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International Co-operative Programme on Effects on Materials, including Historic and Cultural Monuments

Evaluation of decay of painted systems for wood, steel and galvanized steel after 8 years exposure

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Summary

International Co-operative Programme on Effects on Materials, including Historic and Cultural Monuments is a research project launched by the Executive Body for the Convention on Long-range Transboundary Air Pollution for studying the effect of airborne pollution on materials. The study has lasted for eight years and this report summarise the results obtained for painted materials.

The paint systems exposed have been:

- Coil coated steel panels with alkyd melamine (30 µm zinc + 20 µm alkyd melamine). System G.
- Steel panels coated with two layers alkyd paint(80 µm). System H.
- Wood panels coated with two layers alkyd paint. System I.
- Wood panels coated with primer and acrylate (opaque stain). System K.

The damage of the paint systems have been evaluated by using the well established ASTM-standards on samples exposed for one, two, four and eight years. The dose-response functions for the relation between the air pollutants and the damages have been established by means of two steps. The first step has been to define the lifetime for maintenance intervals for fungus growth on the surfaces, for the cracking of the paint systems for wood and for damage spread from a cut in the film for the paint systems for metals. The second step has been to establish the correlation between the lifetime and selected environmental parameters in a dose-response function by stepwise backward regression analysis.

Two sets of functions have been presented, one where most of the possible contributing parameters are tested and the second with a restricted number of parameters involved. The second selection is also taking into account the possibility of modelling the results through out Europe.

Both for cracking and fungus the dominating parameters are climatic parameters like relative humidity, temperature and rain, while damage spread from a cut also were influenced by the SO_2 concentration. For fungus growth the chloride concentration in rain had a fungicide effect.

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1. Introduction

Airborne acidifying pollutants are known to be one major cause of corrosion of different materials including the extensive damage that has been observed on historic and cultural monuments. In order to fill some important gaps of knowledge in this field the Executive Body for the Convention on Long-range Transboundary Air Pollution decided to launch an international co-operative programme within the United Nations Economic Commission for Europe (UN ECE). The programme started in September 1987 and involves exposure at 39 test sites in 12 European countries and in the United States and Canada.

The aim of the programme is to perform a quantitative evaluation of the effect of sulphur pollutants in combination with NO_x and other pollutants as well as climatic parameters on the atmospheric corrosion of important materials. For this purpose measurements of gaseous pollutants, precipitation and climate parameters have been initiated at or nearby each test site, together with evaluation of decay of the test materials exposed at each site.

A Task Force is organizing the programme with Sweden as lead country and the Swedish Corrosion Institute serving as the Main Research Centre. Sub-centres in different countries have been appointed, each responsible for their own materials group. The materials groups are:

Structural metals, including steel, weathering steel, zinc and aluminium (Sub-centre responsible for evaluation: SVUOM Praha a.s., Prague, The Czech Republic), copper and cast bronze (Bayerisches Landesamt für Denkmalpflege, Munich, Germany).

Stone materials, including Portland limestone and White Mansfield dolomitic sandstone (Building Research Establishment, Department of Environment, Watford, United Kingdom).

Paint coatings, including coil coated steel with alkyd melamine, steel with alkyd paint, wood with alkyd paint system and wood with primer and acrylate (Norwegian Institute for Air Research, Kjeller, Norway).

Electric contact materials, including nickel, copper, silver and tin as coupons; Eurocard connectors of different performance classes (Swedish Corrosion Institute and Royal Institute of Technology, Stockholm, Sweden).

Environmental data storing, reporting and evaluation are the responsibility of the Norwegian Institute for Air Research.

The aim of this report is to present results of the painted systems withdrawn after 8 years of exposure. Statistical evaluation of the connection between the decay of the paint systems and environmental factors is also reported, and uses the same evaluation techniques as for the four year's evaluation (Henriksen et al., 1993)

2. Materials

The paint systems tested were:

- Coil coated steel panels with alkyd melamine (30 µm zinc + 20 µm alkyd melamine). System G.
- Steel panels coated with two layers alkyd paint(80 µm). System H.
- Wood panels coated with two layers alkyd paint. System I.
- Wood panels coated with primer and acrylate (opaque stain). System K.

3. Evaluation

The evaluation has followed the available ASTM standards and ISO standards, and the ASTM rating numbers from RN = 10 to RN = 0 have been used. Annex 3 gives a description of the different standards used. The types of damages evaluated are: General appearance, dirt, chalking, fungus, flaking, cracking, checking and gloss. For the paint-systems for metals damages around an artificial cut through the paint were evaluated. The results of the evaluation for two, four and eight years are given in Annex 1 and 2.

The evaluation systems used in the ASTM and ISO standards for paint systems define parameters which may turn up to be visually connected. The general appearance results, which in our terms are an overall description of the visual impression, are after eight years more affected by fungus occurrence than by the other parameters evaluated. Chalking may reduce the impression of dirt to some degree because of the white deterioration products formed on the surface.

After eight years main changes for the paint systems are still found for the parameters general appearance, dirt, chalking, gloss and fungus. Effects along the cut in the steel systems also occurs. An evaluation of the damage around the cut in the paint film on the painted steel panels by using the Swedish standard SS 184219 has been introduced for the four and eight years exposures. The standard expresses the damage as spread from the cut in millimetre instead of the rating number. Very little of flaking, cracking and checking are observed. In the following pages the paint systems for steel and wood are reported separately.

The results (tables and figures) are shown in Annex 1 and 2.

4. The series: coil coated steel with alkyd melamine (G) and steel panel with alkyd (H)

The test panels of these paint systems have a horizontal cut on the front surface. Type G has alkyd melamine on the front side only, but the H-type has alkyd on both sides.

The panels at sites no. 34 and 35 have been placed with the front side down. The parameter “gen.app.” therefore has been neglected for both systems, because facing the cut downwards makes it difficult to compare the front side with those at the other test sites. For the H-panels with the same paint system on both sides, some of the parameters were evaluated on the side facing up, but evaluation of damage in cut was neglected.

For the G-panels, coil coated alkyd melamine at site 34 and 35 with the specified coating only on the side facing down, none of the results will be comparable with the panels from the other test sites. No evaluation of the panels has therefore been carried out. Also for the site 12 no evaluation has been performed. The eight year’s panels on this site had laid on the ground for an unspecified time before collection.

4.1 General appearance

4.1.1 Type G (Table 2.1)

The rating numbers (RN) are reduced on nearly all the sites from 4 to 8 years of exposure. Only the sites FIN 4, SPA 31 and SPA 33 had still the same or some higher RN than 4 years ago.

The four sites having RN = 9 after four years were not among the best ones after eight years.

SPA 33 had the best result (RN = 8.5), and lowest RN were seen on the sites NOR 22 with RN = 3 (damage in cut) and ITA 16 with RN = 3.5 (much fungi).

Most sites had RN from 5 to 6.5.

4.1.2 Type H (Table 2.3)

The general appearance of the alkyd paint was not so much affected as the alkyd melamine paint. SPA 33 had again the best result with RN = 9.5. Second best were FIN 6, NOR 21, SWE 24 and SWE 25 and RU 34, all with RN = 8.5. USA 39 had the lowest score with RN = 2 (damage in cut and much fungi) and CS 3 with RN = 3 (damage in cut). Most panels had RN from 6.5 to 8. The change of the evaluation results after eight years exposure compared to the previous ones were rather small.

4.2 Dirt

4.2.1 Type G (Table 2.1)

Eight panels got RN = 9 after 8 years of exposure. the number after four years was 12. The best ones of the eight panels were those from UK 28 and SPA 33 if we take into account the results from all evaluation periods.

Most dirty were the panels from ITA 16 (RN = 4) and ITA 15 (RN = 5).

4.2.2 Type H (Table 2.3)

Many of these panels seemed to be less dirty than those of type G. Seven panels got RN = 9.5. That is some more than 4 years ago.

Considering all the four evaluations the site SWE 24 had the best result with the site SPA 33 as second. Lowest scores we had in ITA 16 (RN = 4) and ITA 15 (RN = 5.5).

4.3 Chalking

Figures 1.1 and 1.2 show a significant increase in chalking after 4 years of exposure. Particularly alkyd melamine (type G) was affected and had reached the limit for the evaluation method, but also the alkyd showed strong chalking, a further change after eight years of exposure will therefore be minor. For the eight year's evaluation the same flexible tape as before (Scotch electric insulating tape, black) was used.

4.3.1 Type G (Figure 1.1 and Table 2.1)

The results showed strong chalking on all the sites, and the worst ones were quite near the limit for the method used.

For some places the RN had increased somewhat, possibly because weather erosion had removed some chalk. This was true especially for CS 2 (RN: 0.5→2), FIN 4 (RN: 0.5→3), FIN 6 (RN: 1→3), FRG 9 (RN: 1→4.5), SWE 24 (RN: 0.5→2), UK 29 (RN: 0.5→2.5), SPA 32 (RN: 1→2.5), POR 36 (RN: 0.5→2) and USA 39 (RN: 0.5→2). Highest RN we now found for the site FRG 9 (RN = 4.5). Beside this, no remarks were made.

4.3.2 Type H (Figure 1.2 and Table 2.3)

More chalking was also registered on the panels with alkyd paint.

The mean RN for all the sites was after four years of exposure 2.3 and after eight years the number was reduced to 0.8. The corresponding numbers for alkyd melamine paint (type G) were 0.9 and 1.3 respectively. After eight years the site RU 34 had the highest rating (RN = 4) and FRG 7, ITA 16 and USA 38 all with (RN = 0) the lowest RN.

Totally we observed more chalking on type H than on type G after eight years. After four years it was vice versa.

4.4 Fungus

The results of the evaluation of the fungus for the types G and H are shown in Figures 1.3 and 1.4 together with the evaluation after 2 and 4 years of exposure. No exact identification of the fungi has been done so far. But most of the fungi seemed to be *Aureobasidium pollulans* or types related to it. After eight years of exposure alkyd paint (type H) was still some more affected by fungi than alkyd melamine paint. The mean values of RN are 7 and 7.5 respectively.

4.4.1 Type G (Figure 1.3 and Table 2.1)

After eight years fungi were observed on 26 panels or sites. That is two panels more than after four years. This means that 10 panels are free from fungi so far. Many of these panels are found in Spain, Sweden and Norway.

Most attacked was FRG 11 (RN = 4.5).

The difference between RN from four and eight years of exposure was small. Yet, some panels had got a relatively big raise in growth of fungi from four to eight years of exposure. These panels were from the sites FRG 8, UK 27 and UK 28.

4.4.2 Type H (Figure 1.4 and Table 2.3

30 panels were infected by fungi after eight years. Only 8 panels were now uninfected, and these included two of the three sites in Norway and Sweden.

Lowest RN (= 4) we found in the site ITA 16, but the RN were also low in FRG 8, FRG 9 and FRG 10 and USA 38, all with RN = 4.5.

At FRG 8, FRG 11 and UK 27 we got a relative big raise in growth of fungi from four to eight years of exposure.

4.5 Flaking, cracking and checking

No remarks have been made with reference to the parameters flaking, cracking and checking concerning type G and H.

The panels of type G have no masking on the edges. This has caused the paint to creep more or less from the edge. We have made separate evaluation scale for this parameter (Annex 3). None or insignificant creepage had occurred on these sites: CS 2, FIN 5, FRG 8, SPA 31 and SPA 33, POR 36 and CAN 37. Bad was NOR 22, followed by CS 3 and UK 39 and UK 30. The results from this evaluation are found in Annex 2, Table 2.2.

4.6 Damage located in and near cut (type G and H)

The type of damages codes B/b blistering, F/f flaking and rust should not be compared from one year to the next. This is because these parameters are not fixed with numbers but are more subjective. Particularly the steel system without zinc (H) showed attack in the cut, and all panels were affected after four years. Figures 1.5 and 1.6 show the results for the second, fourth and eighth year for damages along the cut after ASTM ratings.

The strongest effects were observed at the industry sites, particularly for system H.

4.6.1 Type G (Figure 1.5 and Tables 2.1 and 2.2)

The panels in the sites SPA 33 and SPA 31 had the highest RN with the results 8.5 and 8 respectively. Bad was the situation in NOR 22 (RN = 3), ITA 15 and USA 39 (RN = 4).

On most of the sites the damages near cut had not been more serious than four years ago.

4.6.2 Type H (Figure 1.6 and Tables 2.3 and 2.4)

Best results we found in SPA 33 (RN = 9), ITA 13 and POR 36 (RN = 8).

The panels on following sites had serious damages in cut: CS 3 and USA 39 (RN = 0), ITA 15 (RN = 1), FRG 8 and SPA 32 (RN = 2), NOR 22 and NOR 23, UK 29 and USA 38 (RN = 3).

4.7 Gloss

The big drop in gloss occurred in most of the sites after four years of exposure, but in some cases a strong drop happened even after two years.

The results are given in Figures 1.7 and 1.8 (Annex 1), and in the Tables 2.2 and 2.3 (Annex 2). The measurements referred to have been made on unwashed surface.

When studying the gloss values one should have in mind the values of unexposed panels. For the type G this value was 34.8% (reflection), and for the type H 75.6%.

4.7.1 Type G

Very little gloss is now measured on these panels. The site SPA 31 had gloss value of 2.4%. All the other sites had values of 2 or less. The lowest values we found in USA 38, UK 29 and NOR 22.

4.7.2 Type H

Most gloss we could observe in NL 19, FRG 9 and SPA 31. These sites were the only ones where the gloss values were equal to or exceeded 7%. The lowest values were found in USA 38, NOR 23, UK 29 and ITA 13.

The panels with alkyd paint were even measured on the backside. The result is shown in Figure 1.9 (Annex 1) and in Table 2.3 (Annex 2). The values are as expected much higher because of the protection against sunshine and dirt contamination.

Best were the panels in the sites SPA 31 and so followed NOR 21, SWE 25 and FRG 8.

Least gloss we found in UK 29, NL 18, CAN 37 and NOR 23.

5. The series: Wood panel with alkyd paint (type I) and with primer and acrylate (type K)

5.1 General appearance

The results of types I and K are shown in the Tables 2.5 and 2.7 (Annex 2). The mean RN of all the sites is shown in Figure 1.10 (Annex 1). We see that the RN for type I has decreased from year to year. The general appearance of the type K was very good even after four years. But also this type has been considerably affected at the last evaluation.

The acrylate paint has, however, still higher mean RN than the alkyd paint.

It is the parameters dirt and fungus, and after a few years also cracking that mainly reduce the RN of general appearance.

5.1.1 Type I (Table 2.5)

After four years only three sites (NOR 21, SPA 31 and SPA 33) had still RN = 10. After eight years the RN is strongly reduced also for these sites, but SPA 31 is the best one with RN = 8.5 followed by SWE 24 and RU 34 (RN = 8). Most sites have RN between 3 and 5.

The least good-looking panel was located in ITA 16 (RN = 1), but also the panels from the sites in Netherlands were bad-looking (RN = 2).

5.1.2 Type K (Table 2.7)

Some corrections have been made for the four year data at the sites NOR 22, SWE 24 and SWE 25, SPA 33 and CAN 37. The new ratings for the four sites are RN = 10.

After eight years no site got RN = 10. The best one at the last evaluation was SWE 25 (RN = 9.5) followed by the sites FIN 6, UK 30, SPA 31 and RU 34, all with RN = 9.

The worst ratings observed were FIN 4, ITA 16, NL 18 and SWE 26, all with RN = 3.

5.2 Dirt

For all the sites the dirt on the panel increases more or less with time. This parameter is very important when setting the RN of general appearance. Fungus and even cracking can at distance give a visual impression of dirt. This makes the rating-setting more complicated (see point 3 and point 1 in Annex 3). Furthermore it is so that a new painted panel easier will retain dirt owing to its more sticky surface. Chalking may cause dirt to be masked, and also to be removed by windy weather.

The parameter is therefore complicated to interpret, and shall only be used as a guide together with other parameters.

5.2.1 Type I (Table 2.5)

SPA 31 is the only site which has got RN = 10. Next follow FIN 6, NOR 21, SWE 24 and SWE 25, all with RN = 8. In the other end of the scale we find ITA 16 (RN = 1) and the sites in Netherlands (RN = 2). The panels in these sites were so dirty that this completely determined the RN of general appearance.

5.2.2 Type K (Table 2.7)

The amount of dirt on the panels was still rather modest at several sites. Best were SWE 25, SPA 31 and SPA 31, all with RN = 10. RN = 9.5 had the sites FIN 6, SWE 24, UK 30 and RU 34. In the other end of the scale we found sites with RN = 3 (ITA 16, NL 18 and SWE 26).

5.3 Chalking

We have observed some increase in chalking for both the paint systems.

The mean RN for all the sites shows unimportant difference between the two systems the first four years. After eight years we got a mean RN for type I like 4.1, and 5 for the type K.

5.3.1 Type I (Figure 1.11 and Table 2.5)

Least chalking we had at the site NL 17 (RN = 7) and most chalking at USA 38, SPA 33 (RN = 1), and NOR 23 and POR 36 (RN = 2).

5.3.2 Type K (Figure 1.12 and Table 2.7)

Least chalking we had at the site SWE 26 (RN = 8), RN = 7 had GER 12, NL 17 and NL 18 and RU 34.

Most chalking we found on the panels at USA 38 (RN = 1) and POR 36 (RN = 2).

5.4 Fungus

The alkyd paint system was much more attacked by fungi than the acrylate system.

5.4.1 Type I (Figure 1.13 and Table 2.5)

No fungus was found at the three sites SPA 31 and SPA 33 and RU 34.

The following sites were fungus-free after four years, but have later on been attacked (RN after eight years in parentheses): CZE 3 (5), FIN 6 (4.5), ITA 13 (5), ITA 15 (6), NOR 21 (6), SWE 24 (4.5), SWE 25 (7) and SPA 32 (4.5).

Most fungus was observed at the sites in CZE, FIN and GER.

Algae were observed in most of the countries (Table 2.6). The highest attack were seen for the panels at FIN 5, NL 17 and SWE 26.

5.4.2 Type K (Figure 1.14 and Table 2.7)

No fungus was found at these sites: SWE 25, SPA 31 and SPA 33 and RU 34. The three last ones are the same sites as for type I.

As many as 20 which were free from fungus four years ago have been attacked in the course of the next four years.

Most fungus was registered at the sites GER 12 and ITA 16 (RN = 3).

Algae were especially abundant at the sites in Netherlands, FIN 4 and SWE 26 (Table 2.8).

5.5 Cracking

Cracking was more widespread for the alkyd paint system than for the acrylate paint system.

Cracking has developed fairly much the last four years, especially for the alkyd paint system. The alkyd system was also more affected to checking and development of sigmoid cracking forms, even if these forms also were observed on the acrylate paint system.

5.5.1 Type I (Figure 1.15 and Tables 2.5 and 2.6)

The panels at all the sites had cracking. Least cracking we observed at the sites RU 34 (RN = 8) and SPA 31 (RN = 7.5). At the site GER 8 the RN value had fallen from 10 to 5.5 from four to eight years of exposure, and for EST 35 was the corresponding fall from 9.5 to 5. The worst panel we found in the sites POR 36 and USA 38, both with RN = 3.

5.5.2 Type K (Figure 1.16 and Tables 2.7 and 2.8)

Also the acrylate paint system had some cracking, but less than alkyd.

The best score we got at the sites SWE 25 (RN = 9.5) and CZE 1 (RN = 9). NOR 21 and NOR 22 and SWE 24 had RN = 8.5. The worst panel we found in ITA 16 (RN = 3.5), but also USA 38 and ITA 14 were bad (RN = 4). In this connection it should be mentioned that RN of the panel in USA 38 had dropped from 9.5 to 4 the last four years.

6. Deterioration parameters -limitations for use in dose-response studies

ASTM evaluation of paint systems is based on a visual inspection of characteristics which give changes in the paint film or on the material where the paint is applied. Some of these characteristics may be a mixture of different parameters, other describe more physical/chemical or biological processes.

