisture movement can be followed by measuring the overall moisture content fluctuations of the wood substrate. The systems should avoid the building up of a water content at a level which permits fungal decay. This level is generally fixed at 20 %. As previously discussed the diffusivity resistance coefficient is the major controlling factor.

In Figure 5 the moisture content fluctuations of the four untreated wood species during 137 weeks of natural weathering are given. The overall moisture content of the softwood species showed the greatest variations. They increased with a proceeding weathering time.

The changes in moisture content of meranti samples treated with 4 different systems are visualized in Figure 6. All treatments were sufficient to keep the moisture content below the critical 20 % level. However, the difference between the treated and the untreated meranti decreased with time due to physical degradations, increased water vapour permeability etc. From Figure 7 it is also obvious that after 3 years' weathering none of the tested systems was still able to keep down the moisture content in the wood.

On merbau (Figure 8) the stabilizing effect of the various treatments was better compared to meranti, probably because of the higher dimensional stability of this timber species and the high μs values (50,000 to 80,000).

The results on spruce (Figure 9) were unexpectedly encouraging. Both tested systems significantly reduced the moisture content in comparison with the untreated samples. On the basis of these results spruce proves to be a suitable timber species for external joinery.

The overall moisture content of Scotch pine sapwood samples pretreated with a C3-product and finished with a medium- or high-build stain exhibited important fluctuations. During the wettest periods the moisture content even exceeded the fibre saturation point of 30-35 % (Figure 10). This leads to the conclusion that Scotch pine sapwood is less suitable for external joinery.

ACTION BY LIGHT

Besides the effect of water, radiation also causes a superficial deterioration of wood stains and exposed wood surfaces. The effect of a light degradation can be observed in a variety of phenomena e.g. the loss of gloss, the darkening of the coating etc. Some of these visually noticeable changes were quantitatively determined during this research programme.

The glossy appearance of exterior wood stains is a decorative aspect which should last as long as possible, preferentially up to the end of the period of maintenance. In Table 7 a summary of the gloss-values before and after 6 months of weathering is given. The gloss percentage was measured with a Multiangle Glossmeter under a light incidence angle of 60°. Only a minimal loss of 0 to 13 % was noted after 6 months.

Spectral reflectance measurements were used to determine the visual changes on an objective basis. Figure 11 shows the effect of light falling on a coating before and after weathering. A part of the incident light (Io) is reflected by Fresnel-reflection (Su). The non-reflected part penetrates the film and is refracted, scattered or absorbed. The remaining non-absorbed part of the light is again reflected by Fresnel-reflection at the underside of the film (Si) and leaves the film as diffuse reflected light (D). Through these selective absorptions and reflections the human eye can detect the colour of the film. If the surface is still "smooth", the Fresnel-reflection will be a 'specular reflectance'. If the film has degraded by, say, natural weathering the 'diffuse reflectance' will increase.

In our research ten systems were applied to an aluminium surface in three coats. Before and after 6 months' weathering, the spectral reflectance over the wavelength range of 240-800 nm was measured. Berner and Rembold (1982) demonstrated that about 4 % ofthe light falling on a smooth surface (n=1.5) is directly reflected (Rs1). The remaining 96 % penetrates the film and is absorbed or undergoes multiple internal reflections. The remaining part is reflected by the aluminium support and is detected by the spectrophotometer as the specular reflectance (Rs2). The residual part of the light is measured as diffuse reflectance (Rd). For each system the reflectance parameters were measured as Rt = Rs1 + Rs2 + Rd, in which Rs1 = 4 % x G (gloss value).

The changes in light reflectance of two specific systems due to natural weathering are given here as examples. The dark pigmented C2-type system (Figure 12) showed about 10 % more reflection in the UV-light range compared to the semi-transparent C2+Top-system (Figure 13). The total reflection, on the contrary, was lower in the visible light range with the C2-system. This difference could be visually detected as a difference in gloss. Due to weathering the specular reflection over the 240-800 nm range decreased in both systems. The diffuse reflection on the contrary increased, which indicates the start of a surface erosion. From both figures (12 and 13) it also appears that iron oxide pigments which were used to colour the tested stains are very effective UV light absorbers.

Our research indicated that spectral reflectance measurements proved to be an appropriate technique to quantify light degradation effects.

BLUE STAIN-IN-SERVICE RESISTANCE

Exterior wood stains will last longer when they resist the growth of blue stain fungi. The CEN has developed the EN 152 standard to assess the performance of wood preservative treatments including exterior wood stains against blue stain-in-service. According to this procedure, both the proportion of surface stain and the depth of wood free from stain are determined.

In this project the EN 152 was used for testing whole system performances instead of single product performances. A 6 months' natural weathering was applied as ageing procedure. The results of the tests carried out between 1980 and 1985 are presented in Figure 14. Out of 67 systems only 4 showed an internal protected zone less than 2 mm whilst 54 had a blue stain-free zone larger than 3.5 mm. All systems could be divided into four groups:

A . Systems with a good to excellent blue staining resistance.

B . Systems with a medium blue stain protective action. In this case, some superficial staining occurred during the subsequent laboratory test owing to the erosion during weathering.

C . In this group only a failing superficial protection was noted.

D . These systems both fail at the surface and underneath the coating system.

Obviously, a pretreatment applied by immersion or vacuum-pressure resulted in the largest blue stain-free zones.