General appearance is often the parameter which in practice is used by the owner of a house to decide when maintenance shall start. It combines in many ways all the other parameters. However, due to variation of the climatic impact on the paint surface, the rating will often go up and down with time. Example: after a dry, hot and dusty period the evaluation result could be influenced by dirt on the surface which will be washed away during heavy rain later in the year and give a better rating. To be used for dose-response studies, the parameter general appearance needs a different and more detailed information about the changes in the climatic conditions than what is available in this project. The same argument can be accomplished for dirt and chalking. For chalking the evaluation method by itself has limitations. Chalking is tested by how much loose paint powder that will stick to a tape. This method will only work on fairly clean surfaces. When the chalking covers the surface, the method will not evaluate the thickness of the deteriorated layer.

Fungus sticks well to the surface when it is established. Theoretically it could also be washed away after heavy chalking. In practice on our panels, we have mostly observed increased amount of fungi with time. The parameter could therefore be of interest for defining a dose/response relationship with some of the environmental parameters.

Flaking, cracking and checking are irreversible processes and these parameters should therefore be useful for studying the environmental impact. However, for our samples flaking and checking are mostly observed after 8 years on a small number of panels. Cracking has been observed on most of the wood samples and can therefore be evaluated for environmental impact.

For painted steel and coil coated galvanised steel the spread from the cut is a parameter which is irreversible and useful for dose/response studies.

Wearing of paint layer has earlier been used as a parameter for dose/response studies. However, this parameter has been difficult to observe on the panels in our project. The painted wood samples have a fairly rough surface. The thickness of the paint layer will therefore vary throughout the surface. The wearing will therefore first be observed on the upper fibres. The upper fibres will also be the area where cracking is observed. For painted wood, cracking has been selected as a suitable parameter for establishing relations with the environmental factors.

For painted and coil coated steel where the thickness of the paint film is more predictable, the wearing should be easier to detect. However, modern corrosion protection paint systems seem to be very resistant to wearing. Even after eight years of exposure we have not been able to detect a thickness reduction outside the uncertainty level of the starting film thickness. Modern systems seems to loose their protection ability by other mechanisms such as corrosion linked to mechanical damages. Spread from a cut has therefore been selected as a suitable parameter for the evaluation of corrosion protection paint systems.

7. Estimation of lifetime from ASTM evaluation

The scale used in the visual ASTM evaluation is based on pictures and verbal description and cannot be directly used as a damage scale for dose-response correlation. In this study this problem has been solved by taking into account ht practical use of the standards. The recommendations from the paint industry have been that maintenance should be carried out when the surface condition for the parameter evaluated has reached the rating 5. For parameters like cracking this means repainting, while washing down the fungi could be sufficient for the fungus parameters. Depending on the climatic conditions and the paint composition this means that different parameters in different climate could bc thc timc dcpending factor for maintenance work. This time between maintenance is defined as the *lifetime* of the paint system.

For estimating the lifetime of the paint system or in practice the time between maintenance, we have used a log plot between the ASTM rating and the exposure time, the ASTM values was transferred to a generated factor $ASTM_{gen} = 11 - ASTM_{rating}$.

In Chapter 8 the calculation method for lifetime is described and Figure 1 gives an illustration of the plots used and how the lifetime was defined. The calculation uses the rating from 0, 1, 2, 4 and 8 years. As there is no deterioration of the paint systems when the panels are put up the ASTM values were set to 10 for all paint systems and all parameters. For some sites like Toledo, where little had happened during the 8 years of exposure, it is impossible to draw a well-fitted line. For sites where no trend in the damage processes is observed, lifetime calculations were excluded.

8. Method - statistical analysis

The statistical analysis was done in two steps. First, the functional relationship between ASTM rating and length of exposure was estimated (see Chapter 7) using equation (1) with condition (2).

$$11 - \text{ASTM} = \underline{a} * \exp(\underline{b}*[\text{exposure length}]), \qquad (1)$$

with the restriction

$$\text{ASTM at [exposure length=0]} = 10. \qquad (2)$$

The condition (2) is equivalent to setting a=1.

The lifetime Lv was then defined as the time at which the damage evaluation is classified as ASTM rating 5, as suggested by the paint industry, and calculated using the relationship

$$Lv = \ln(6)/b^*, \qquad (3)$$

where b* is an estimate of parameter b from (1). Example of the procedure is shown in Figure 1.

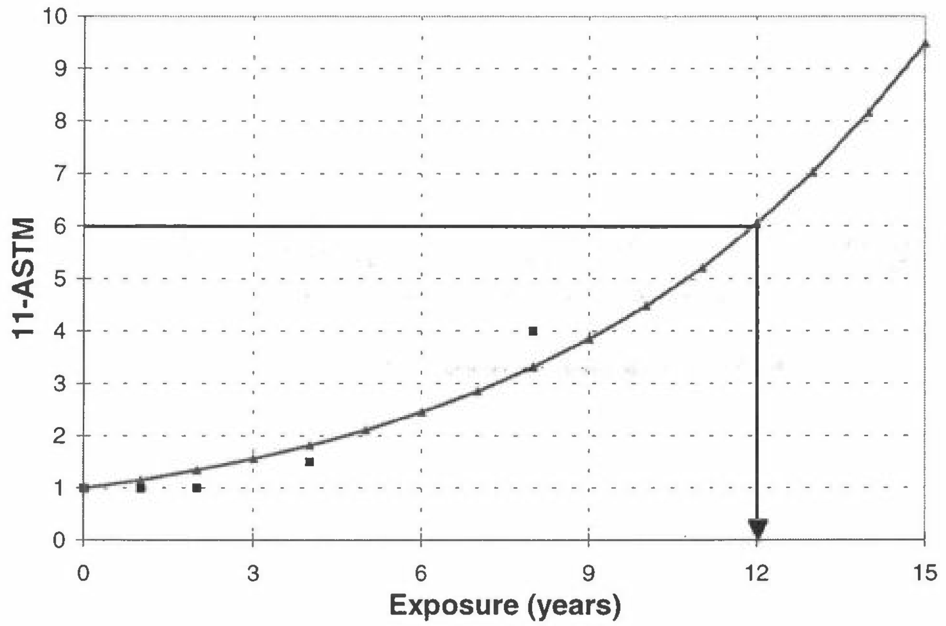


Figure 1: *Prediction of lifetime from ASTM rating and maintenance action at ASTM rating 5.*

In Table 1, Chapter 8.1, the lifetime Lv for fungus for all paint systems, cracking for both wood systems and damage from cut for the two metal systems is presented. Lifetimes which exceed four times the exposure time is not used in the dose-response studies.

In the second step of the analysis, the parameter Lv was related to selected environmental parameters expressed as 8-year average, using a relationship

$$Lv = \sum_i B_i * X_i \ , \tag{4}$$

where X_i are the different environmental factors and B_i are the parameters to be estimated. The dependency of lifetime on environmental parameters was formulated assumed linear, and modelled using multiple regression analysis with stepwise selection of variables was used. In all analyses, site no. 29 Clatteringshaws Loch was deleted from the data set.

An additional sensitivity analysis was performed to investigate the dependency of lifetime on temperature. It was assumed that there exists a "limiting temperature" T_{lim}, below and above which the dependency on temperature is reversed. No conclusive evidence of this was found.

8.1 Results

Table 1 gives the calculated lifetime all selected parameters.

Table 1: Calculated lifetime for the parameters fungus, cracking and damage from cut based on observations after 0, 1, 2, 4 and 8 year's of exposure.

	LIFETIME							
Site no.	cwk	cwi	fmg	fmh	fwk	fwi	dmg	dmh
1	18.3	7.1	47.0	8.5	13.1	7.0	6.4	5.7
2	12.7	8.3	8.2	6.5	10.2	5.9	7.8	6.3
3	11.9	8.4	17.3	11.8	15.2	10.6	6.8	4.4
4	8.1	7.3	6.7	6.1	8.5	6.5	6.2	5.8
5	17.3	7.9	8.1	6.7	10.6	6.0	7.8	6.1
6	12.0	9.2	31.3	31.3	15.2	10.2	7.6	6.4
7	10.5	8.5	7.7	6.4	7.4	5.8	6.2	5.8
8	17.3	11.2	9.9	7.4	9.4	7.0	6.4	5.4
9	13.7	7.9	7.3	6.5	10.2	6.2	6.8	6.1
10	10.3	7.2	9.5	9.2	10.2	7.4	6.4	5.2
11	15.2	7.4	6.9	7.4	10.2	7.3	6.6	6.0
12	9.7	6.3	4.5	4.2	6.6	3.7	4.0	3.5
13	9.3	8.1	*	*	15.2	10.6	7.8	9.7
14	7.4	6.9	13.1	11.2	8.9	6.3	7.0	6.5
15	13.7	8.5	*	27.5	13.1	11.8	5.9	4.7
16	6.5	6.7	6.3	5.7	5.9	4.7	7.4	5.7
17	11.0	7.1	7.1	6.6	27.5	6.2	6.8	5.6
18	7.3	7.9	8.6	6.5	10.4	5.7	6.8	5.8
19	9.8	7.9	8.7	6.7	12.3	6.8	6.8	5.6
20	8.3	6.7	7.0	6.7	8.9	5.6	6.4	5.7
21	15.1	8.9	*	*	47.0	11.8	6.4	6.1
22	17.0	7.7	*	*	27.5	12.6	5.4	5.5
23	9.5	8.1	7.2	6.4	7.9	5.9	5.9	5.3
24	17.0	8.9	*	*	13.7	10.2	7.0	7.4
25	31.3	8.8	*	*	*	13.7	7.6	7.6
26	9.5	7.7	7.0	6.1	7.4	5.9	7.8	6.1
27	14.6	9.3	9.2	8.8	10.6	7.9	7.0	6.5
28	9.3	8.5	10.3	8.8	11.2	7.6	7.6	6.7
29	7.9	7.7	11.6	16.7	7.7	7.4	6.8	5.2
30	13.7	8.1	17.0	16.7	27.5	7.6	6.6	6.1
31	8.3	10.1	*	*	*	*	9.5	7.6
32	10.5	7.1	*	47.0	11.2	10.2	7.0	5.4
33	12.0	7.7	*	93.9	*	*	12.5	14.6
34	11.0	11.6	*	*	*	*	*	*
35	9.5	9.5	*	25.0	10.1	6.3	*	*
36	10.0	6.3	*	31.3	47.0	7.0	9.2	10.2
37	11.2	7.7	8.5	6.6	10.6	7.4	7.0	6.1
38	8.9	7.2	6.6	5.6	7.1	7.2	6.9	5.6
39	9.5	7.2	7.3	6.4	8.8	6.5	5.7	4.5

To defined the relationship between the lifetime and the environment two sets of parameters were considered, and included in equation (4). All the environmental data used is taken from data reported in this project (Henriksen et al., 1997):

(a) parameters describing a number of processes contributing to the deterioration of the paint systems:
Time of wetness (TOW, fraction of the year), yearly value of solar radiation (SUN, in MJ/m^2), SO_2 ($\mu g/m^3$), NO_2 ($\mu g/m^3$), O_3 ($\mu g/m^3$), measured or calculated based on relationship with NO_2, annual average of precipitation amount (MM, in millimetres), annual average concentration of H^+ (HPLUSS, in equ/l), and annual average concentration of Cl^- (Cl, mg/l). Interaction terms: SO_2*TOW, NO_2*TOW, SO_2*NO_2*TOW, SO_2*NO_2*O_3; MM*HPLUSS, TOW*SUN.

(b) restricted parameter set with straight-forward physical or chemical explanation:
SO_2 ($\mu g/m^3$), relative humidity RH (RH, annual average, %), temperature (TEMP, annual average, °C), precipitation amount (MM, in millimetres). In addition, Cl^- (Cl, mg/l) for fungus, and yearly radiation (SUN) for cracking.

For the parameter set (b) the ranges and distribution for the parameters are calculated. The results of the calculation are presented in Table 2 and the results of the multiple regression analysis in Table 3.

Table 2: Ranges of selected environmental parameters.

		Minimum	10%	50%	90%	Maximum
Temperature (°C)	1,2,4,8-year averages	3.1	5.9	10.2	15	17.7
	8-year averages	3.3	5.9	9.9	14.8	17.7
Relative humidity (%)	1,2,4,8-year averages	58	64	77	83	86
	8-year averages	59	64	76	83	83
Radiation (MJ/m^3)	1,2,4,8-year averages	2396	2601	3150	4779	5158
	8-year averages	2403	2600	3172	4887	4995
Precipitation (mm)	1,2,4,8-year averages	292	451	675	1115	2144
	8-year averages	324	469	658	1049	1472
Chloride (mg/m^3)	1,2,4,8-year averages	0.11	0.35	1.72	4.44	8.19
	8-year averages	0.11	0.34	1.60	5.08	8.19
SO_2 ($\mu g/m^3$)	1,2,4,8-year averages	0.6	3.3	14.8	52.8	88.9
	8-year averages	0.6	2.4	9.6	49.4	67

Table 3: The regression coefficients for relations between lifetime for selected damages to paint systems and environmental variables.

LV(A,G,D)[1]=	8.02+0.0013*SUN-0.0937*NO2+0.0539*O3-0.00443*MM -0.0667*HPLUS-0.0534*SO2TOW+0.282*NO2TOW +0.0651*MMHPLUS-0.0035*TOWSUN+0.272*CI	R^2=0.93	N=30
LV(B;G;D) =	17.2-0.0299*SO2-0.105*RH-0.00249*MM	R^2=0.55	N=36
LV(A,H,D) =	3.55+0.00095*SUN+0.146*O3-0.00568*MM -0.0875*HPLUS+0.207*NO2TOW -0.00003*SO2NO2O3+0.0906*MMHPLUS -0.00313*TOWSUN+0.236*CI	R^2=0.91	N=30
LV(B,H,D) =	21.7-0.0473*SO2-0.168*RH-0.00271*MM	R^2=0.58	N=36
LV(A,H,F) =	-12.6+0.402*NO2+0.623*O3-0.154*MMHPLUS -0.0112*TOWSUN+2.73*CI	R^2=0.46	N=31
LV(B,H,F) =	51.5-0.582*RH+1.90*CI	R^2=0.36	N=31
LV(A,G,F) =	57.8-76.5*TOW-0.475*O3-2.35*SO2TOW -0.00044*SO2NO2O3+0.106*SO2O3TOW +3.26*CI	R^2=0.58	N=26
LV(B,G,F) =	17.6-9.83MM	R^2=0.11	N=26
LV(A,K,F) =	-49.7+41.7*TOW+2.03*SO2+0.864*NO2+0.968*O3 +2.26*SO2TOW-0.0911*SO2O3TOW -0.00132*SO2NO2O3 -0.0157*TOWSUN+1.30*CI	R^2=0.65	N=33
LV(B,K,F) =	67.7-0.639*RH-1.26*TEMP+2.71*CI	R^2=0.41	N=33
LV(A,I,F) =	9.97+0.0562NO2-0.00351*TOWSUN+0.497*CI	R^2=0.54	N=34
LV(B,I,F) =	29.2-0.252*RH-0.367*TEMP+0.484*CI	R^2=0.29	N=34
LV(A,I,C) =	9.14+11.8*TOW+0.123*NO2-0.00416*MM -0.0945*HPLUS-0.263*NO2TOW +0.0936*MMHPLUS-0.00188*TOWSUN	R^2=0.57	N=33
LV(B,I,C) =	18.0-0.0861*RH-0.00134*MM-0.00072*SUN	R^2=0.55	N=33
LV(A,K,C) =	31.2-26.0*TOW-0.00271*SUN-0.613*SO2 +0.0271*SO2O3TOW+0.000219*SO2NO2O3	R^2=0.31	N=33
LV(B,K,C) =	49.9-0.339*RH-0.00365*SUN	R^2=0.50	N=33

The results obtained from models using the full set of variables are interesting, but complicated. The interaction terms are acting as modifiers of effects of individual variables, as could be expected, but the 2nd and 3rd order interactions are difficult to translate into simple terms. In addition, the environmental variables are not

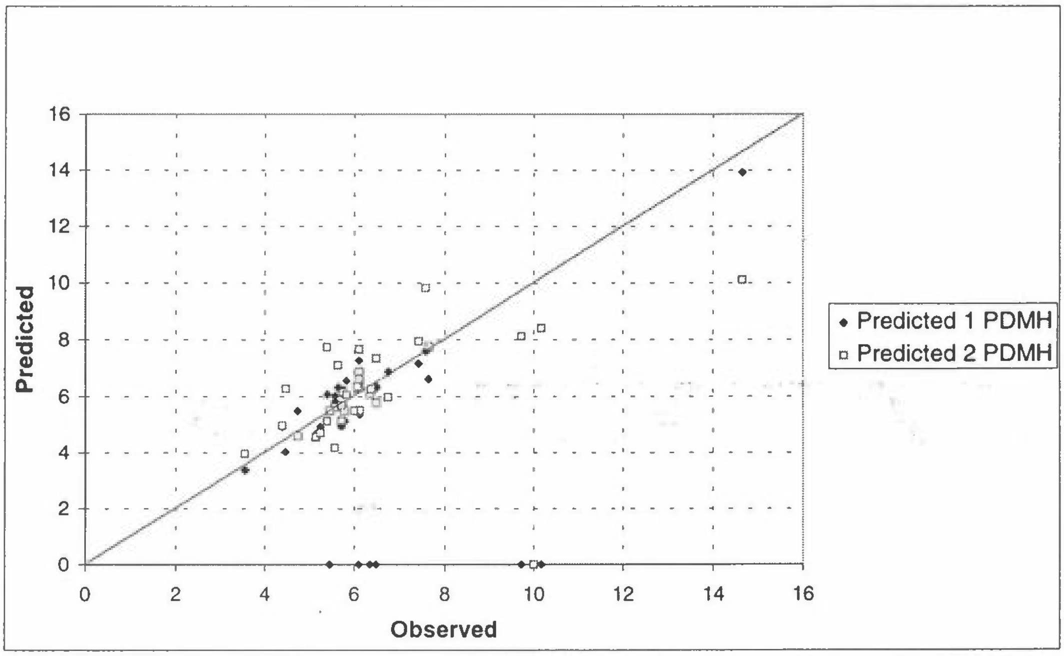
[1] Symbols in parentheses:

A, B	Set of environmental variables used in estimating parameters of the lifetime equation
G, H, I, K	Paint system (G: alkyd melamine on zinc, H: Alkyd on steel, I: Alkyd on wood, K: acrylate on wood)
D, C, F	Damage parameter (D: Damage from cut (Paint system G and H), C: Cracking (paint system I and K), F: Fungus (all paint systems)).

independent of each other, and this complicates the interpretation further. In practice, the results obtained using the first parameter set need further analysis before they can be applied to estimating changes in damage connected to development in exposure parameters.

The restricted parameter set, explains the variability in lifetime for damage from cut and cracking reasonably well despite the much reduced number of parameters. SO2 is the only air pollutant used, and it is associated only with damage from the cut (on both paint systems), but not with other damage parameters.

A comparison of lifetime predicted using the two regression models with the lifetime estimated for each site using only time-dependency function, is given in Figure 2.