In order to find out which treatment types provide an adequate protection, a blue staining index was calculated:

Ib = Surface staining + 1/mean protected depth

For the untreated samples Io was determined in the same way. Each year Ib and Io were compared and an Efficacy Value (%) was calculated:

E (%) = 100 - [(Ib/Io x 100)]

By using E (%) the natural resistance of the untreated wood samples and the seasonal variations were taken into account. Effective protection can be guaranteed by a E-value of 65 % minimum.

From Table 8 it appears that 37 systems proved to be effective. The number of systems with a E ≥ 65 % for each treatment type are also indicated in the score column. These scores vary between 0 (no system with E ≥ 65 %) and 1 (all systems with E ≥ 65 %). Both the absence of an effective fungicide and the failing weathering resistance are the main reasons for an inadequate overall protection. It was also noted that protective systems with a medium- or high-build stain topcoat performed better than low-build finishes.

All systems which passed the EN 152 tests were further examined microscopically. Different blue staining patterns were observed. It again appeared that the biological resistance of the systems against superficial staining largely depended upon the weathering resistance, proving ageing procedure before biological assessment. Since film thickness and weathering resistance are rather related to each other, it seemed logical to investigate the influence of the number of coats on the blue staining resistance. System combinations of a C2 -and a Top-product both containing 0.6 % dichlofluanide were studied in this respect. Table 9 reveals that a minimum of three coats is needed to achieve a good performance independent of the combination. This leads to the conclusion that external joinery constructed of blue staining susceptible timbers should receive different treatments.

From the previous discussions, it also can be concluded that each product applied to externally exposed timbers should contain an anti-blue stain fungicide. Under these conditions the treatment types used here can be regrouped i.e. III, IX, X = VI and IV, V = VII. A further conclusion regards treatment type II (C1 + C2 combination) which seems unsuitable for exterior exposures, reducing the ten treatment types to four final systems.

WEATHERING PERFORMANCE

Apart from defining the physico-chemical and biological influences responsible for the degradation of the exposed systems also the general weathering performance was investigated.

During the 36 months' exposure period alle samples underwent a visual and a microscopic inspection at regular interval. All samples treated with the same system received a mean score from 4 to 1.

Score	Visual assessment
4	- No change compared to unweathered conditions.
3	- Small changes i.e. loss of gloss, a homogeneous darkening or lightening of the colour. No asthetic or technical loss.
2	- Significant changes i.e. peeling, slight blue staining, microchecks etc. A maintenance coat can still restore these defects.
1	- Advanced erosion i.e. checking, significant blue staining etc. A maintenance coat can no more restore these failures.

Table 10 shows that all untreated samples had completely degraded at the surface after only 12 months of exposure. The most significant changes observed during the weathering process are marked in Table 11. A superficial greying due to light degradation was seen in all tested species. This was accompanied by a dirt accumulation on the softwood species. After 3 years' exposure an incipient decay (brown rot) was observed on the sapwood of both spruce and pine. Typical degradations linked to the type of wood such as bleeding, resin exudation etc. were noted as well.

From the visual evaluation of the treated wood samples some general conclusions could be drawn:

1. Systems with a film thickness lower than 25 µm failed systematically, independent of the wood species.
2. The nature of the binders used in the exterior wood stains seemed to have a great influence on the global weathering resistance.
3. Tropical wood species such as merbau having a high extractive content must be finished with a semi-film-forming or a film-forming system even when they have been pretreated to avoid bleeding.
4. When softwood is used, it seems advisable to expose the heartwood face to the exterior conditions as much as possible.

The microscopic observations revealed some typical erosion patterns for both the hardwoods and the softwoods. In the tropical hardwood species the erosion occurred the fastest on the sharp edges and in the vessel lines, whereas in the softwood samples degradation of the coatings was first noted at the sharp edges, on areas with high resin content, on the interface of spring- and summerwood and around knots.

In an attempt to divide the tested systems into different microscopical erosion types, two typical patterns could be defined:

A . Systems with a homogeneous erosion pattern

Appearance:

- colour changes: homogeneous darkening or lightening of the colour;
- loss of gloss;
- powderlike degradation ("farinage");
- microscopical checks in the coating.

Erosion pattern: "crocodile skin pattern"

V- shaped microchecks can be seen all over the surface. Dirt accumulation and in some instances blue staining first occurred in these microchecks. Systems with this erosion type can be recoated without an intensive maintenance procedure.

B . Systems with a heterogeneous erosion pattern

Appearance:

- colour changes: spotwise or patchwise darkening or lightening;
- peeling of the layer;
- pronounced blue staining;
- formation of microchecks in the wood substrate.

Erosion pattern: "birdsfeet pattern"

The surface is irregularly eroded. The maintenance is very intensive and it is mostly difficult to restore the original coating appearance.

By coupling the visual inspection with the microscopic observations it became once again clear that the biological performance and the physico-chemical performance are closely related. A regrouping such as performed after the biological tests was not possible here. The main reasons were:

- the use of stable and durable wood substrates;
- the use of film-forming products showing a slower degradation compared to the non-film-forming ones. Perhaps accelerated weathering can indicate much faster the differences between the film-forming systems;
- the quality of the individual products in a system has a substantial effect on the overall efficacy of the system.

GENERAL CONCLUSIONS

The various experiments carried out gave evidence that only three different types of exterior wood stains should be defined for further homologation i.e. low-build stains (C1), medium-builds (C2) and high-builds (Top). The main characteristics these products should possess are given in Table 12.