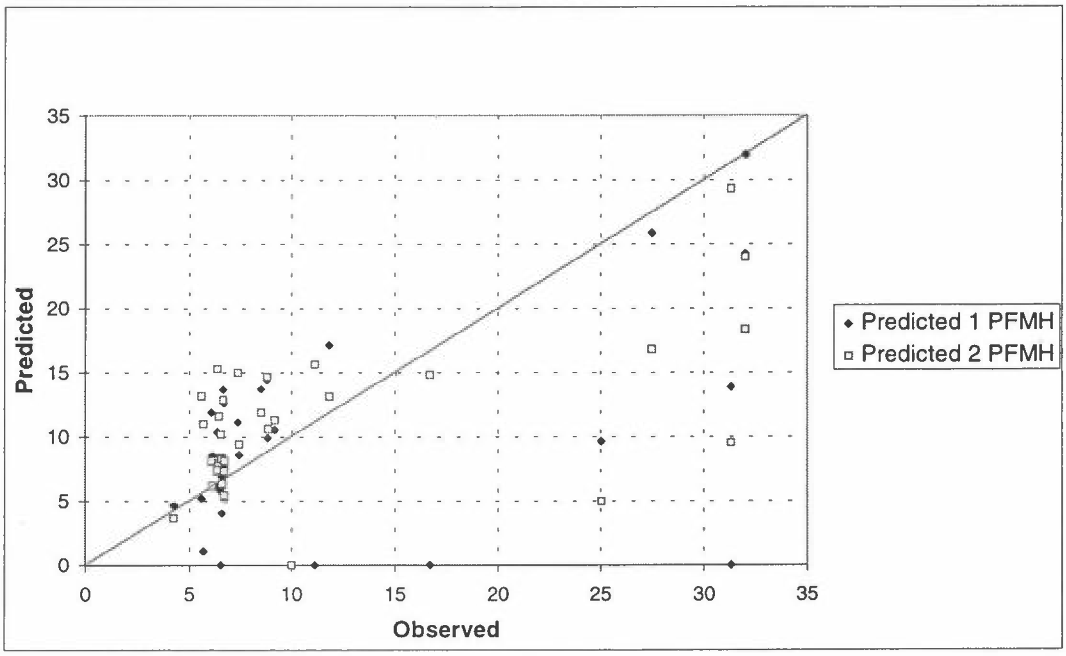
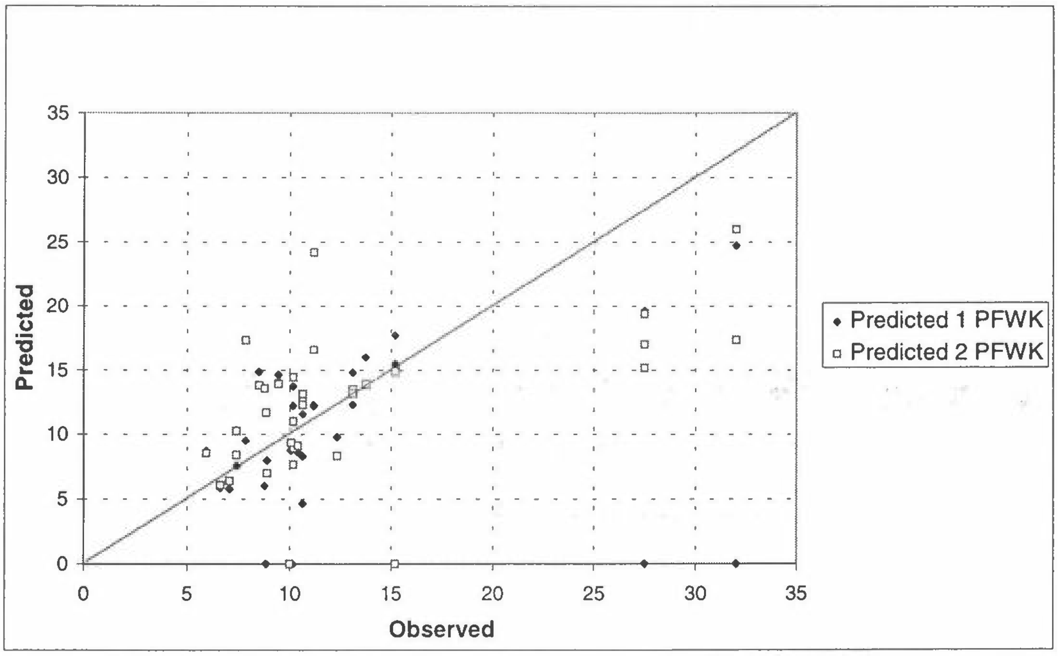


Figure 2: *Comparison of lifetime determined by function (3) ("Observed") and lifetime estimated from the regression (4) with the data from Table 2, using the model with unrestricted number of variables (Predicted 1)) and the model with the restricted variable set (Predicted 2). Type of damage - see footnote to Table 2.*



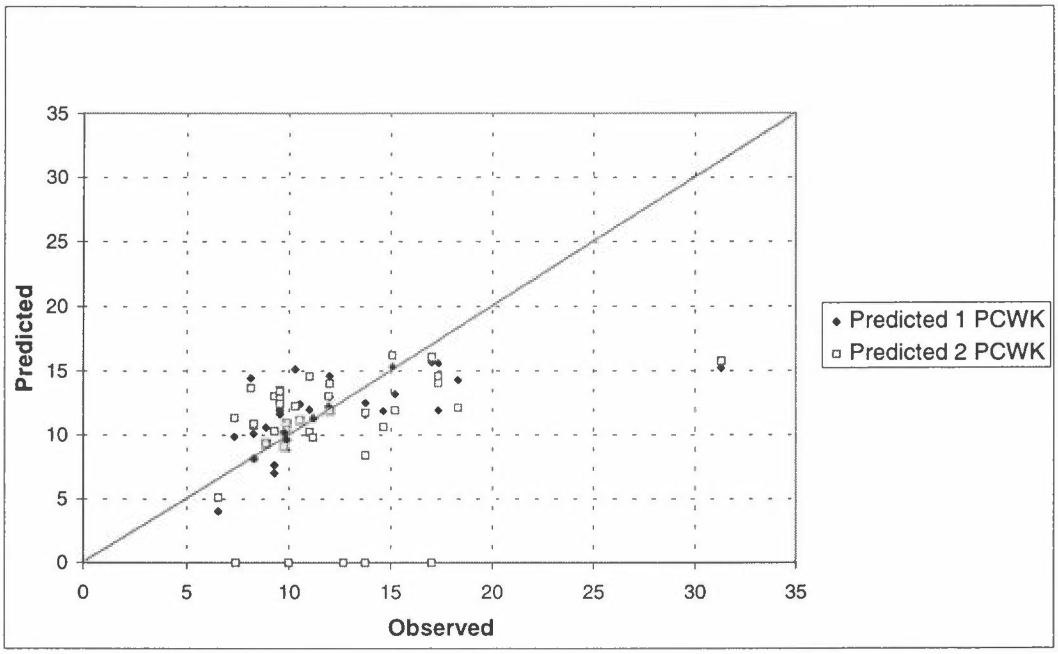
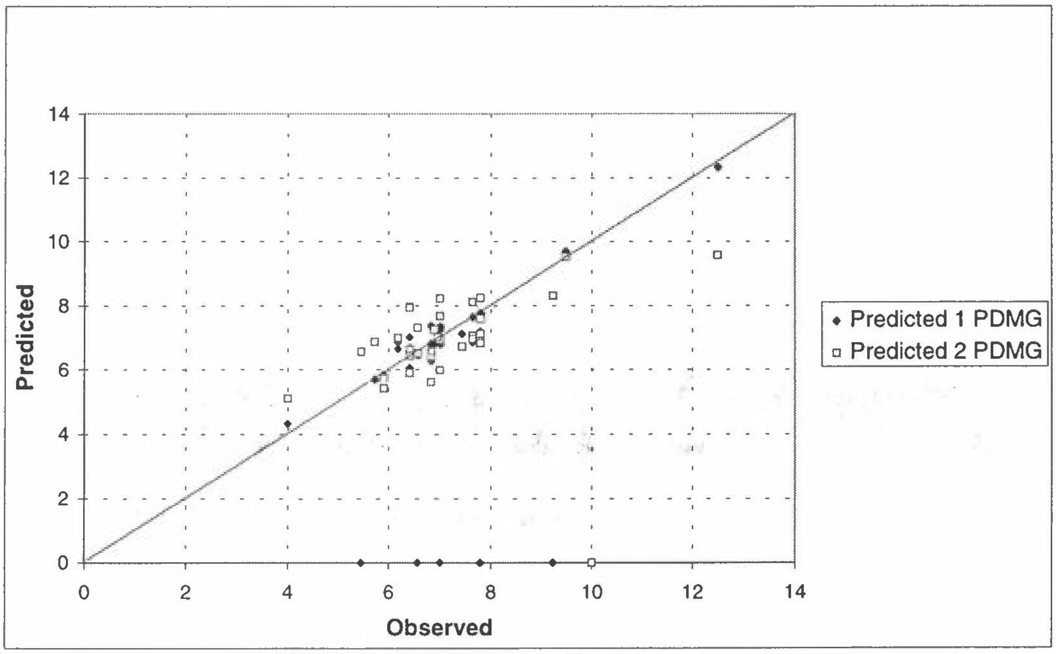


Figure 2, cont.



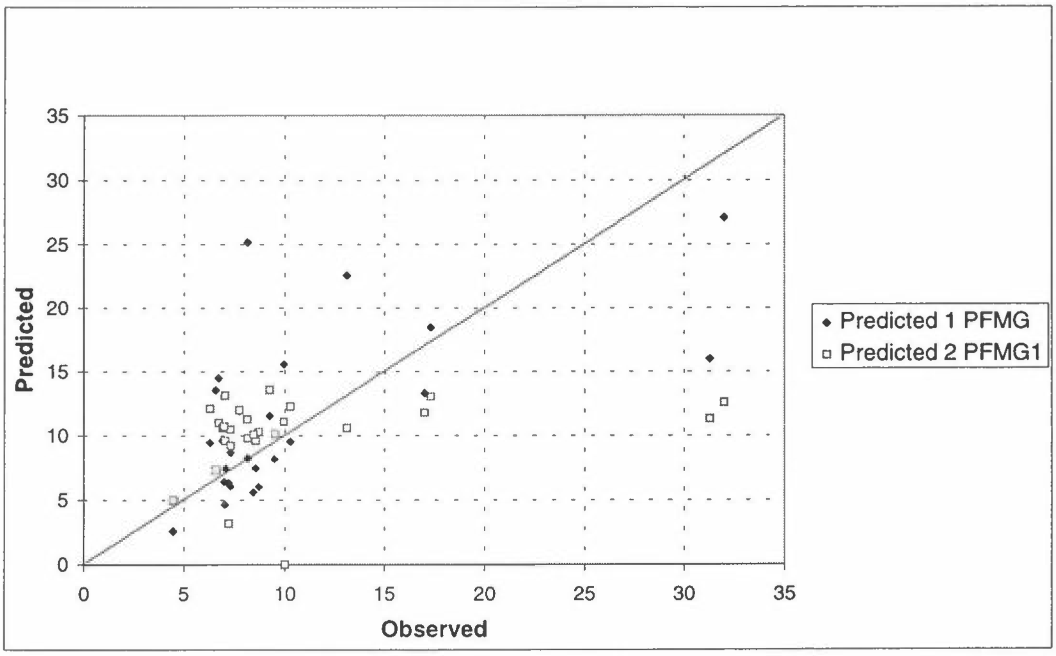


Figure 2, cont.

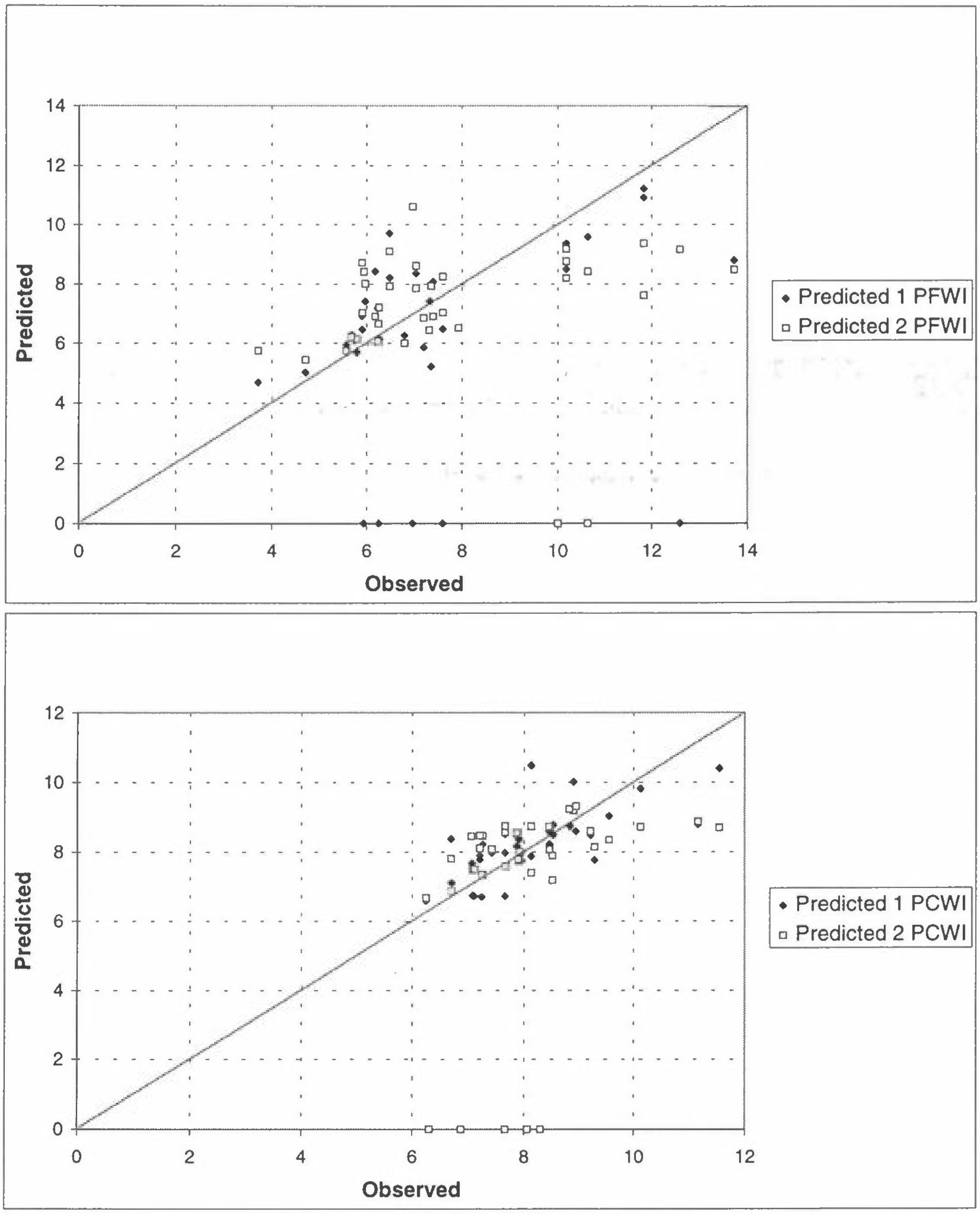


Figure 2, cont.

8.2 Change of lifetime attributable to changes in ambient concentrations of SO_2

The estimated functions may be used to evaluate the impact of changes in pollutant concentrations on material degradation. For this purpose, we have chosen the functions based on the simplified set of environmental variables. As it only is damage from cut that shows association with air pollutant (SO_2), we shall only show results for this parameter

A supplementary analysis done in Report no. 30 (1998) provides basis for comparison of environmental impact. In this study the damage (in ASTM units) has been expressed directly as a function of the environmental parameters, using a data set consisting of pooled data for 1, 2, 4 and 8 years. The estimated parameters A, B, C, D, M and S were calculated for the function:

$$\begin{aligned}10\text{-ASTM} = {} & (A*SO_2 + B*RH + C*(T-T_{lim})*IND(T-T_{lim}<=0) \\ & + D*(T-T_{lim})*IND(T-T_{lim}>0) + M*MM)*Time\verb|^|S, \qquad (5)\end{aligned}$$

where Time is in years. T_{lim} is "limiting temperature", defined as the temperature below which the damage linearly increases, and above which the damage linearly decreases. In our analyses, a limiting temperature was not conclusively confirmed.

In order to give meaningful comparisons, it is necessary to consider the ranges and/or frequency distributions of the environmental parameters. The cumulative frequencies for SO_2, relative humidity, temperature and precipitation amount are given in Table 2 both for annual average and 8-year averages.

Table 4 gives estimated lifetime with changes of SO_2, precipitation amount and relative humidity for lifetime for damage from cut, zinc, paint system H and steel, paint system H, using results of models for lifetime (eq. 4) and by using the ASTM as parameter (eq. 5). Generally, the equation (5) gives a steeper slope of dependency on SO_2, however, this may be explained by the fact that in estimating eq. 5, SO_2 is expressed as annual averages, while in estimating eq. 4, 8-year averages are used. From the table it can be seen that the lifetime is more influenced by changes in the natural parameters relative humidity and precipitation amount, than by changes in SO_2.

Table 4: Estimated lifetime for damage from cut on zinc and steel, with varying values of environmental parameters.

	Lifetime: Damage from cut, zinc, G				Lifetime: Damage from cut, steel, H			
RH (%)	81		70		81		70	
MM (mm)	1200		800		1200		800	
SO_2 (µg/m^3)	**Eq. (4)**	**Eq (5), T=9**	**Eq. (4)**	**Eq (5), T=9**	**Eq. (4)**	**Eq (5), T=9**	**Eq. (4)**	**Eq (5), T=9**
5	4.6	4.0	7.5	7.7	5.6	6.7	7.7	8.0
15	4.1	3.0	7.0	5.5	5.3	6.1	7.4	7.3
25	3.6	2.4	6.6	4.0	5.0	5.7	7.1	6.7
30	3.4	2.1	6.3	3.5	4.8	5.4	7.0	6.4
60	2.0	1.2	4.9	1.8	3.9	4.3	6.1	5.0

Figure 3 shows a comparison of the estimates of lifetime based on Equation 4 with restricted parameter sets, and lifetime based on the Equation 5 (function of ASTM), for both metals.

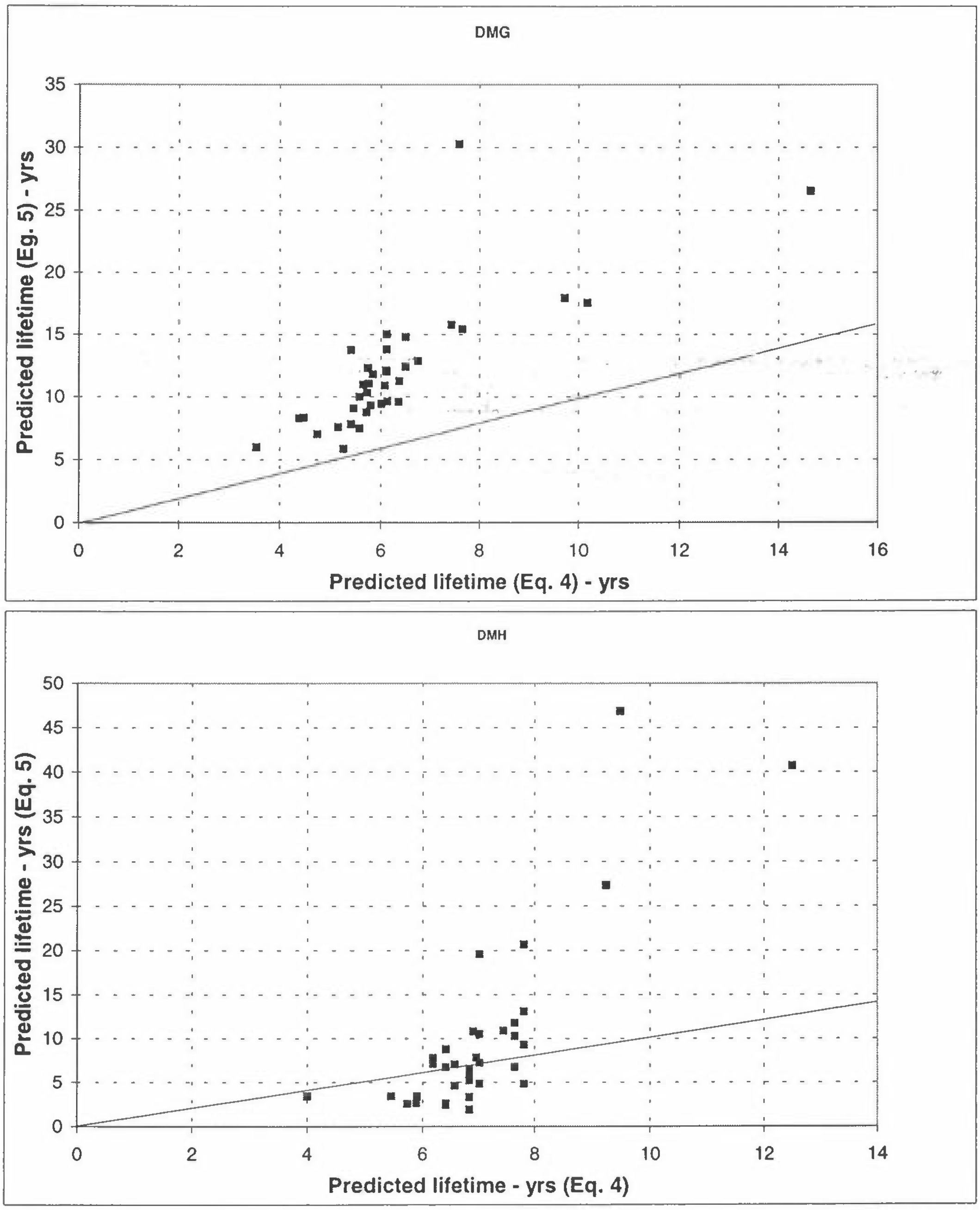


Figure 3: Comparison of lifetime calculated for each site using Equation 4 with restricted parameter sets and Equation 5.

9. Discussion

As discussed in Chapter 6 an evaluation of the deterioration of paint by use of ASTM standards has some limitations. Even if the deterioration processes themselves are irreversible, the evaluation techniques based on visual inspections and use of simple tools are not able to record the processes correctly. A major problem is that the processes interact with each other and the resulting damages can be affected be the environment. Total reduction of the paint film could have been a measurement which summarises many of the processes. However, the durability of the paint systems used has been so good that the thickness reduction has been smaller than the variation of the paint thickness between places on the panel and between different panels.

The results of all evaluated parameters are given in Annex 2 and are presented as graphs in Annex 1. For all parameters, a strong change in the ASTM values can be observed. All parameters are reduced with time and the values for each parameter from the same year varies from site to site. The general conclusion is therefore that we can observe a clear environmental impact on all paint systems for all ASTM parameters evaluated.

For the statistical dose-response evaluation we have chosen the deterioration parameters where the irreversible processes are easiest to follow. For painted wood it has been fungus growth and cracking of the paints which was observed mainly after four years, while for the corrosion protection paints damage from a cut in the paint and fungus were selected. Cracking of the corrosion protection paint films had still not been observed on samples even after 8 year of exposure

The concept of selecting the time needed to reach the ASTM value 5 as the lifetime before new treatment for the painted surface has improved the possibility of defining a dose-response relationship for painted surfaces. Even with this basic approach the analyses can be made in different ways. In this report most of the evaluations have been done in two steps. First by defining the lifetime from the functional relationship between ASTM values and time and afterward to correlate the results with the selected environmental parameters. See Figure 2. This method is comparable with methods often used in other types of effect studies like health studies. This approach reduces the amount of uninformative variability in the data by working with aggregated values and long-term averages (averages of the environmental variables over the exposure period). For the variables that can be considered stable over time and only fluctuate due to meteorological variability (precipitation amount, radiation), this may be an advantage as the year-to-year variability is smoothed. However, trends in air pollutant concentrations may affect the damage process. Within the current programme, trends to lower consentrations have been observed for several parameters like SO_2 acid load and NO_2. This will complicate the statistical treatment of the data. In addition, estimating changes in lifetime directly may have practical advantages for the paint companies when using this approach for other field test programmes.

The possibility of combining these two steps into one model by introducing time as a variable in the dose-response equation has been done for the damage from cut parameter in the joint evaluation report from the main centre (Tidblad et al., 1998). In this approach, the data sets for damage after 1, 2, 4 and 8 years are pooled together, so that the environmental variables used are aggregates with differing aggregating periods. In this analysis, the damage is modelled directly, so that damage may be predicted for any time period. A comparison between the two approaches is shown in Figure 3.

The multiple regression analysis performed have been stepwise backward analysis, where a selected number of environmental parameters has been defined for testing. In test (a) both individual and combined parameters which could have a possible effect were selected. In test (b) the test was restricted to individual parameters where sufficient data for modelling the results on an European scale exist. Scatter plots of the results from analysis (a) and (b) against the determined lifetime calculation by function (3) are shown in Figure 2.

Model (a) gave promising results for all paint systems, but the interpretation of all the parameters left in the equations is complicated. The interaction terms are acting as modifiers of effects of individual variables, as could be expected. However, the 2nd and 3rd order interactions are difficult to translate into simple terms. In addition, the environmental variables are not independent of each other, and this complicates the interpretation further. In practice, the results obtained using the first parameter set need further analysis before they can be applied to estimating changes in damage caused by environmental parameters.

In Model (b) with a reduced number of variables for the calculation taking into account the knowledge from previous calculations, the results are more in accordance with the expected parameters for damage from the cut and cracking but with less confidence. From Figure 2 it is obvious that this reduced confidence is caused by the sets with long lifetime. If we reduce the acceptable lifetime data to three timer the exposure period or 24 years most of the data will have a much better fit. SO_2 is the only air pollutant used, and it appears as an explanatory factor only for damage from the cut (on both paint systems).

For fungus the R^2 for all types of paint are in the range of 0.54 to 0.65 for Model (a), with the same type of interacting terms as for damage from cut. Wetness parameters are dominating as expected. Chloride seems to have fungicide effect for all paint systems for both Model (a) and (b). The reduced number of variables in Model (b) again gave a weaker explanation to the results and the reduced R^2 is again dominated by the deviation for long lifetimes.

For cracking the number of variables left after the regression analysis is small both for Model (a) and (b). The Model (a) again gave the best explanation of the results.

Since the lifetime used in the analysis are already extrapolated with some degree of uncertainty, it is important that we use weighted stepwise regression. With a closer look at contribution of the interacting terms, it could be possible to improve the results obtained. The method of transferring the results from ASTM values to lifetime seems to be a great benefit to the interpretation of the paint results and to further use of the data for cost/benefit analysis.

10. Conclusions

The damage of the paint systems have been evaluated by using the well established ASTM-standards on samples exposed for one, two, four and eight years. The dose-response functions for the relation between the air pollutants and the damages have been established by means of a two steps calculation. The first step has been to define the lifetime for maintenance intervals for fungus grow on the surfaces, for the cracking of the paint systems for wood and for damage spread from a cut in the film for the paint systems for metals. The second step has been to establish the correlation between the lifetime and selected environmental parameters in a dose-response function by stepwise backward regression analysis.

Two sets of functions have been presented, model (a) where most of the possible contributing parameters are tested and model (b) with a restricted number of parameters involved.

Model (a) gave promising results for all paint systems, but the interpretation of all the parameters left in the equations is complicated. The interaction terms are acting as modifiers of effects of individual variables, as could be expected. However, the 2nd and 3rd order interactions are difficult to translate into simple terms. In addition, the environmental variables are not independent of each other, and this complicates the interpretation further.

In Model (b) the calculation has taken into account the knowledge from previous calculations. The results are more in accordance with the expected parameters. From Figure 2 it is obvious that this reduced confidence obtained with model (b) is caused by the sets with long lifetime. If we reduce the acceptable lifetime data to three timer the exposure period or 24 years most of the data will have a much better fit.

For fungus the R^2 for all types of paint are in the range of 0.54 to 0.65 for Model (a). Wetness parameters are dominating as expected. Chloride seems to have fungicide effect for all paint systems for both Model (a) and (b). The reduced number of variables in Model (b) gave a weaker explanation to the results and the reduced R^2 is dominated by the deviation for long lifetimes

For cracking the R^2 for both paint systems are good with Model (b) and the dominating parameters are climatic parameters like relative humidity, solar radiation and rain.

For damage from a cut the dose-response functions also included the SO_2 concentration as an explanatory factor together with relative humidity and rain. Model (a) gave higher R^2 values than Model (b).

The method of transferring the results from ASTM values to lifetime seems to be a benefit to the interpretation of the paint results for dose -response studies and to further use of the data for cost/benefit analysis.

11. References

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Annex 1

Figures

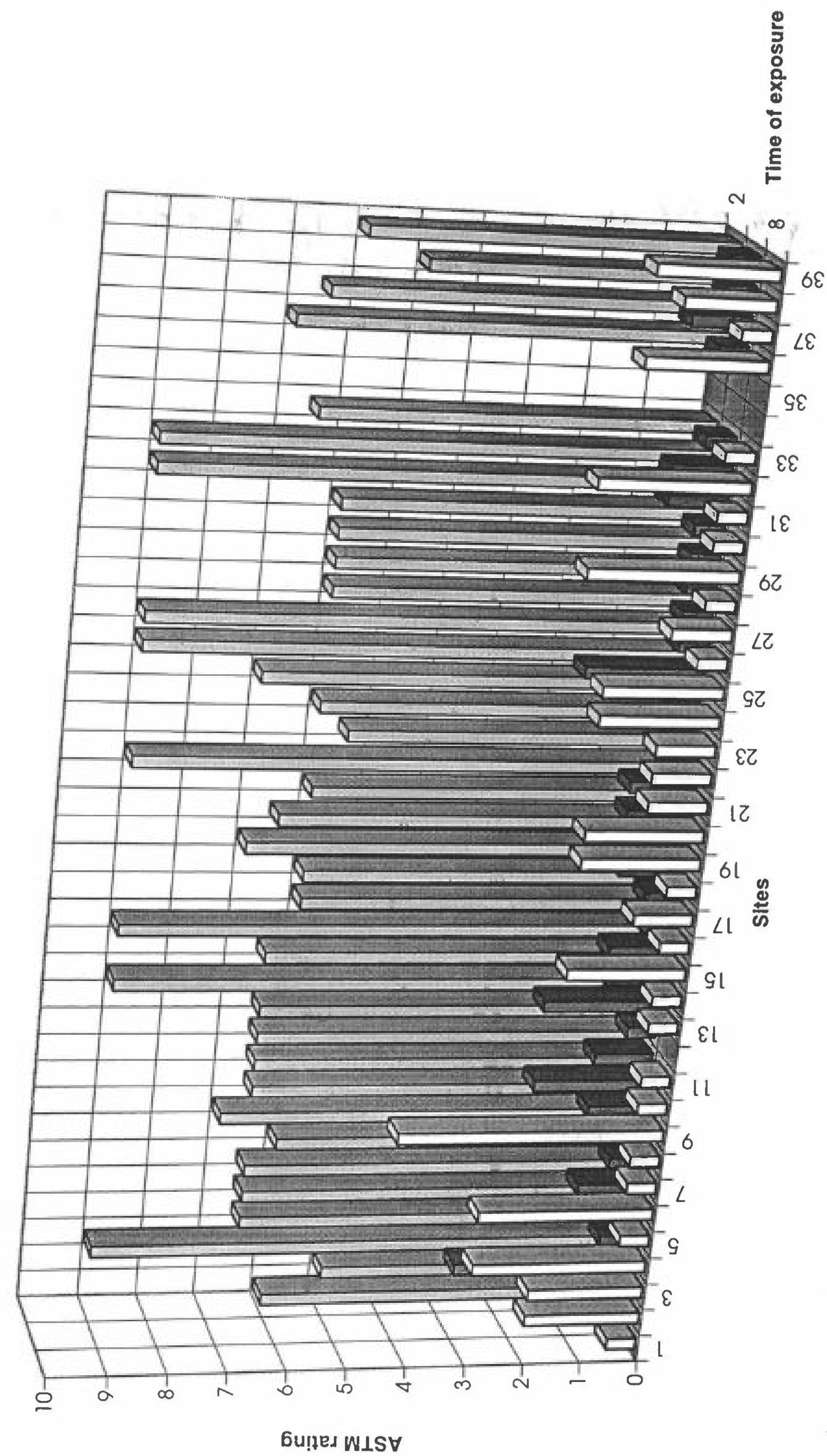

Figure 1.1: Type G. Chalking after 2, 4 and 8 years of exposure.

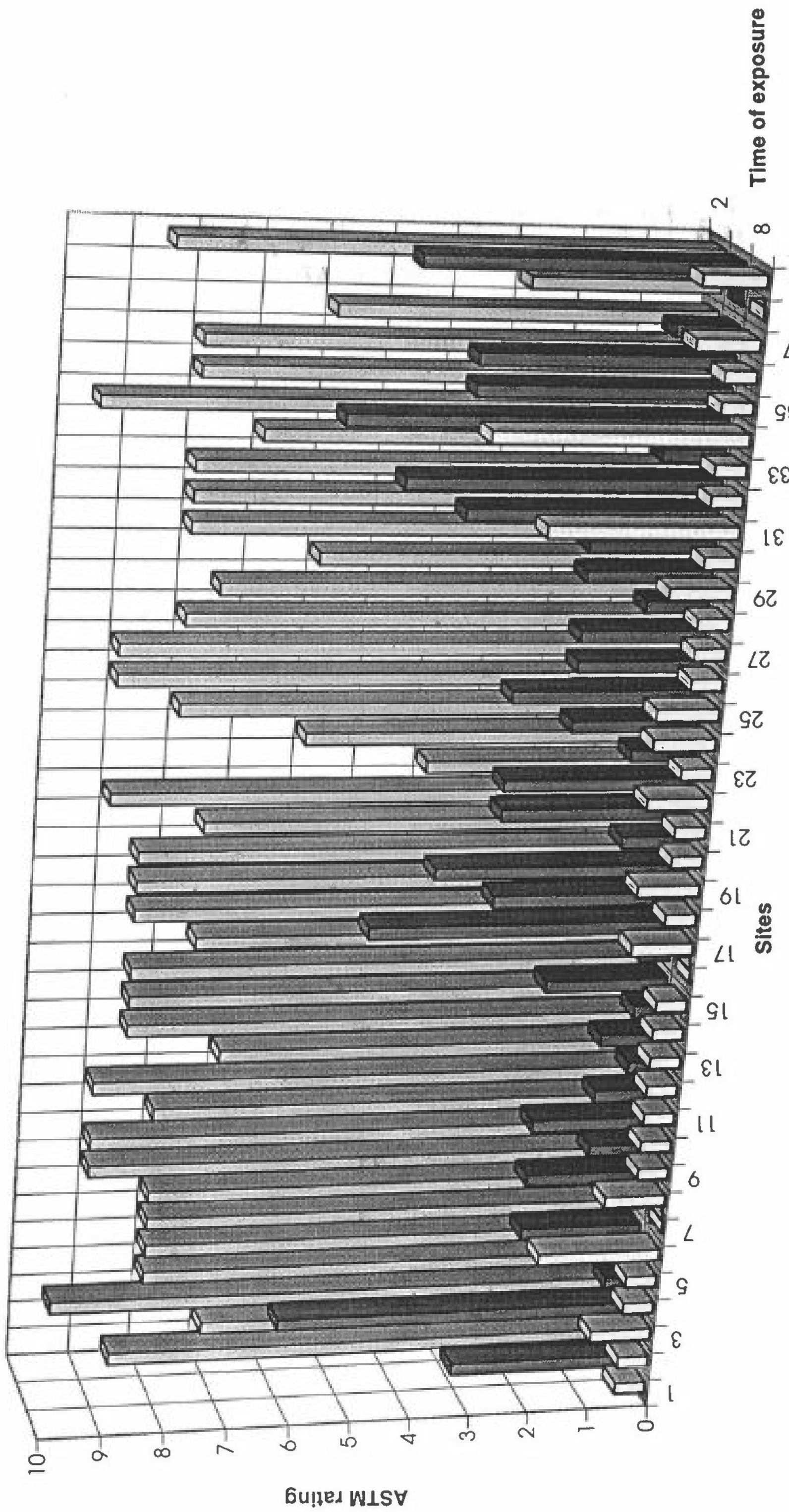

Figure 1.2: Type H. Chalking after 2, 4 and 8 years of exposure.

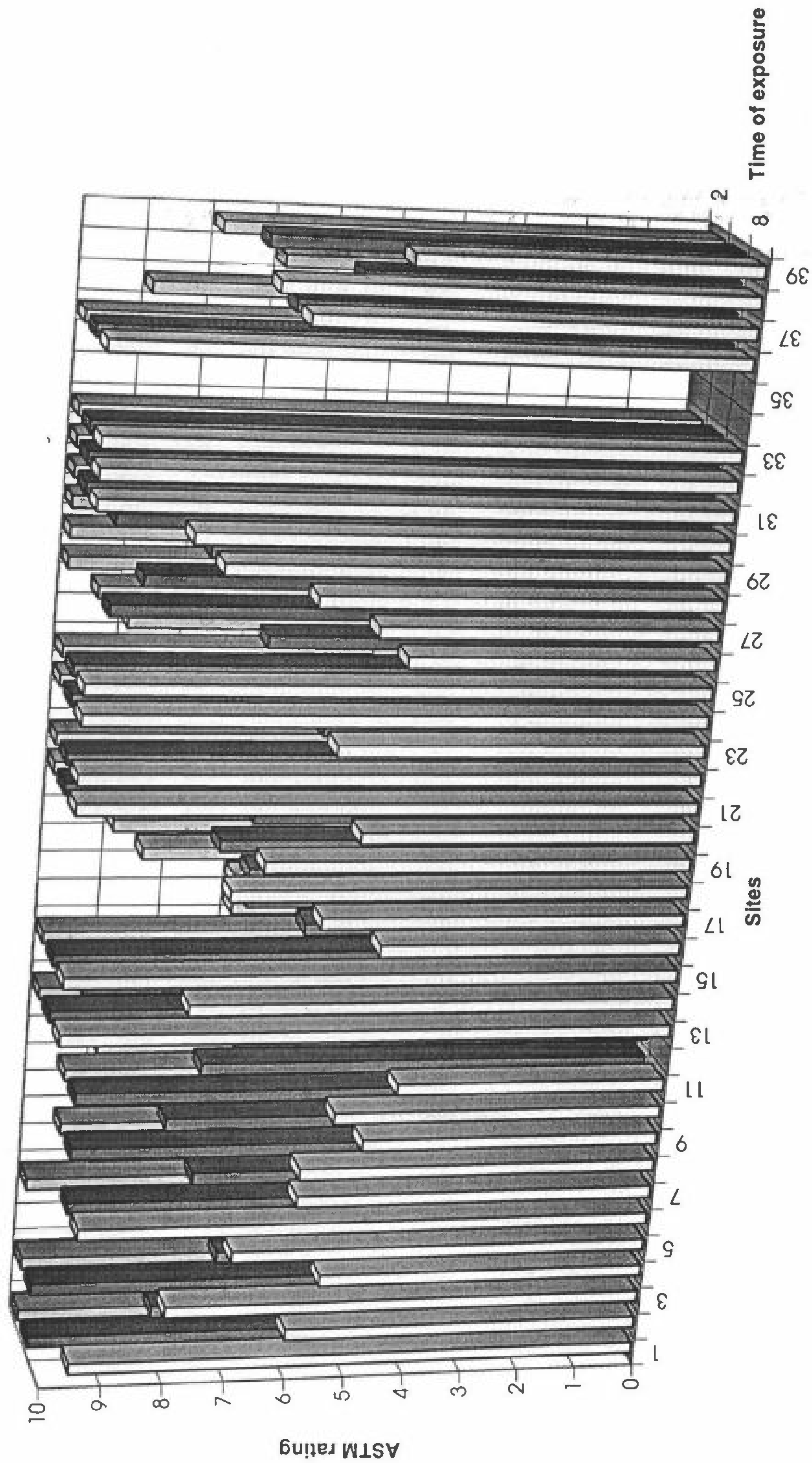

Figure 1.3: Type G. Fungus after 2, 4 and 8 years of exposure.