The above-mentioned product types can be combined to six different treatment types, which proved to be acceptable for the preservative-finishing treatment of external joinery (Table 13). It is recommended to apply the different coats with the shortest delay in order to avoid premature erosion during the first exposure period of the joinery elements.

Table 14 summarizes the suitability of the various treatment types for their application to external joinery timbers under different exposure conditions. From this table the most appropriate combination i.e. with the best life-expectancy can be derived.

TABLE 1: Homologation classes for wood preserving products used on external joinery in Belgium.

Homologation	Function	Treatment	Remarks
C1	protection against fungal decay, insect attack, blue staining and temporary penetration of water	dipping, brushing, double vacuum impregnation	treatment must be followed by a finishing system (paint, C2 product...)
C2	ditto C1 complete system of protetion and pigmented finishing	3 coats brushing, dipping	must be compatible with paints and varnishes
C3*	ditto C1 external joinery made of Pinus sylvestris	ditto C1	ditto C1

C3* has recently been deleted from this list (1988).

TABLE 2: Product types used for the external joinery treatment systems.

Number of Products	Belgian Classification	Solid Content %	Biological efficacy					Hilditch & Crookes Classification exterior wood stains
			DBI	DB	DI	B	NONE	
10	C1/C3	10-20	4	5	-	-	1	penetrating stains (low-build stains)
12	C2	20-35	7	2	-	3	-	medium-build stains
18	TOP	35-60	3	-	-	9	6	high-build stains
2	A1	-	-	-	2	-	-	CCA-C type salts

D = product containing fungicide against decay fungi
B = product containing fungicide against blue stain-in-service
I = product containing insecticide

TABLE 3: Treating types for external joinery used in outdoor weathering.

Treatment Type	Product Combination	Number of Coats	PRODUCT FUNCTION		
			Preservation	Finishing	Maintenance
I	3 x C2	3	C2	C2	C2
	2 x C2WB	2	C2WB	C2WB	C2WB
II	C1/C3 + 2 x C2	3	C1 & C2	C2	C2
	An + 2 x C2	3	An & C2	C2	C2
	C1 + 3 x C2	4	C1 & C2	C2	C2
III	C1 + 2 x (TOP)	3	C1	(TOP)	(TOP)
	C1 + 3 x (TOP)	4	C1	(TOP)	(TOP)
IV	C2 + 2 x (TOP)	3	C2	C2 & (TOP)	(TOP)
V	(C1) + 2 x (TOP)	3	-	(C1) & (TOP)	(TOP)
	3 x (TOP)	3	-	(TOP)	(TOP)
	2 x (TOP)	2	-	(TOP)	(TOP)
VI	C1/C3 + 2 x TOP*	3	C1/C3 & TOP*	TOP*	TOP*
	An + 2 x TOP*	3	An & TOP*	TOP*	TOP*
	2 x C1 + 2 x TOP*	3	C1 & TOP*	TOP*	TOP*
VII	C2 + 2 x TOP*	3	C2 & TOP*	C2 & TOP*	TOP*
VIII	3 x TOP*	3	TOP*	TOP*	TOP*
IX	C1 + 2 x TOP	3	C1 & TOP	TOP	TOP
X	2 x C2 +TOP	3	C2 & TOP	C2 & TOP	TOP

C2WB = waterbased C2-product
(TOP) = high-build stain without active ingredients
TOP* = high-build stain with only fungicide against blue stain-in-service
TOP = high-build stain with fungicide against decay and blue stain-in-service
(C1) = C1-type product without active ingredients

TABLE 4: Influence of pigmentation on penetration depth.

System	Pigmentation	Mean pigmentation depth (mm) (120 measurements)
3 x C2	colourless	3.5
	Teak	1.9
C2 + 2 x TOP	colourless	2.5
	Teak	1.4
3 x TOP	colourless	0.0
	Teak	0.0

TABLE 5: Influence of natural weathering on the diffusivity resistance coefficient.

System	Non-weathered		Weathered	
	μs	Us (m)	μs	Us (m)
3 x C2	28,700	0.9	8,800	0.3
	20,300	0.6	12,000	0.4
2C2 + 2 x TOP	52,400	2.6	45,400	2.3
	51,800	2.6	52,800	2.6
C2 + 2 x TOP	77,600	5.4	72,300	5.1
	76,000	5.3	76,600	5.4
C1 + 2 x TOP	30,000	1.8	28,800	1.7
	30,500	1.8	23,800	1.4
3 x TOP	29,000	2.6	28,700	2.6
	24,000	2.1	24,400	2.2
3 x C2	29,600	0.9	11,000	0.3
2 x C2 + TOP	83,800	4.2	76,700	3.8
C2 + 2 x TOP	72,900	5.1	71,600	5.0
3 x TOP	79,600	7.2	80,400	7.2

TABLE 6: Change of the contact angle due to the weathering

System	Wood Species	Pigmentation	CONTACT ANGLE		
			start	3 y.weath. no recoating	3 y.weath. recoating
2 x C2 + TOP	meranti	light	114	14	20
		dark	107	8	15
	merbau	light	113	25	23
		dark	107	8	17.5
C3 + 2 x TOP	red pine	light	95	10	34
C2 + 2 x TOP	spruce	light	95	10	16
3 x C2	meranti	light	95	8	12

TABLE 7: Change of gloss-percentage after 6 months natural weathering.