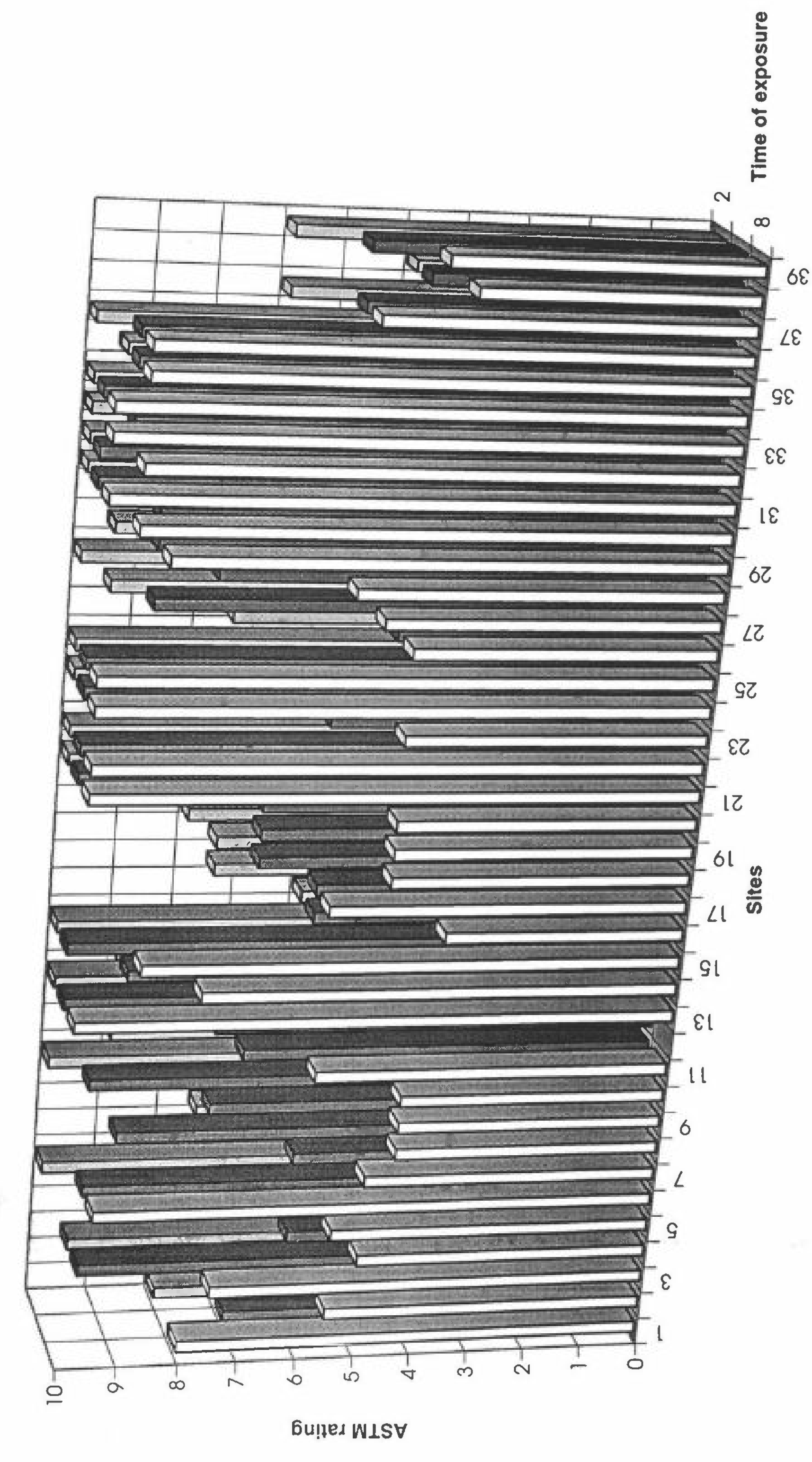

Figure 1.4: Type H. Fungus after 2, 4 and 8 years of exposure.

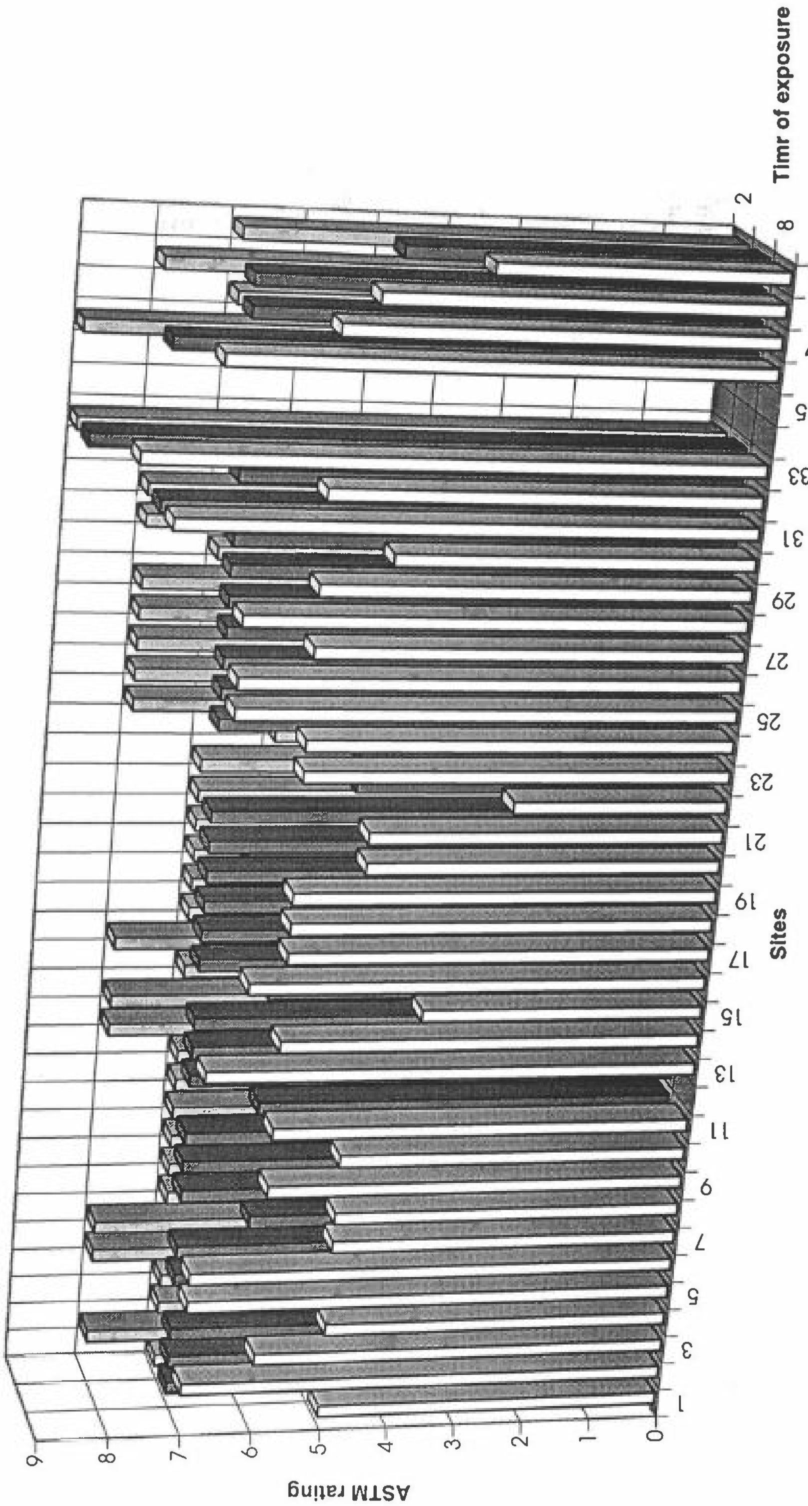

Figure 1.5: Type G. Damage from cut after 2, 4 and 8 years of exposure.

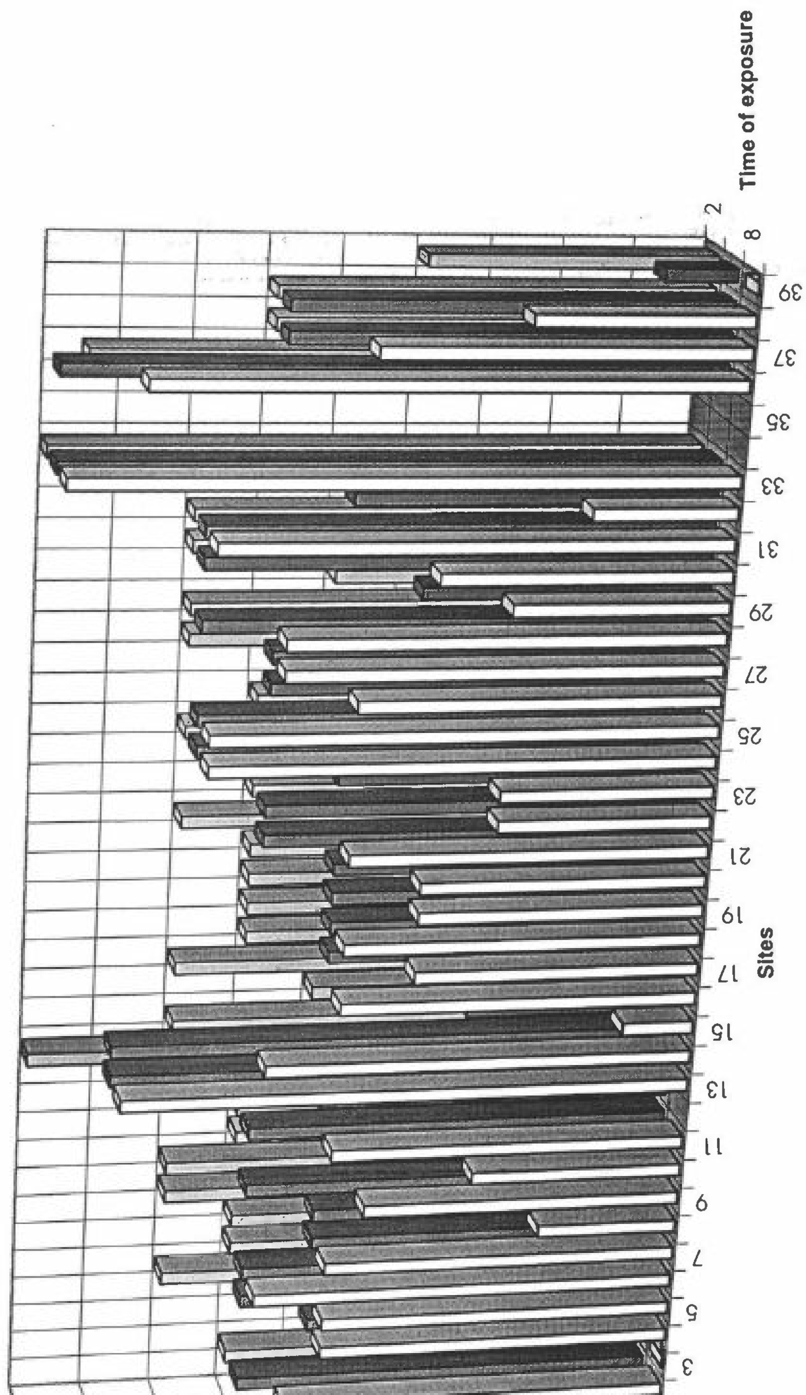

Figure 1.6: Type H. Damage from cut after 2, 4 and 8 years of exposure.

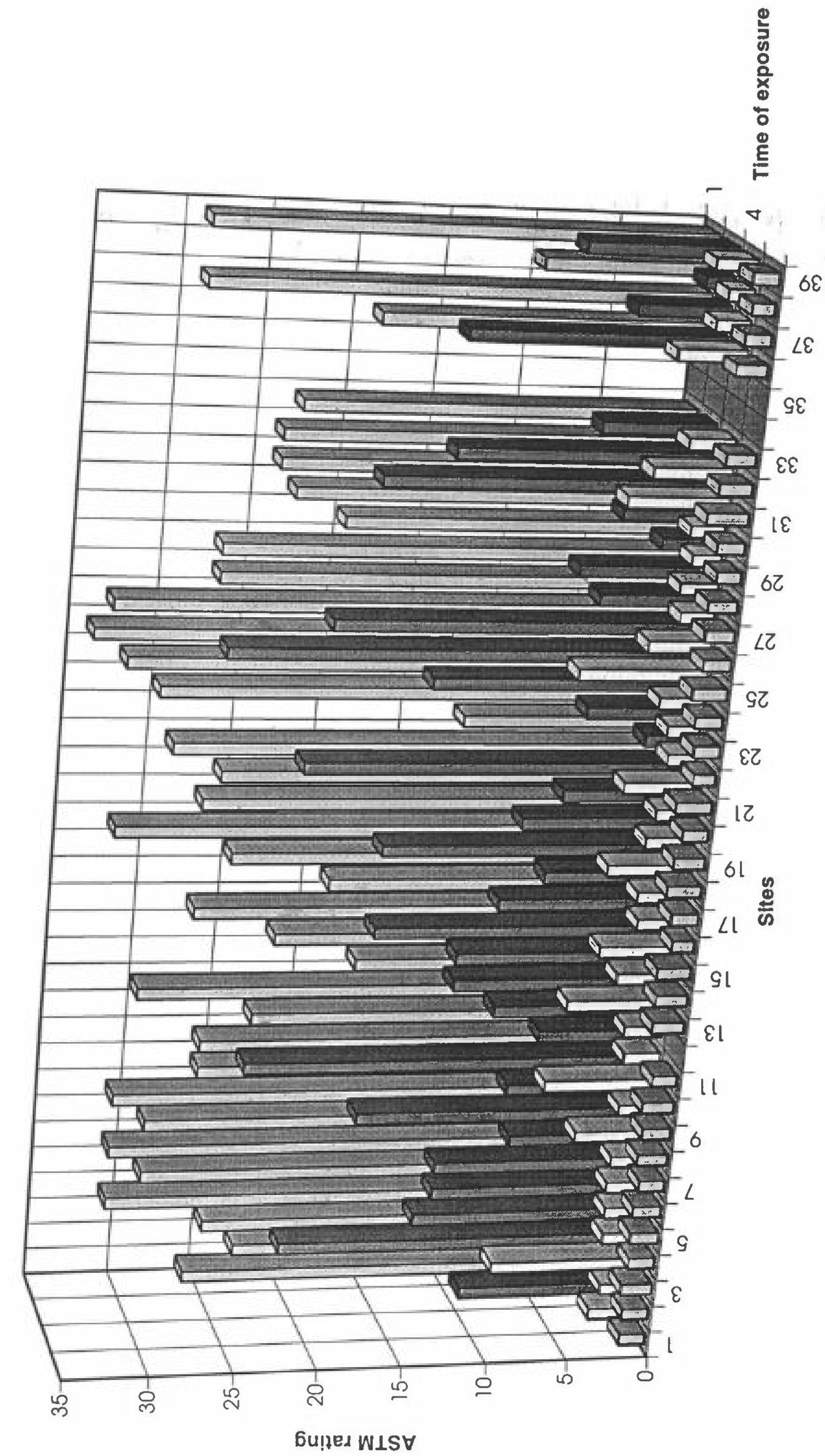

Figure 1.7: Type G. Gloss after 1, 2, 4 and 8 years of exposure.

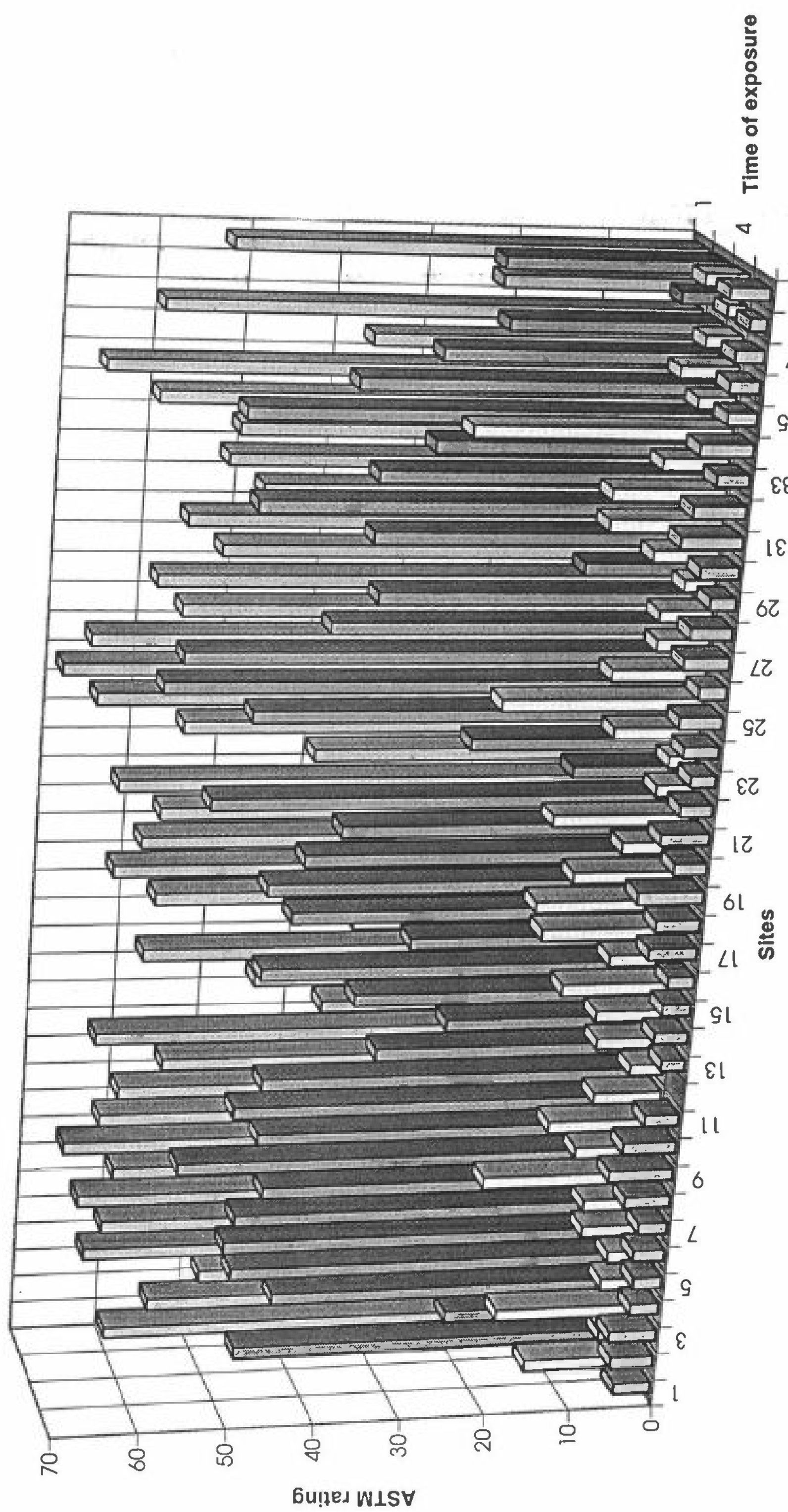

Figure 1.8: Type H. Gloss (front) after 1, 2, 4 and 8 years of exposure.