System	Colour	Start weathering %	After 6 months weathering %
3 x C2	teak	83	73
3 x C2	oregon	81	80
3 x C2	teak	65	59
3 x C2	teak	55	54
2 x C2 + TOP	light brown	34	34
C2 + 2 x TOP	teak	27	23
C2 + 2 x TOP	teak	61	60
C2 + 2 x TOP	light brown	38	25
C2 + 2 x TOP	dark brown	40	33
C2 + 2 x TOP	teak	86	84

TABLE 8: Efficacy values for the different treatment types.

Treatment type	Total Number	Not-effective E < 65 %	Effective E > 65 %	Score
I	15	7	8	0.53
II	10	9	1	0.10
III	2	-	2	1.00
IV	4	3	1	0.25
V	3	3	-	0.00
VI	18	3	15	0.83
VII	6	1	5	0.83
VIII	3	1	2	0.67
IX	3	-	3	1.00
X	3	3	-	0.00

TABLE 9: Influence of the number of coats on the blue staining resistance.

Treatment		Surface score	Blue stain-free zone (mm)
C2	1 coat	2.4	0.8
	2 coats	0.4	1.3
	3 coats	0.0	2.7
TOP	1 coat	3.0	0.5
	2 coats	2.4	2.7
	3 coats	0.0	2.4
C2 + TOP	1 + 1	2.2	3.0
	1 + 2	0.2	2.9

TABLE 10: Visual assessment of untreated samples at regular intervals during weathering.

Wood species	Exposure period									
	0 m	3 m	6 m	9 m	12 m	15 m	18 m	21 m	24 m	36 m
Meranti	4	3	3	3	2	2	2	2	2	1
LRM	4	3	3	2	2	2	2	2	2	-
DRM	4	3	3	3	2	2	2	2	2	-
Merbau	4	3	3	3	2	2	2	2	2	2
Spruce sapwood	4	2	2	1	1	1	1	1	1	1
Spruce heartwood	4	2	2	1	1	1	1	1	1	1
Pine sapwood	4	2	2	2	1	1	1	1	1	1
Pine heartwood	4	2	2	2	2	2	1	1	1	1
Pine flatsawn	4	2	2	2	1	1	1	1	1	-
Pine quartersawn	4	2	2	2	2	1	1	1	1	-

TABLE 11: Degradation phenomena observed during weathering after 3 years' exposure.

Degradation pattern	Wood species					
	Meranti	Merbau	Scotch pine		Spruce	
			Sapwood	Heartwood	Sapwood	Heartwood
Greying	x	x	x	x	x	x
Blue-staining	(x)	(x)	x	x	x	x
Dirt accumulation	x	x	x	x	x	x
Vesselline erosion	x	x	-	-	-	-
Bleeding	-	x	-	-	-	-
Resin Exudation	-	-	-	x	-	-
Checking	(x)	-	x	(x)	x	(x)
Fibrous surface	-	-	x	(x)	x	(x)
Algae growth	-	-	x	-	-	-
Decay	-	-	(x)	-	(x)	-

\- = not observed
x = pronounced
(x) = starting

TABLE 12: Optimal characteristics for exterior joinery wood preservatives and exterior wood stains.

Optimal Characteristics	PRODUCT TYPE		
	Low-build C1	Medium-build C2	High-build TOP
Solid content (%)	10-15	30-35	~ 50
Pigmentation	none	semi-transparent	semi-transparent
Film thickness (1 coat)	~ 5 µm	15-20 µm	25-30 µm
Water repellent	no	yes	yes
Penetration (Scotch pine sapwood)	min. 2 mm	min. 2 mm	min. 2 mm
Decay fungicide	yes	yes	no
Blue stain fungicide	yes	yes	yes
Insecticide	yes	no	no
Treatment process	Double-vac. impr Short immersion Spraying Brushing	Spraying Brushing	Brushing
Coverage rate g/m^2 (1 coat)	~ 100	~ 70	~ 70
Wood Moisture Content	max. 25 %	max. 20 %	max. 18 %

TABLE 13: Treatment types for external joinery.

Product Type	Treatment Type	Combination	FUNCTION		
			Protection	Finishing	Maintanance
C	I	C1 + 2C2	C1 & C2	C2	C2
	II	3C2	C2	C2	C2
T	I	C1 + 2TOP	C1 & TOP	TOP	TOP
	II	C2 + 2TOP	C2 & TOP	C2 & TOP	TOP
	III	2C2 + TOP	C2 & TOP	C2 & TOP	TOP
	IV	3TOP	TOP	TOP	TOP

TABLE 14: Suitability of various treatment types for external joinery under differer exposure conditions.

Exposure type	Treatment type	Joinery Type								Pigmentation
		Constructional				Non-constructional				
		A	B	C	D	A	B	C	D	
<u>Indirect weathering</u>	CI	x	x	x	x	x	x	x	x	All colours
No direct exposure	CII	x	x	x	x	x	x	x	x	admitted
to rain nor	TI	x	x	x	x	x	x	x	x	
irradiation	TII	x	x	x	x	x	x	x	x	
	TIII	x	x	x	x	x	x	x	x	
	TIV	x	x	x	x	x	x	x	x	
<u>Direct weathering</u>	CI	x	-	x	-	x	-	x	-	3 not on B
<u>Type a</u>: normal	CII	x	-	x	-	x	x	x	x	and D
buildings with max.	TI	x	x	x	x	x	x	x	x	
3 stages	TII	x	x	x	x	x	x	x	x	
	TIII	x	x	x	x	x	x	x	x	
	TIV	-	-	x	x	-	-	x	x	
<u>Type b</u>: enforced	CI	-	-	-	-	-	-	-	-	1 not on
buildings with more	CII	-	-	-	-	x	-	x	-	A, B, C
than 3 stages	TI	x	x	x	x	x	x	x	x	and D
	TII	x	x	x	x	x	x	x	x	3 not on B
	TIII	x	-	x	-	x	-	x	-	and D
	TIV	-	-	-	-	-	-	x	x	

x = compatible
\- = not compatible

Pigmentation:

1. Light : colourless to light brown
2. Medium : light brown to medium red
3. Dark : dark brown to black

Timber species:

A. Softwoods with low resin content, e.g. spruce, redwood, red cedar
B. Softwoods with high resin content, e.g. Scotch pine, oregon, larch, pitch pine
C.. Hardwoods with low extractives content, e.g. afzelia, meranti, mahogany, padouk
D. Hardwoods with high extractives content, e.g. merbau, niangon, kerowing, mengkulang

FIGURE 1: Mean film thickness of different treatment types.

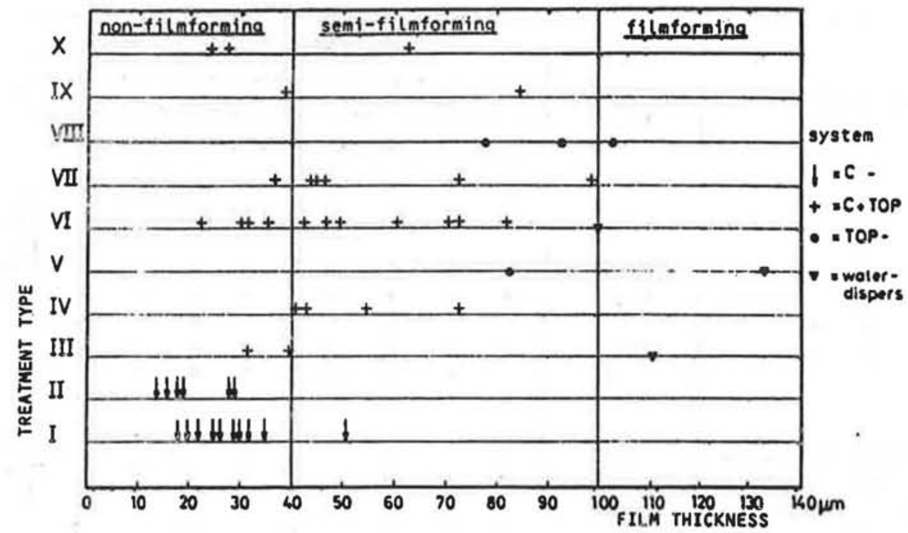


FIGURE 2: Penetration values obtained according to the DIN52162 standard compared with the Biological Effective Penetration Depth.

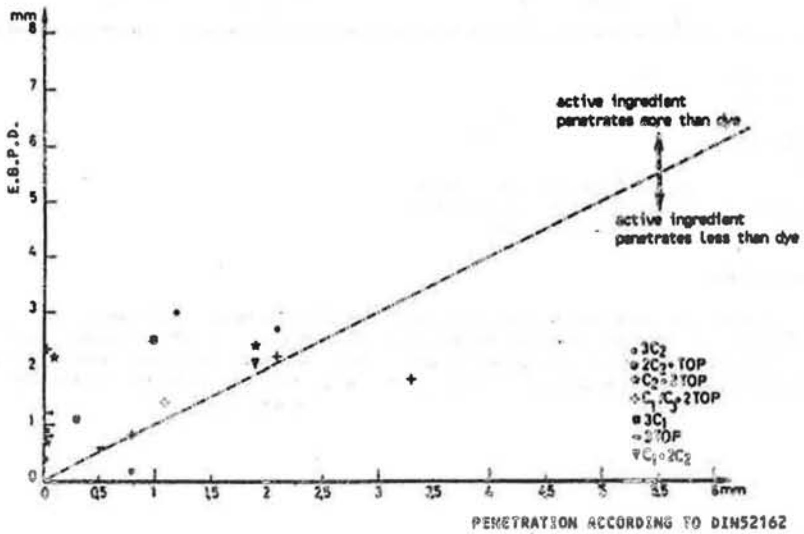


FIGURE 3: Change of the water vapour permeability λs due to natural weathering.