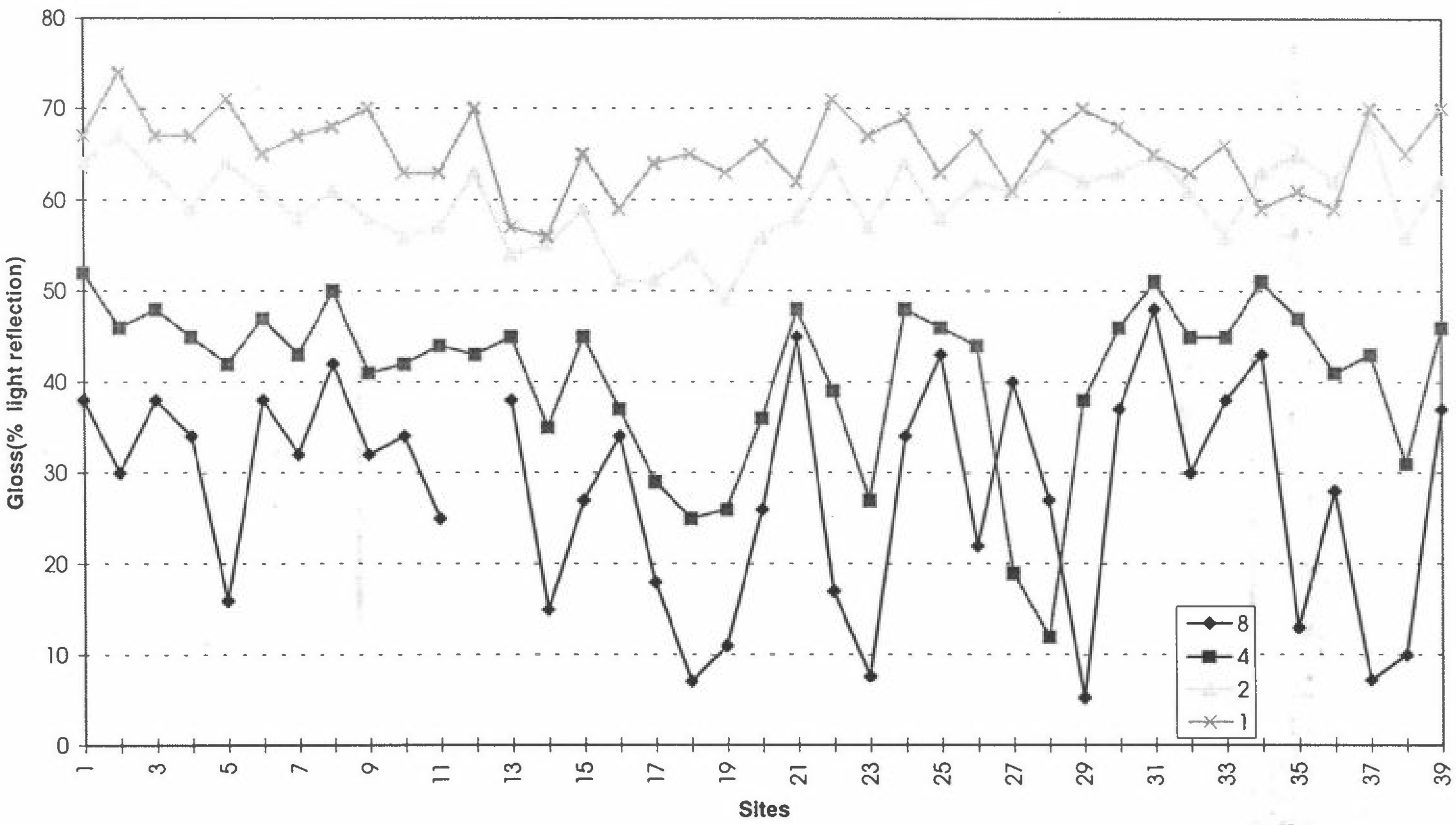

Figure 1.9: Loss of gloss on the backside of the alkyd painted panels after 1, 2, 4 and 8 years of exposure.

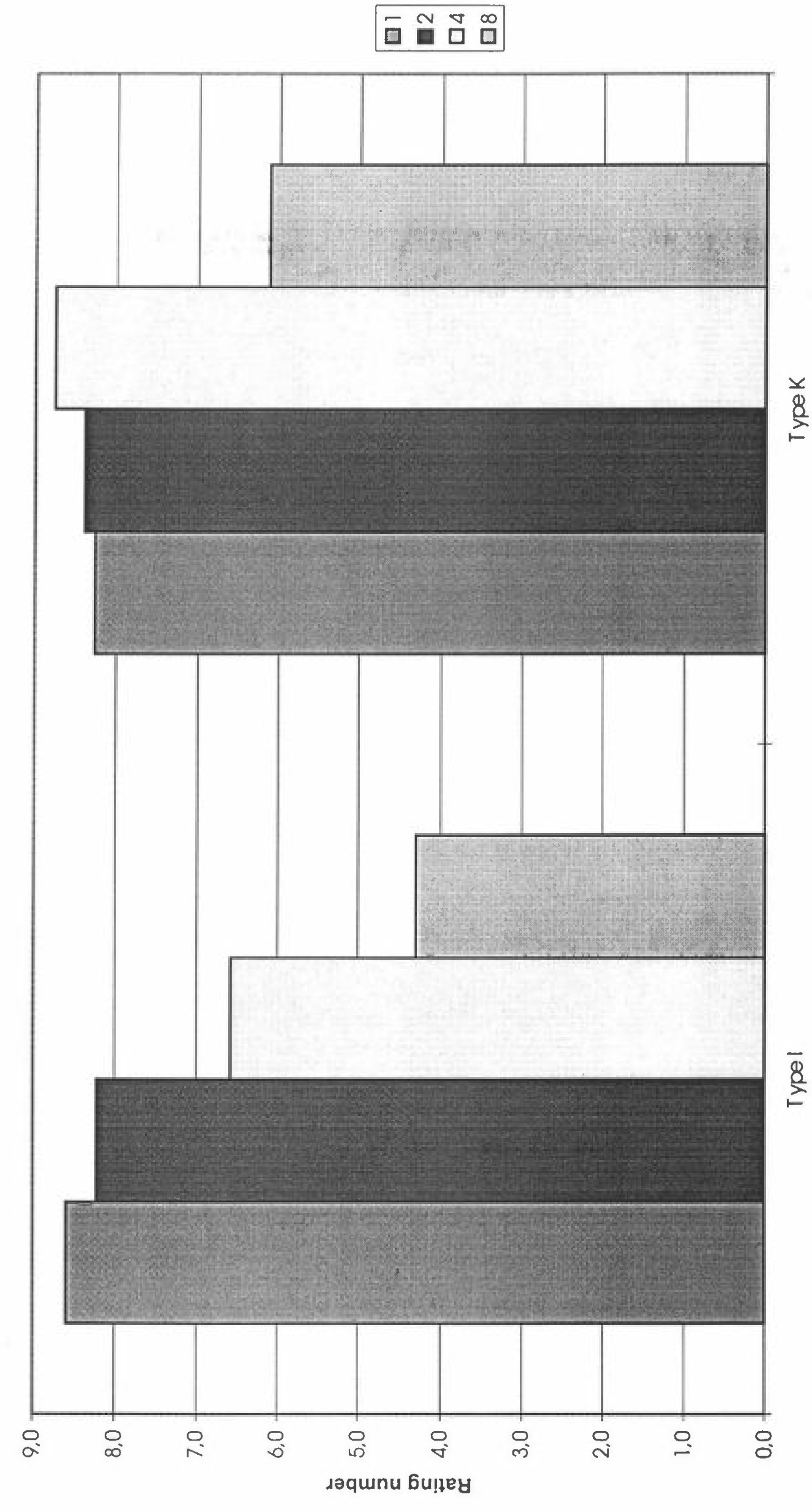

Figure 1.10: General appearance after 1, 2, 4 and 8 years of exposure (medium values, all sites included).

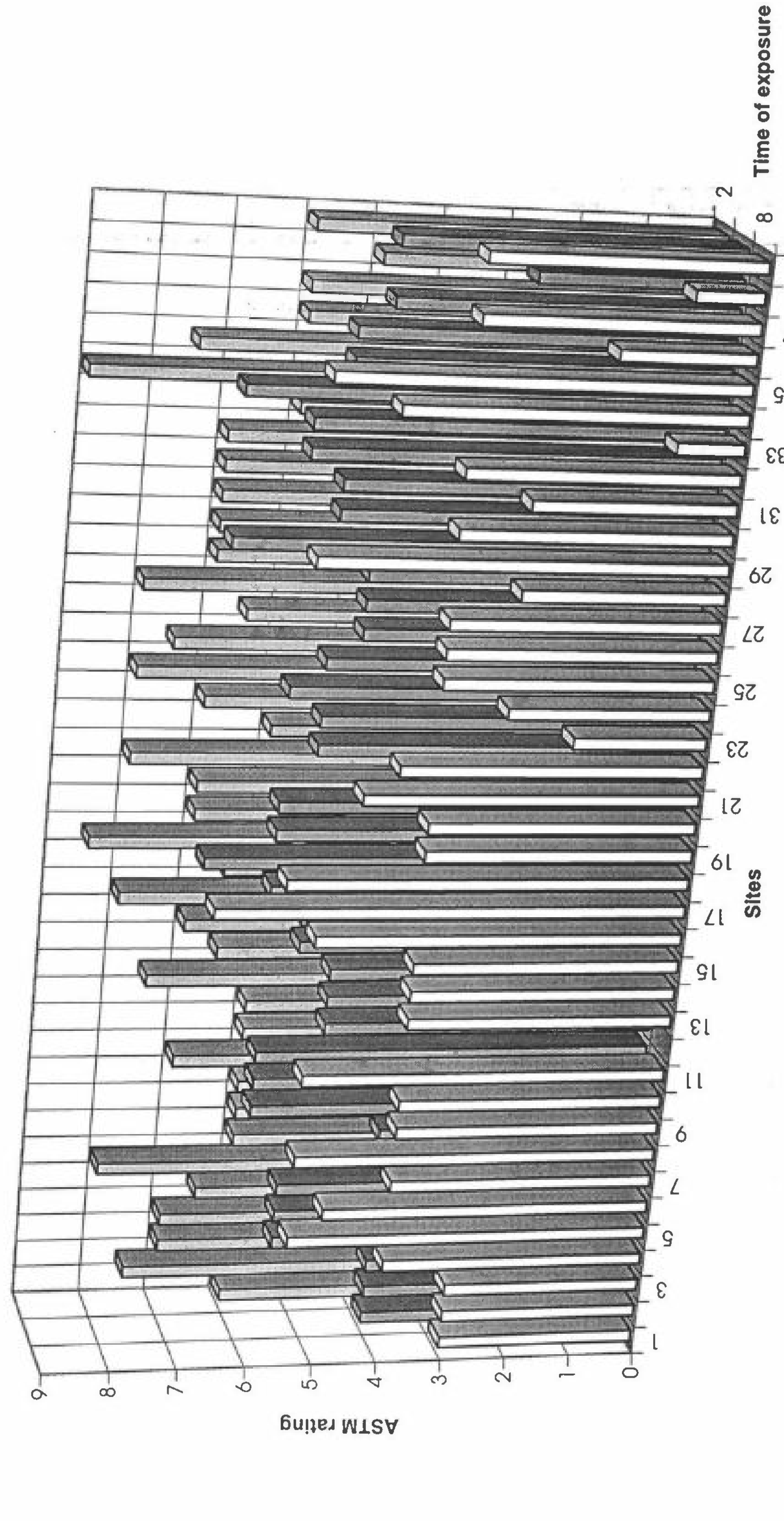

Figure 1.11: Type I. Chalking after 2, 4 and 8 years of exposure.

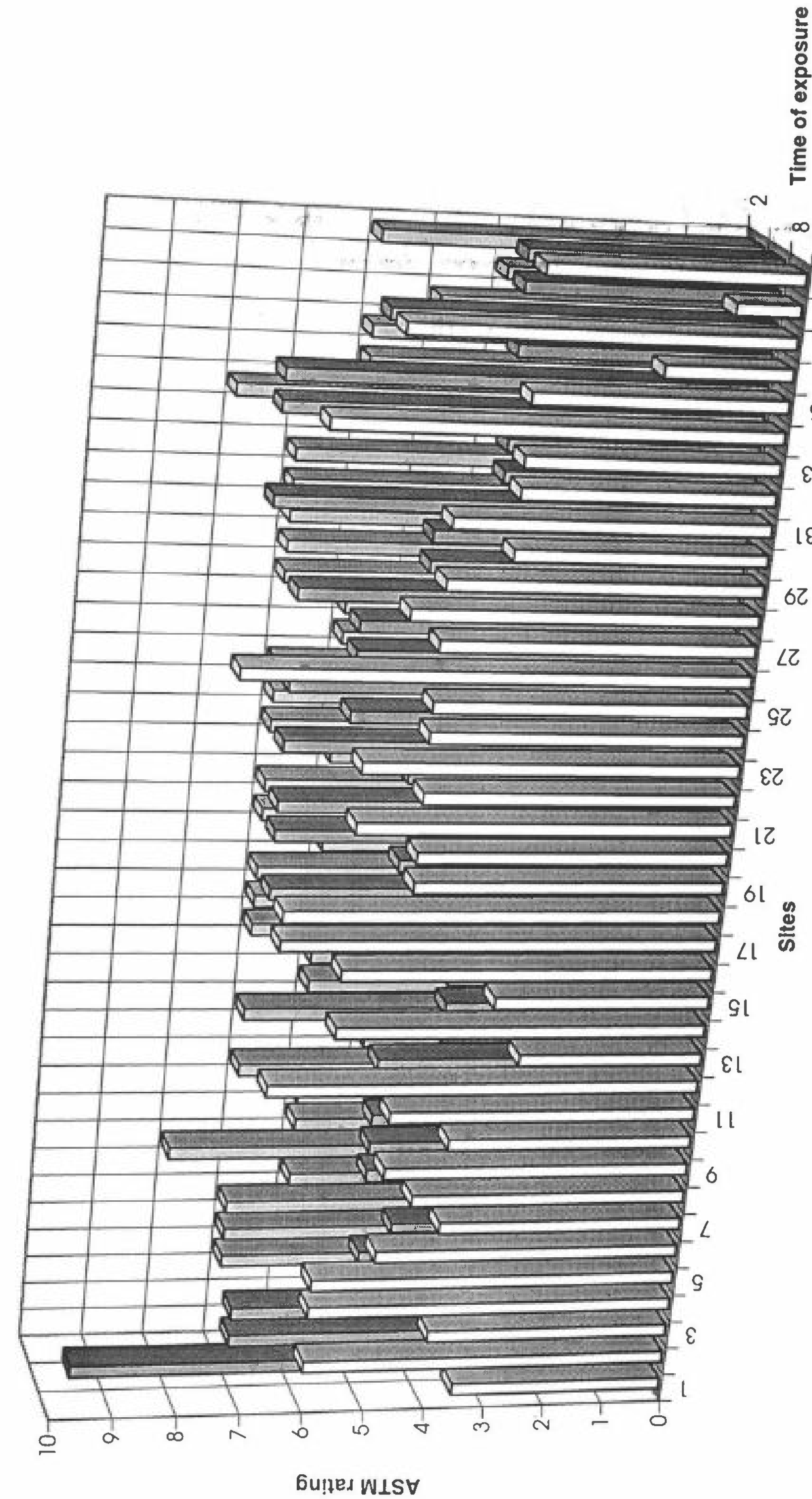

Figure 1.12: Type K. Chalking after 2, 4 and 8 years of exposure.

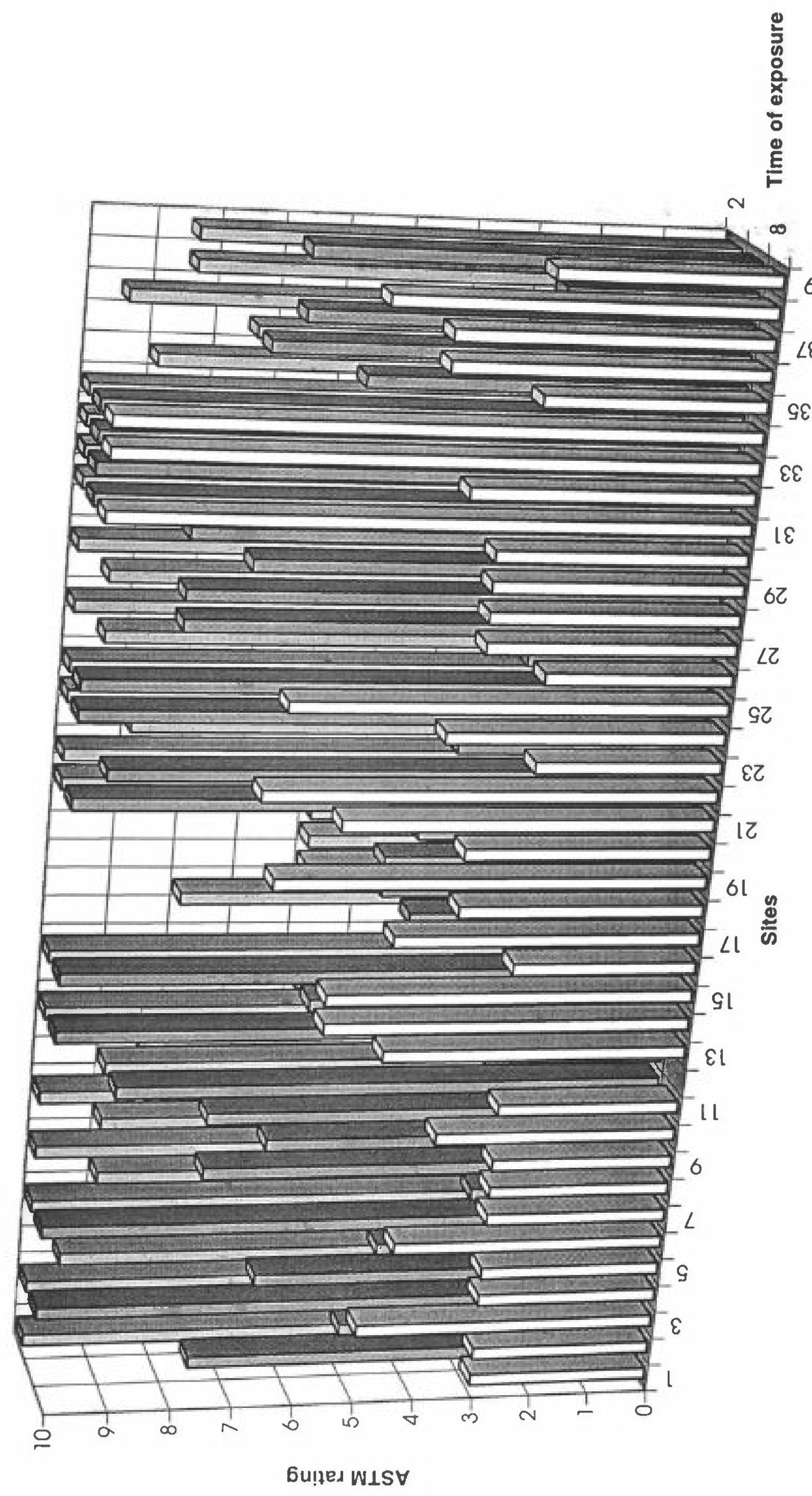

Figure 1.13: Type I. Fungus after 2, 4 and 8 years of exposure.

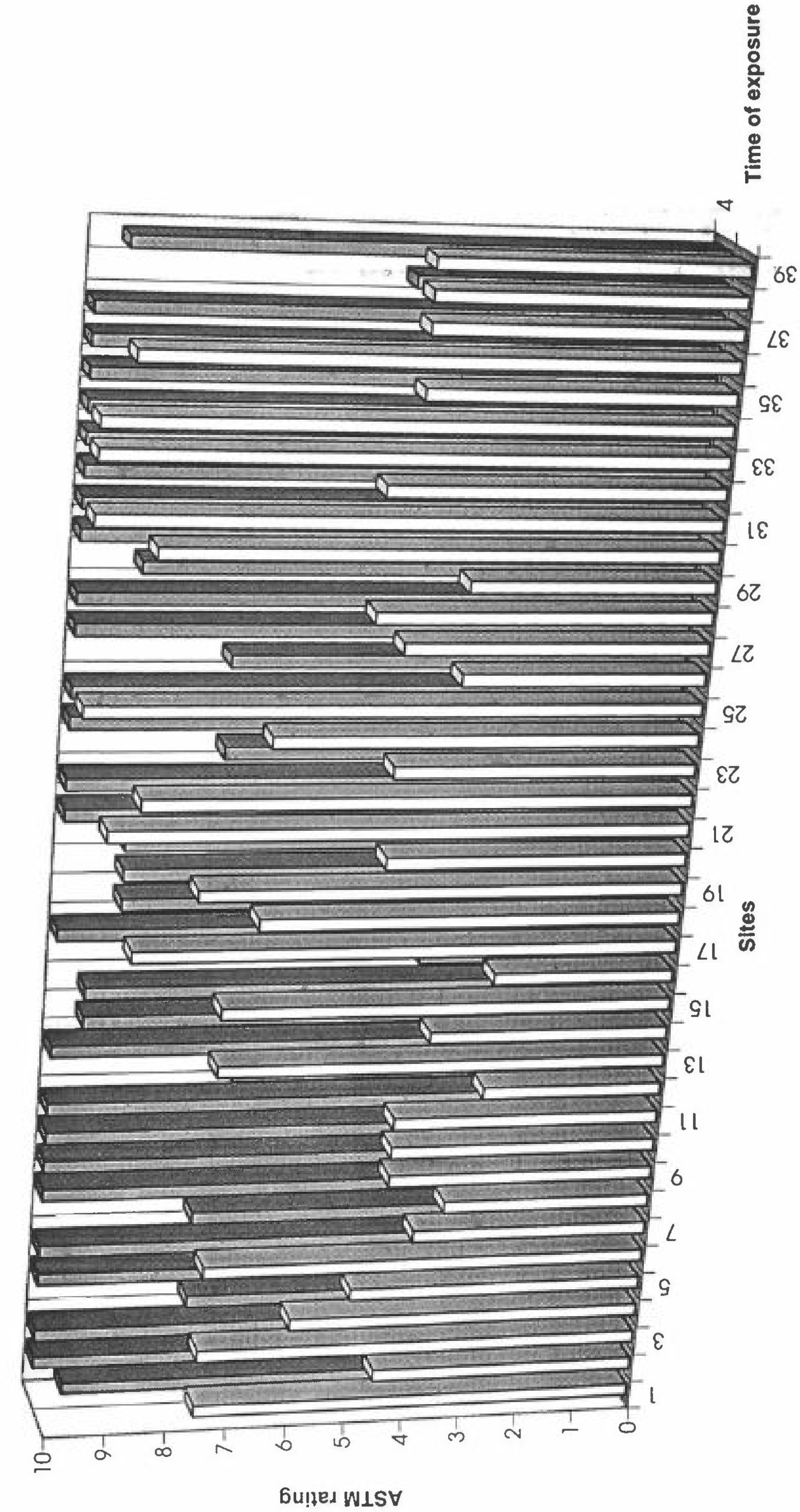

Figure 1.14: Type K. Fungus after 4 and 8 years of exposure.