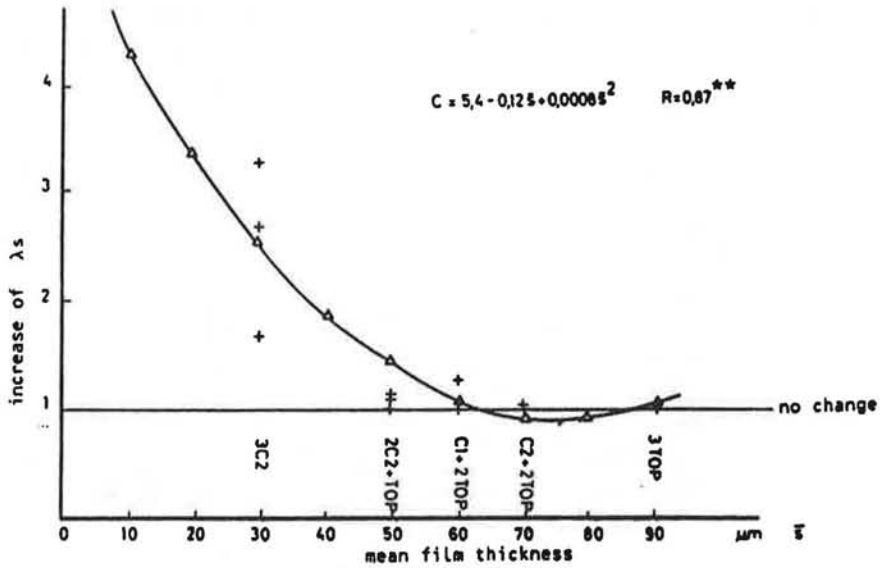


FIGURE 4: Determination of the critical film thickness S.

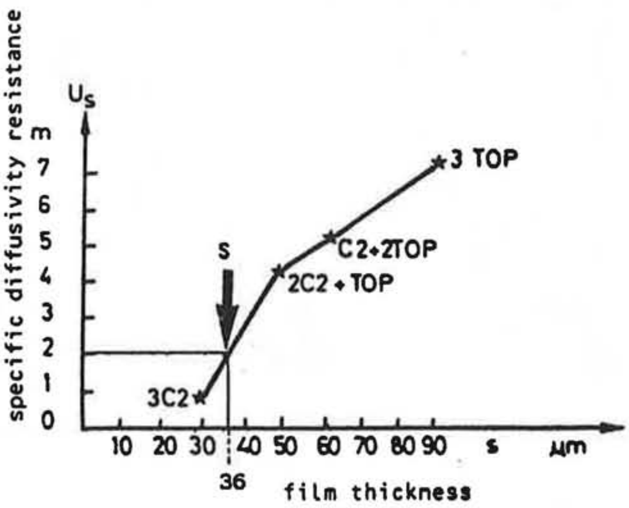


FIGURE 5: Overall moisture content of untreated species during 137 weeks' exposure.

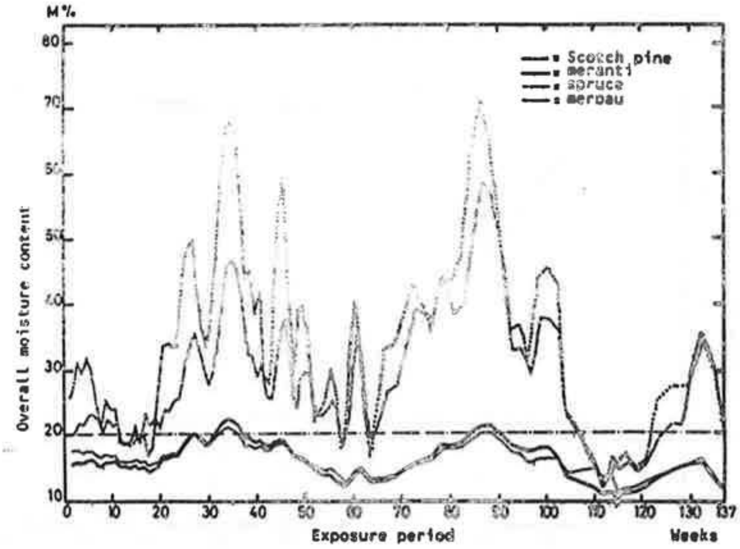


FIGURE 6: Overall moisture content of meranti samples during 137 weeks' exposure.

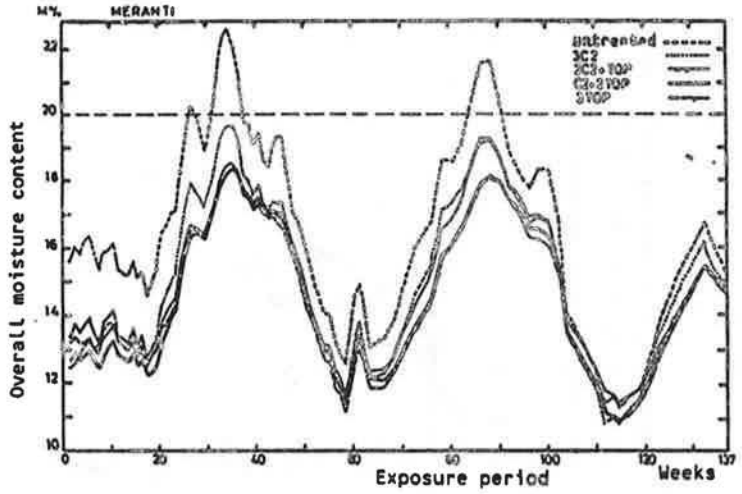
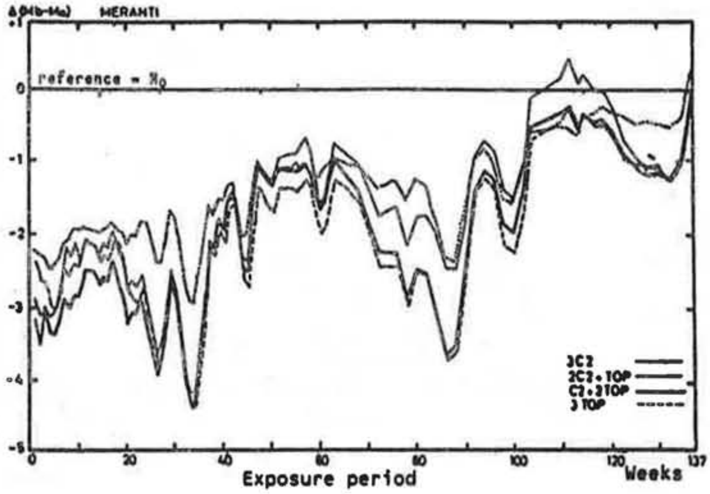


FIGURE 7: Difference in overall moisture content between treated and untreated meranti samples during 137 weeks' exposure.



Mb = Overall moisture content of treated meranti samples
Mo = Overall moisture content of untreated meranti samples

FIGURE 8: Overall moisture content of merbau samples during 137 weeks' exposure.

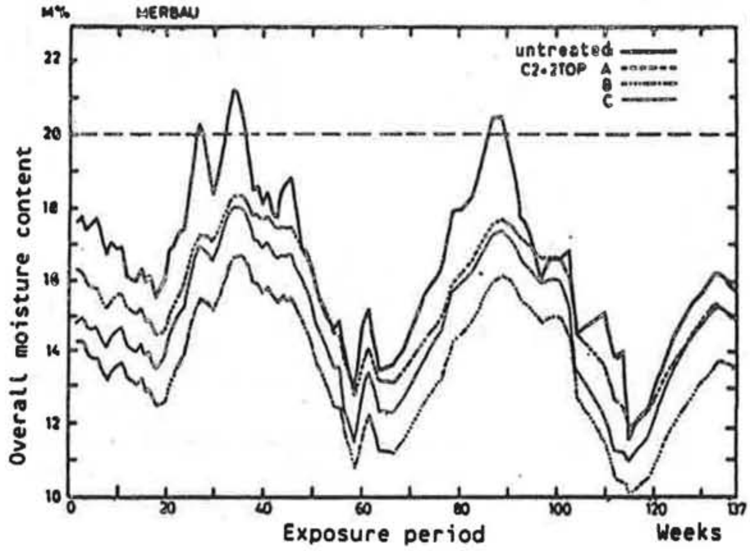


FIGURE 9: Overall moisture content of spruce samples during 137' weeks exposure.

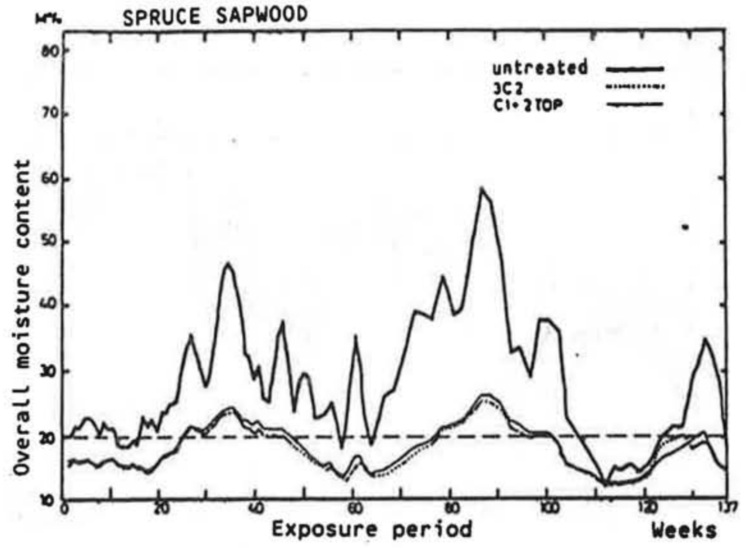


FIGURE 10: Overall moisture content of Scotch pine samples during 137 weeks' exposure.

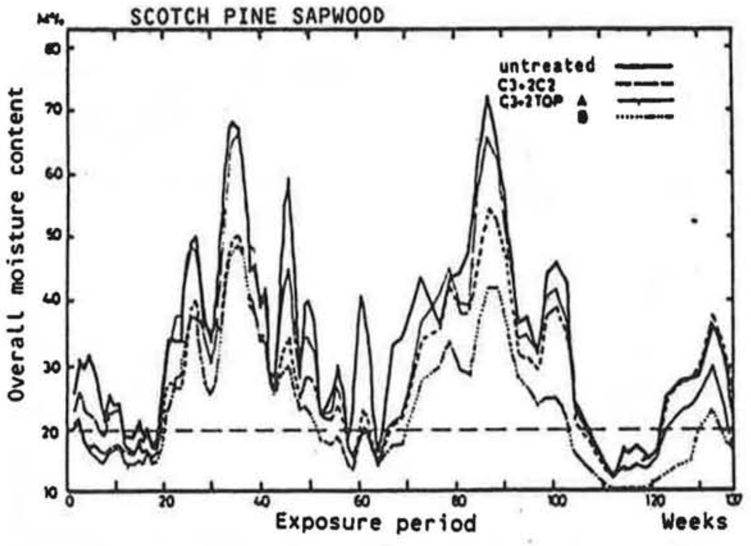


FIGURE 11: Spectral reflectance characteristics before and after weathering.