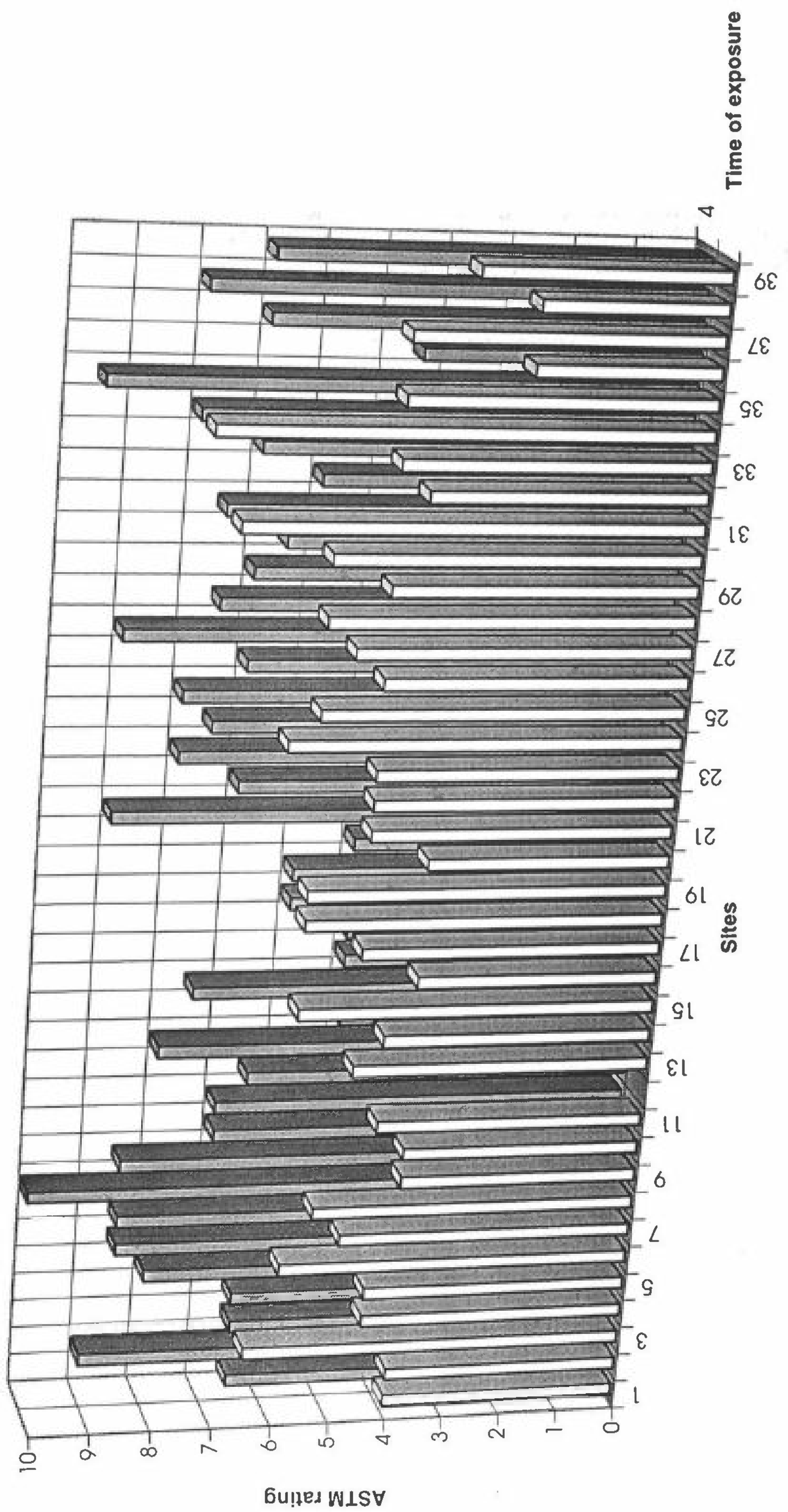

Figure 1.15: Type I. Cracking after 4 and 8 years of exposure.

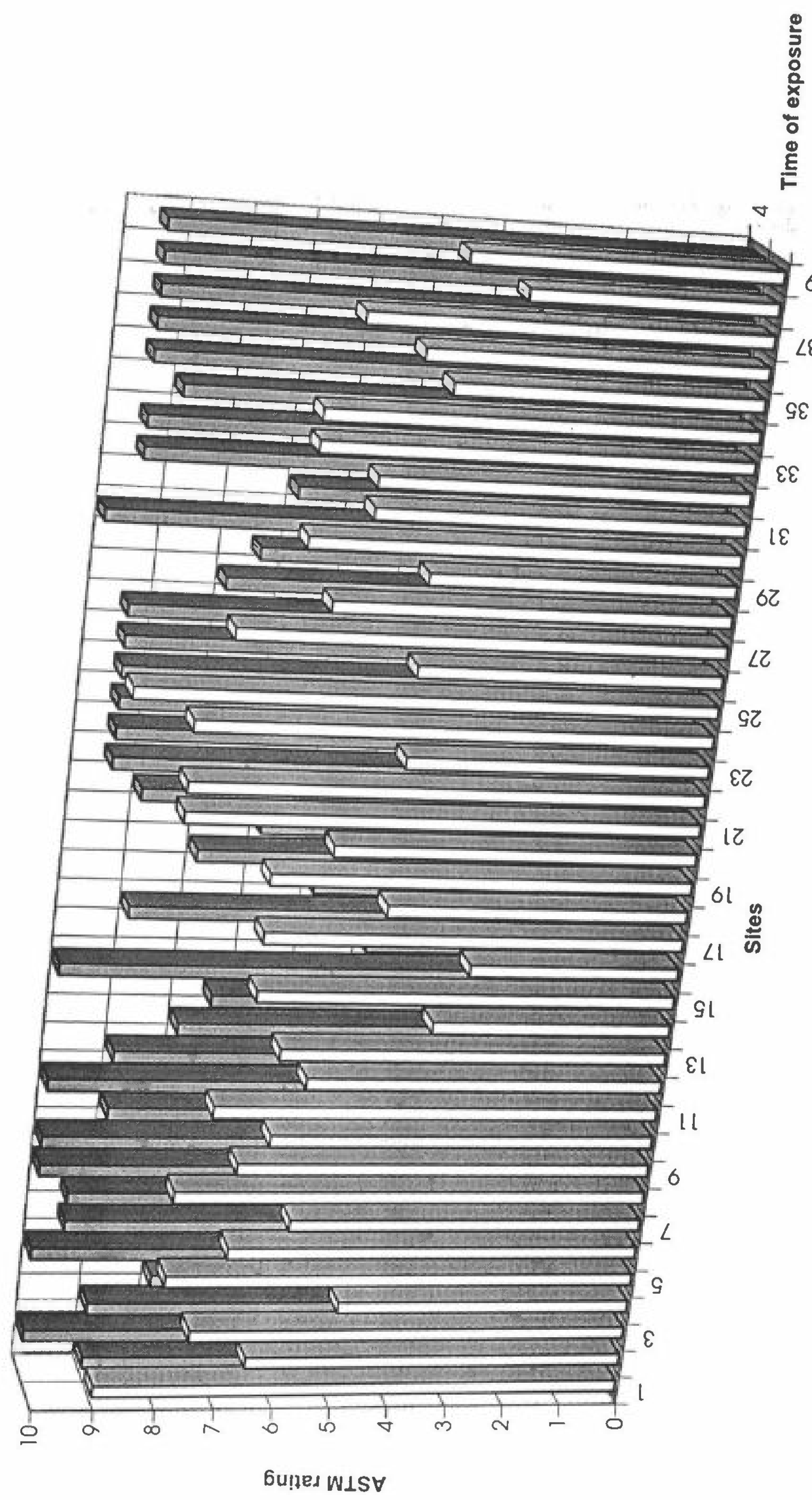

Figure 1.16: Type K. Cracking after 4 and 8 years of exposure.

Annex 2

Tables

Table 2.1: Evaluation of coil coated steel with alkyd melamine coating (type G) after 1, 2, 4 and 8 years of exposure.

Site No.		Parameter											
		General appearance				Dirt				Chalking			
		1	2	4	8	1	2	4	8	1	2	4	8
1	CZE	5,5	7	8	6	6	7	8,5	9	9	6	0,5	0,5
2		8	7	8	6,5	8	7	8,5	8	9	5	0,5	2
3		6	6,5	7,5	4	6	6,5	8	6	9,5	9	3	2
4	FIN	5	6,5	6	6	5	6,5	8	7	9	6,5	0,5	3
5		5	6,5	9	6,5	5	6,5	9	8	9	6,5	0,5	0,5
6		6	7	8,5	7	6	7	8,5	9	9	6,5	1	3
7	GER	6	6,5	6,5	6	6	6,5	8	8	8,5	6	0,5	0,5
8		5	4,5	6,5	5,5	5	5	9	6,5	9,5	7	1	0,5
9		6	5,5	8	5,5	6	5,5	8	8	9	6,5	1	4,5
10		5	5,5	7,5	5,5	5	5,5	8	8	9,5	6,5	2	0,5
11		5	6,5	7	5	5	6,5	8	6	8,5	6,5	1	0,5
12		6,5	7	6		6,5	7	8,5		9,5	6,5	0,5	
13	ITA	4	4,5	6	5,5	4	5,5	6	7	9	9	2	0,5
14		7	7	7	6	7	7	8	7	9	6,5	1	0,5
15		3	6	8	5	3	6,5	8,5	5	9,5	9	1	2
16		3	4	6	3,5	3	4	6,5	4	8,5	6	0,5	0,5
17	NL	5	5,5	7,5	6	5	5,5	8	7	8	6	0,5	1
18		6,5	5	8	6	7	5,5	8,5	7	9	7	1	0,5
19		7	5	8,5	5	7	5,5	8,5	6	9	6,5	1	2
20		7	5	6	5	7	6,5	8	6	9	6	1	2
21	NOR	6	7	7,5	6	6	7	9	9	9,5	9	1	1
22		6	8	5	3	6	8	9	9	5,5	5,5	0,5	1
23		7	8	6,5	6	7	8	6,5	8	9	6	0,5	1
24	SWE	7	7	9	6,5	7	7	9	9	9	7	0,5	2
25		5	6	7,5	7	5	6,5	9	8,5	9,5	9	2	2
26		7	6,5	7,5	6,5	7	6,5	7,5	7	9	9	0,5	0,5
27	UK	8	7	8	5,5	8	7	9	7	9	6	0,5	1
28		8	7	9	6,5	8	7	9	9	9	6	0,5	0,5
29		7	8	9	5,5	7	8	9	8,5	8	6	0,5	2,5
30		7	7	7	5,5	7	7	9	8,5	8,5	6	0,5	0,5
31	SPA	5	7	7	7	5	7	9	9	9,5	9	1	0,5
32		5	5,5	8	6	5	5,5	8	8,5	9,5	9	1	2,5
33		8	7	7	8,5	8	7	9	9	9	6,5	0,5	0,5
34	RU												
35	EST												
36	POR	7	7	8	6	7	7	8,5	8	8	7	0,5	2
37	CAN	8	8	7,5	6,5	8	8	8	8	9	6,5	1	0,5
38	USA	7	8	6,5	6	7,5	8	8	7	5	5	0,5	1,5
39		5,5	6	6	4	5,5	6,5	8	7	9,5	6	0,5	2

Table 2.1, cont.

		PARAMETER													
		Fungus				Edge damage		Damage from cut				Gloss			
Site No.		1	2	4	8	4	8	1	2	4	8	1	2	4	8
1	CZE	10	10	10	9,5	9	8	8	7	7	5	26	9,7	2,5	1,6
2		10	9	8	6	10	9,5	9	8	7	7	23	4,3	2	1,6
3		10	10	10	8	9	6	8	7	7	6	25	21	9	1,9
4	FIN	9	7	7	5,5	9,5	9	8	7	6	5	31	13	2,2	1,6
5		8	9	7	7	10	10	9	8	7	7	29	12	2,2	1,7
6		10	10	9,5	9,5	9,5	9	8	8	7	7	31	12	2,3	1,7
7	GER	9,5	9	7,5	6	9,5	8	8	7	6	5	29	7,6	2,2	1,5
8		10	9,5	9,5	6	10	9,5	8	7	7	5	31	17	4,6	1,8
9		10	8	8	5	9	8	8	7	7	6	26	8,1	2,1	1,7
10		10	9,5	9,5	5,5	9,5	9	8	7	7	5	26	24	6,9	1,9
11		9	9	7,5	4,5	9	8	8	7	6	6	23	6,4	2,2	1,5
12		9	8	7				8	7	7		30	9,4	2,3	
13	ITA	10	10	10	10	10	9	9	8	7	7	17	12	6	1,9
14		9,5	9,5	9,5	8	9,5	9	8	8	7	6	22	12	3,2	1,9
15		10	10	10	10	9,5	8	8	7	6	4	27	17	4,4	2
16		9	7	6	5	9,5	9	9	8	7	6,5	19	9,8	2,3	1,3
17	NL	9,5	7	7	6	9,5	9	8	7	7	6	25	7,2	2,5	1,6
18		9,5	8,5	7	7,5	9,5	9	8	7	7	6	32	17	4,5	2
19		10	9	7,5	7	9,5	7	8	7	7	6	27	8,9	2,4	1,8
20		9,5	8	7	5,5	9,5	9	8	7	7	5	26	6,6	2	1,5
21	NOR	10	10	10	10	9,5	9	8	7	7	5	29	22	4,1	2,1
22		10	10	10	10	8	3	7	7	5	3	12	2	1,7	1,3
23		9,5	9	6	6	10	9	8	6	5	6	30	5,7	1,9	1,5
24	SWE	10	10	10	10	9,5	9	8	8	7	6	32	15	2,6	1,6
25		10	10	10	10	9,5	9	8	8	7	7	34	27	7,6	2
26		9,5	9	7	5	10	9	9	8	7	7	33	21	3,7	1,6
27	UK	9,5	9,5	9,5	5,5	9,5	8	8	8	7	6	27	5,7	2	1,7
28		10	10	9	6,5	9,5	8	8	8	7	7	27	7,1	2,2	1,7
29		10	10	8	8	9	6	8	7	7	6	20	2,4	1,7	1,4
30		10	10	9,5	8,5	9	6	8	8	7	5	23	4,9	2	1,6
31	SPA	10	10	10	10	10	9,5	9	8	8	8	24	19	5,9	2,4
32		10	10	10	10	9,5	8,5	8	8	7	6	24	15	4,6	1,9
33		10	10	10	10	10	10	9	9	9	8,5	23	6,7	2,7	1,7
34	RU														
35	EST														
36	POR	10	10	10	10	10	9,5	9	9	8	7,5	19	15	4	1,8
37	CAN	10	9	7	7	10	10	9	7	7	6	29	5,4	2	1,5
38	USA	8	7	6	7,5	10	9	9	8	7	5,5	10	1,7	1,5	1,3
39		10	8	7,5	5,5	9,5	7	8	7	5	4	29	8,7	2,4	1,5

Table 2.2: Evaluation of panels exposed in field. Type G. Damage along edge and by cut. Type of material: Steel: Alkyd melamine coating. Exposure period: 1987–1995.

Site		Flaking from edge (mm)		Damage near cut		Type of damage			Notes
		Exposed 8 years	Exposed 4 years	Damage (mm) from cut	Total width of damage	Blister	Flaking	Rust in cut	
CS	1	1	<0.5	2-5	5-8		fF	r	
	2	t	0	2	4-5	(b)	(f)	r	
	3	2(r)	<0.5	3	5-6	b	f	r	
FIN	4	<<0.5	t	4	6-8	b	(f)	(r)	
	5	0.5-1	0	1-2	2-5	(b)		r	Adhesion 9.5(ASTM)
	6	0,5	t	2	5	b	(f)	r	Orange stain of surface
FRG	7	o.5-1	t	4	1-7	(b)	f	r x)	Rusty water from cut
	8	t	0	2-4	2-5	b	fF	r-rR	
	9	1(r)	<0.5	3	5-6	b	f	r	Orange stain of surface
	10	0.5r	t	3-4	5-8	(b)	f	r	
	11	1r	<0.5	2-3	6 x)	b		r	Bad parallels
	12								Panels exposed from ground
ITA	13	<0.5	0	2	2-4		F	r	
	14	<0.5	t	0-3	3-4	(b)	(f)	(r)	
	15	1r	<<0.5	1-7	4-9	b	f	r	
	16	<<0.5	t	0-3	1-5	b	(f)	(r)	
NED	17	0,5	t	1-3	4-7	(b)	(f)	(r) x)	Some rusty water from cut
	18	<0.5	t	1-3	3-5	b	(f)	r	
	19	0.5-1.5	<<0.5	1-3	3-7		F	r	
	20	0,5	<<0.5	2-4	5-8	b	fF	r	
NOR	21	<<0.5	t	2-4	4-6	b	fF	(r)	
	22	2-6R	1r	8	14		F	R	Orange stain of surface
	23	<<0.5	0	1.5-3	4	b		(r)	
SWE	24	0,5	t	2-3	6	bB	(f)	(r)	Orange stain of surface
	25	<0.5	t	1-2	4	b	(f)		
	26	<<0.5	0	0-1	1-3	(b)			
UK	27	0.5-1	t	2-3	5-6	(b)	f	r	All panels from UK had some
	28	0.5 x)	t	2	5	(b)	(f)	(r)	orange stain on surface, most
	29	1-2r	0-0.5	3	6	bB	(f)	r	on no. 29. Flaking of the parallels
	30	1-2(r)	<0.5	3-4	5-6	(b)	fF	r	of no. 28 was rather variable
SPA	31	t	0	1	3		F		
	32	<0.5-1r	t	2,5	5	b	(f)	r	
	33	0	0	0.5-1	2,5		fF		
SOV	34								Both no 34 and no 35 are
	35								exposed on the wrong side
POR	36	t	0	0.5-1.5	2-3	(b)	(f)	(r)	
CAN	37	0	0	3	5		(f)	(r)	Some orange stain.Fungi by cut
USA	38	<0.5	0	1-5	6		f	(r)	Orange stain of surface
	39	1-1.5r	<<0.5	6,5	13		F	R	Some orange stain of surface

Table 2.3: Evaluation of steel panels with alkyd paint (type H) after 1, 2, 4 and 8 years of exposure.