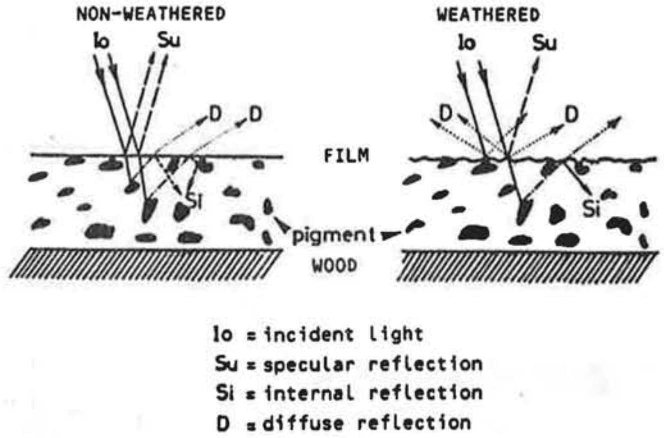


FIGURE 12: Reflectance spectra of a dark pigmented C2-system.

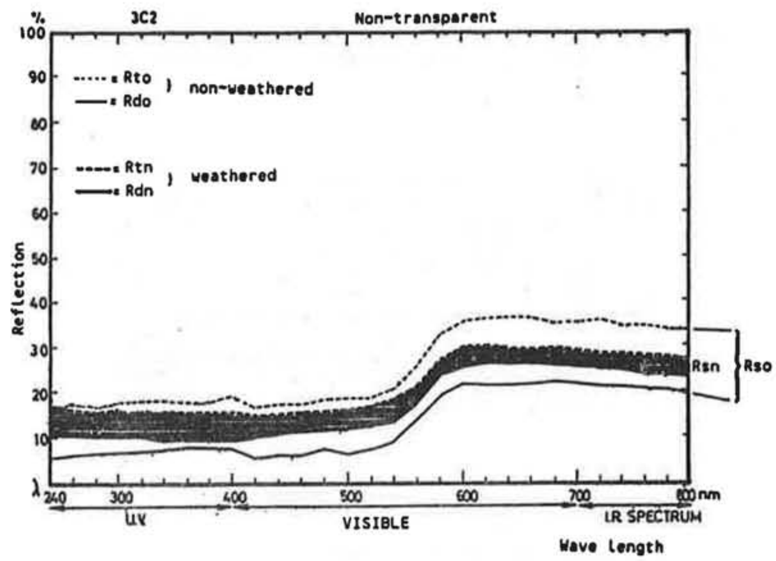


FIGURE 13: Reflectance spectra of a semi-transparent C2 + TOP-system.

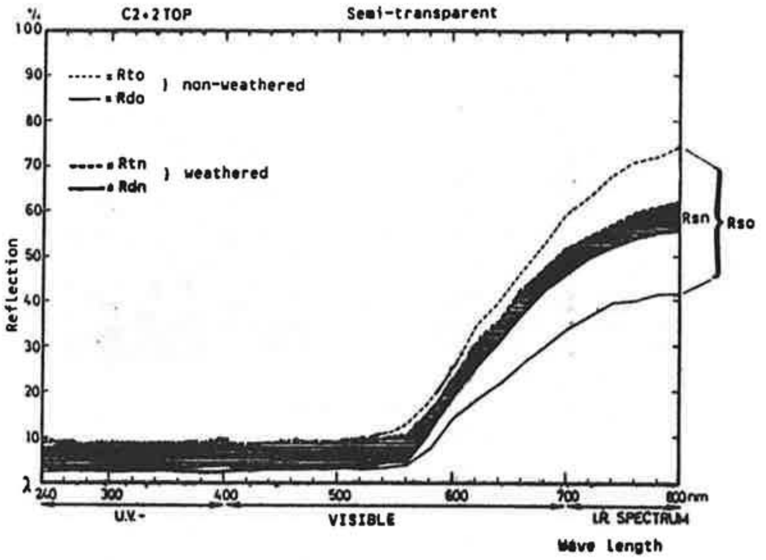
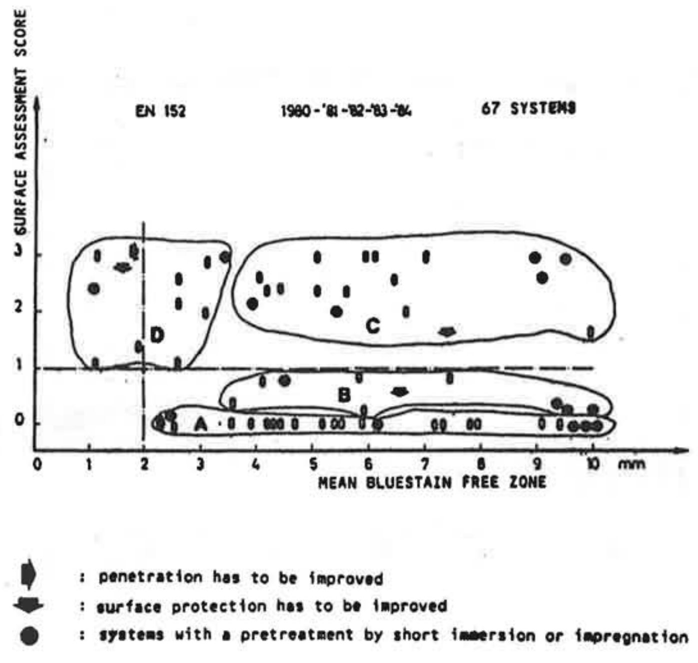


FIGURE 14: Blue stain-in-service resistance of various systems according to the EN 152 standard.



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