		Parameter															
		General appearance				Dirt				Chalking				Fungus			
Site No.		1	2	4	8	1	2	4	8	1	2	4	8	1	2	4	8
1	CZE	7	7	6,5	8	8	7,5	8	9,5	8	8,5	3	0,5	7	8	7	8
2		8	8	8	8	8,5	8	9	9	9	7	0,5	0,5	7	7	7	5,5
3		5	5	3	3	6,5	6,5	6,5	6	9,5	9,5	6	1	9,5	9,5	9,5	7,5
4	FIN	6,5	5,5	6,5	6,5	7	6	7,5	7	9	8	0,5	0,5	8	6	6	5
5		6	7,5	7,5	7,5	6	8,5	8,5	8	9,5	8	0,5	0,5	8	7,5	7	5,5
6		6,5	7,5	7,5	8,5	7	9,5	8,5	9,5	9	8	2	2	9	10	9,5	9,5
7	GER	6,5	7	7	7	7	8,5	7,5	8	9	8	0,5	0	9	7,5	6	5
8		6,5	7,5	8	7	7	8	9	7	8	9	2	1	9,5	7,5	9	4,5
9		7	7,5	7,5	6,5	7	8	8,5	7	9	9	1	0,5	8,5	7,5	7,5	4,5
10		5,5	7	6,5	4,5	6	8	8,5	7	9	8	2	0,5	10	10	9,5	4,5
11		6	7,5	7	6	6	8	8	7	9	9	1	0,5	9	9	7	6
12		8	7,5	6,5		8	8	8		9	7	0,5	0,5	7	7,5	7,5	
13	ITA	5	5,5	5,5	6	5	5,5	5,5	6	9	8,5	1	0,5	10	10	10	10
14		6,5	7	7	6,5	7	8	8	7	9	8,5	0,5	0,5	7,5	9	9	8
15		4,5	6	5	4,5	5	8	8	5,5	9	8,5	2	0,5	10	10	10	9
16		3	4	6	4	3,5	4,5	7,5	4	9	7,5	0,5	0	6	6	6	4
17	NL	5,5	6,5	7	6,5	6	7	8	7	8	8,5	5	1	8	7,5	6	6
18		6	6	5	5,5	8	8	7,5	7	9	8,5	3	0,5	8,5	7,5	7	5
19		6,5	6	6	4,5	8	7,5	8,5	5	9	8,5	4	1	9	8	7	5
20		7,5	7,5	7	6,5	8	8,5	8	8	9	7,5	1	0,5	9,5	7,5	7	5
21	NOR	7,5	7	8,5	8,5	8	7,5	9	9,5	9	9	3	0,5	10	10	10	10
22		6	7	6,5	6,5	7	8	8,5	9,5	7,0	4	3	1	10	10	10	10
23		5,5	5,5	5	4,5	8,5	9,5	8	8	8,5	6	1	0,5	9	8	6	5
24	SWE	8	9	8,5	8,5	8,5	9,5	9,5	9,5	9,5	8	2	1	10	10	10	10
25		7,5	8,5	9	8,5	8	9	9,5	9	9,5	9	3	1	10	10	10	10
26		7,5	7,5	6,5	6,5	8,5	9	7,5	8	9	9	2	0,5	8,5	7,5	5	5
27	UK	6	8	8,5	7	6	9	9,5	8	9	8	2	0,5	10	9,5	9	5,5
28		7,5	8,5	8	7,5	9	9	9,5	8,5	9	7,5	1	0,5	10	10	8	6
29		7,5	7,5	6	5	8,5	9	9	9	9	6	2	1	10	9,5	9	9
30		7,5	8	7	7,5	8	8,5	8	9,5	9	8	2	0,5	10	9,5	9	9,5
31	SPA	6	8	7,5	8	6	6	9	9	9	8	4	3	10	10	10	10
32		5	6,5	6	6,5	5,5	7	7,5	8,5	9	8	5	0,5	10	10	10	9,5
33		9	8,5	9	9,5	8,5	8	9	9,5	9	7	1	0,5	10	10	9,5	10
34	RU	7	8	8	8,5	7	8	8	8,5	9,5	9,5	6	4	10	10	10	10
35	EST	7	8	8	8	7	8	8	8	9,5	8	4	0,5	9,5	9,5	9,5	9,5
36	POR	7	8	7	7	8	9	8,5	8	9	8	4	0,5	10	10	9,5	9,5
37	CAN	8,5	8	7	6	8,5	8,5	7,5	8	9	6	1	1	8	7	6	6
38	USA	8	6,5	6,5	6,5	8	7	7,5	8	5	3	0	0	6	5	5	4,5
39		5,5	5	4	2	7	8	8	7	9	8,5	5	1	9,5	7	6	5

Table 2.3, cont.

Site No.		Damage from cut				Gloss, front, unwashed (mean value of three panels)				Gloss, back, unwashed			
		1	2	4	8	1	2	4	8	8	4	2	1
1	CZE	6,0	5	5	5	60	46	13	4,4	38	52	64	67
2		9,0	6	6	5,5	55	21	4,4	5,1	30	46	67	74
3		5,0	3	0	0	49	42	17	5,6	38	48	63	67
4	FIN	7,0	5	5	5	63	47	4,8	3,4	34	45	59	67
5		7,0	7	6	5	61	48	4,3	3,4	16	42	64	71
6		7,0	6	6	6	64	47	7,7	3,7	38	47	61	65
7	GER	7,0	6	5	5	60	44	7,9	3,4	32	43	58	67
8		9,0	7	5	2	66	54	20	5,4	42	50	61	68
9		9,0	7	6	4,5	62	45	9,5	7,6	32	41	58	70
10		7,0	6	3	3	60	48	13	6,3	34	42	56	63
11		7,0	6	6	5	55	45	8	4,1	25	44	57	63
12		9,0	7	5		63	32	4			43	63	70
13	ITA	8,0	9	8	8	37	24	8,3	2,8	38	45	54	57
14		7,0	7	8	6	45	35	8,7	4	15	35	55	56
15		5,0	5	3	1	58	46	13	3,4	27	45	59	65
16		7,0	7	3,5	5	34	29	7,8	3,1	34	37	51	59
17	NL	7,0	6	5	4	57	43	16	5,7	18	29	51	64
18		6,0	6	5	5	62	46	17	5,2	7,1	25	54	65
19		7,0	6	5	4	59	42	13	7,7	11	26	49	63
20		9	6	5	4	57	38	7,7	3,8	26	36	56	66
21	NOR	7	7	6	5	62	53	16	5,7	45	48	58	62
22		6	6	6	3	40	12	4,4	3,8	17	39	64	71
23		6	5	5	3	55	24	3,3	2,9	7,6	27	57	67
24	SWE	8	7	7	7	65	49	10	4,1	34	48	64	69
25		8	6	7	7	69	59	23	5	43	46	58	63
26		7	5	6	5	66	57	11	3,1	22	44	62	67
27	UK	7	7	6	6	56	41	6,1	5,2	40	19	61	61
28		7	7	7	6	59	36	6,2	4,8	27	12	64	67
29		7	5	4	3	52	13	3,6	2,9	5,3	38	62	70
30		8	7	7	4	56	37	7,6	4,4	37	46	63	68
31	SPA	9	7	7	7	48	50	13	7	48	51	65	65
32		9,0	7	5	2	52	37	13	6	30	45	61	63
33		9,0	9	9	9	51	31	7,6	3,7	38	45	56	66
34	RU					60	52	29	6	43	51	63	59
35	EST					66	40	4,3	3,3	13	47	65	61
36	POR	9,0	8,5	9	8	37	31	6,7	3,4	28	41	62	59
37	CAN	8,0	6	6	5	60	24	4,2	3,2	7,2	43	68	70
38	USA	9,0	6	6	3	23	5	2,1	1,9	10	31	56	65
39		5,0	4	1	0	53	25	5	4,5	37	46	62	70

Table 2.4: Evaluation of panels exposed in field. Type H. Damage along edge and by cut. Type of material: Steel panels with alkyd paint. Exposure period: 1987–1995.

		Damage near cut		Type of damage			Notes:
Site		Damage (mm) from cut	Total width of damage	Blister	Flaking	Rust in cut	rw =rusty water from cut F= fungi present in visual spots
CS	1	3-4	5-10	b		R	
	2	2-4	5	(b)		R	Some rw
	3	25	35	B	f	R	
FIN	4	4	10	b		R	F
	5	3-4	5	(b)		R	Some rw
	6	1-3	4-5	b		rR	Fungi only near the lower edge
FRG	7	2-4	6-9	b-bB		R	Some rw
	8	5-11	8-18	b		R	F
	9	3.5-6	7	b		R	F
	10	5-10	15	b		R	F
	11	2-4	5	b-bB		R	F
	12						
ITA	13	<0.5	<1.5	(b)		rR	
	14	0-3	1-5	(b)		R	
	15	15	25	B		R	Some rw
	16	4	6	b		R	F. Checking under cut(9, ASTM)
NED	17	1-7	9	b		R	F.Much alga
	18	4	6	b		R	rw
	19	1-7	12	b-bB		R	rw
	20	1-6	9	b-bB		R	F
NOR	21	2-4	6	b		rR	
	22	8	15	b		R	
	23	8	20	b-bB		R	F
SWE	24	2	4	b		rR	
	25	2	3	b		rR	Checking near cut(7, ASTM)
	26	4	7	b-bB		R	F. Some rw
UK	27	3	7	b		R	F
	28	2,5	6	b		R	rw
	29	6-10	15	b		R	
	30	4-7	12	b		R	
SPA	31	2	4	b		R	
	32	11	14	b		R	
	33	<0.5				rR	
SOV	34						No 34 and no 35 have been
	35						exposed on wrong sides
POR	36	1	3	(b)		R	
CAN	37	4	8	b-bB		R	
USA	38	7,5	15	bB		R	
	39	38x)	64	B		R	F.x)That means down to edge

Table 2. 5: Evaluation of wood panels with alkyd paint (type I) after 1, 2, 4 and 8 years of exposure.

		Parameter																	
		General appearance				Dirt				Chalking				Fungus				Cracking	
Site No.		1	2	4	8	1	2	4	8	1	2	4	8	1	2	4	8	4	8
1	CZE	9	8	5	5,5	9	8	6	6	7	6	4	3	10	10	7,5	3	6,5	4
2		9	9	6	3	9	9	9	4	8	7,5	4	3	10	8,5	5	3	9	4
3		9	8	7	5	9	8	9	5	7	7	4	3	10	10	10	5	6,5	6,5
4	FIN	8	9,5	6	3,5	8	9,5	7,5	4	8,5	7	5,5	4	10	9,5	6,5	3	6,5	4,5
5		8	9	5	3,5	8	9	9	4	9	6,5	5,5	5,5	10	9	4,5	3	8	4,5
6		8	9,5	9	6	8	9,5	9,5	8	8,5	8	5,5	5	10	10	10	4,5	8,5	6
7	GER	9	8	5	4	9	8	5	4	8	6	4	4	10	9	3	3	8,5	5
8		9	9,5	9	3	9	9,5	10	3	9,5	6	4	5,5	10	10	7,5	3	10	5,5
9		9	9	7	3,5	9	9	8	3,5	8	6	6	4	9,5	9	6,5	3	8,5	4
10		9	9	8	4	9	9	8	4	7	7	6	4	10	10	7,5	4	7	4
11		9	9	8	3	9	9	9	3	8	6	6	5,5	10	9	9	3	7	4,5
12		9	9	4		9	9	5		7	6	5		10	8,5	3		6,5	
13	ITA	8	6	7	4	8	6	7	4	8	7,5	5	4	10	10	10	5	8	5
14		5,5	5	5	3	6,5	6	5	3,5	7,5	6,5	5	4	5	6	6	6	5	4,5
15		9	9,5	9,5	4,5	9	9,5	9,5	5	7	7	5,5	4	10	10	10	6	7,5	6
16		5	3	2	1	6	4	3	1	8	8	5,5	5,5	5	3	2	3	5	4
17	NL	8	8	4	2	8	9	4,5	2	8	6,5	6	7	10	8	4,5	5	5	5
18		9	5	3	2	9	6	5	2	8,5	8,5	7	6	8,5	6	5	4	6	6
19		9	6	4	2	9	6	4	2	9	7	6	4	8,5	6	5	7	6	6
20		9	5	4	2	9	6	4	2	9	7	6	4	8	6	4,5	4	5	4
21	NOR	8	9,5	10	5	8	9,5	10	8	9,5	8	4	5	10	10	10	6	9	5
22		9	9,5	8,5	5	9	9,5	9,5	6	7	6	5,5	4,5	10	10	9,5	7,3	7	5
23		9	9	4	3,5	9	9	5	4	9	7	5,5	2	10	9	4	3	8	5
24	SWE	9	9,5	8,5	8	9	9,5	9,5	8	9	8	6	3	10	10	10	4,5	7,5	6,5
25		8,5	9	8,5	7,5	8,5	9	9	8	9	7,5	5,5	4	10	10	10	7	8	6
26		9	8	5	3	9	8	5	3	9	6,5	5	4	10	9,5	3	3	7	5
27	UK	8,5	9	9	3	8,5	9	9	3	9	8	5	4	10	10	8,5	4	9	5,5
28		9	9,5	8	5	9	9,5	9	5	8,5	7	5	3	10	9,5	8,5	4	7,5	6
29		9	9,5	6	3	9	9,5	9	4	9	7	7	6	10	10	7,5	4	7	5
30		9	9,5	9	6	9	9,5	9	6	9	7	5,5	4	10	9,5	8,5	4	6,5	6
31	SPA	9	9,5	10	8,5	9	9,5	10	10	7,5	7	5,5	3	10	10	10	10	7,5	7,5
32		8	6	7	4	8	6	7	4	8	7	6	4	10	10	10	4,5	6	4,5
33		9	10	10	5	9	10	10	5,5	7,5	6	6	1	10	10	10	10	7	5
34	RU	8	7	7,5	8	8	7	8	8	9	9	7	5	10	10	10	10	8	8
35	EST	9	8	5,5	5	9	8	9	5	9	7,5	5,5	6	9,5	9	6	3,5	9,5	5
36	POR	8,5	6	5,5	4	8,5	6	6	5	8	6	5,5	2	10	7,5	7,5	5	4,5	3
37	CAN	9,5	10	6	5	9,5	10	8	6	7	6	5	4	10	9,5	7	5	7	5
38	USA	9,5	9	5	5	9,5	9	5	5,5	5	5	3	1	10	8,5	3	6	8	3
39		9	9	6	5,5	9	9	8	6	7,5	6	5	4	10	8,5	7	3,5	7	4
	Type I	8,6	8,2	6,6	4,3				Type I	8,1	6,9	5,3	4,1						

Table 2.6: Type I: Supplementary evaluation of wood panels exposed in field for 8 years.

WOOD PANELS WITH ALKYD PAINT (Type I)					
Site No	Country	Flaking	Checking (+sigmoid forms)	Algae	NOTES: K = flaking on knots. s/S = few/many sigmoid forms observed. F = fungi also in spots. Algae: a/A = few/many.
1	CZE	9,5			
2		9,5		a	
3		10	5		F
4	FIN	9 K		a	
5		10		A	Spots of algae
6		10	7 S		F (may be present)
7	GER	9,5			F
8		10	6 S	a	F
9		10			
10		9,5			
11		9,5		a	
12					
13	ITA	10	s		Bad parallels
14		9	s	a	
15		10	5 s		F
16		10			Fungi not clearly seen by 16x
17	NL	10	s	A	
18		9,5	5		Leight spots w/few fungi
19		9,5	5 s		Surface light yellow stained
20		9 K			
21	NOR	9.5 K			F Bad parallels (fungi)
22		9.5 K	s		F
23		9		a	Spots of algae
24	SWE	10	7		F
25		10	6 s		F
26		10		A	Spots of algae
27	UK	9.5 K			
28		9.5 K	6 s		
29		8	s		
30		9	6		
31	SPA	9.5 K	5 (s)		
32		9.5 K			F
33		9,5	S		Spots with some spores but not hyphaes
34	RU	10	7 s	a	
35	EST	10	S		
36	POR	9,5	(s)		One panel without fungi
37	CAN	10	s		Hyphae difficult to find
38	USA	9.5 K			Hyphae difficult to find
39		8	S		

Table 2. 7: Evaluation of wood panels with opaque stain (type K) after 1, 2, 4 and 8 years of exposure.

		Parameter																					
		General appearance				Dirt				Chalking				Fungus				Cracking	
Site No.		1	2	4	8	1	2	4	8	1	2	4	8	1	2	4	8	4	8
1	CZE	8.5	8	8	8	8.5	8	8	9	8	5	9.5	3.5	10	10	9.5	7.5	9	9
2		8.5	8	9	5	8.5	8	9	5	9.5	5	7	6	10	10	10	4.5	10	6.5
3		8.5	8	8	6	8.5	8	8	8	8	5	7	4	10	10	10	7.5	9	7.5
4	FIN	7.5	9	7.5	3	7.5	9	8	4	9.5	7	5	6	10	10	7.5	6	8	5
5		8	9	9	6.5	8	9	9	9	9.5	7	5	6	10	10	10	5	10	8
6		7.5	9	9.5	9	7.5	9	9.5	9.5	9.5	7	4.5	5	10	10	10	7.5	9.5	7
7	GER	8.5	9	8.5	4	8.5	9	9	6	9.5	6	4	4	10	10	7.5	4	9.5	6
8		7.5	8	9.5	5.5	7.5	8	9.5	6	9.5	8	5	4.5	10	10	10	3.5	10	8
9		8	8	9.5	5	8	8	9.5	5	9.5	6	5	5	10	10	10	4.5	10	7
10		7.5	8	9.5	6	7.5	8	9.5	6.5	9.5	6	5	4	10	10	10	4.5	9	6.5
11		8	8	9.5	6	8	8	9.5	6.5	9.5	7	5	5	10	10	10	4.5	10	7.5
12		9	10	8.5	4	9	10	9	4	9	5	5	7	10	9.5	7	3	9	6
13	ITA	7.5	6	8	5.5	7.5	6	8	6	9	7	4	3	10	10	10	7.5	8	6.5
14		9	9	9.5	6	9	9	9.5	6.5	9	6	4	6	10	10	9.5	4	7.5	4
15		7.5	8	9.5	6	7.5	8	9.5	6.5	9.5	6	4	3.5	10	10	9.5	7.5	10	7
16		7.5	7	3.5	3	7.5	7	4	3	9	7	4	6	9.5	9.5	4	3	5	3.5
17	NL	7.5	7	9	5	7.5	7	9	6.5	9.5	7	5	7	10	10	10	9	9	7
18		8	8	7	3	8	8	7	3	9.5	7	7	7	10	9.5	9	7	6	5
19		9	8	8	3.5	9	8	8	3.5	9.5	6	5	5	10	9.5	9	8	8	7
20		8	8	7.5	3.5	8	8	8	4	9.5	7	7	5	10	10	9	5	7	6
21	NOR	7.5	8	9.5	8	7.5	8	10	9	9.5	7	7	6	10	10	10	9.5	9	8.5
22		8.5	9	10	8.5	8.5	9	10	9	8	6	5	5	10	10	10	9	9.5	8.5
23		9	10	8.5	4.5	9	10	8.5	5.5	9.5	7	7	6	10	10	7.5	5	9.5	5
24	SWE	8	9	10	8.5	8	9	10	9.5	9	7	6	5	10	10	10	7	9.5	8.5
25		7.5	8	10	9.5	7.5	8	10	10	9.0	7	7	5	10	10	10	10	9.5	9.5
26		8.5	9	8.5	3	8.5	9	8.5	3	9.5	6	6	8	10	10	7.5	4	9.5	5
27	UK	8.5	8	9	6	8.5	8	9	7	9	6	6	5	10	10	10	5	9.5	8
28		8.5	9	9	7	8.5	9	9	8	9.5	7	7	5.5	10	10	10	5.5	8	6.5
29		9	9	8.5	4.5	9	9	8.5	6	9.5	7	5	5	10	9	9	4	7.5	5
30		8.5	9	9.5	9	8.5	9	9.5	9.5	9.5	7	5	4	10	10	10	9	10	7
31	SPA	8.5	9	9.5	9	8.5	9	9.5	10	9.5	7	7.5	5	10	10	10	10	7	6
32		7.5	6	8.5	6	7.5	6	8.5	6	9	7	4	4	10	10	10	5.5	9.5	6
33		9	9	10	8.5	9	9	10	10	9	5	4	4	10	10	10	10	9.5	7
34	RU	7.5	7	9	9	7.5	7	9	9.5	9.5	8	7.5	7	10	10	10	10	9	7
35	EST	9	9	9.5	5	9	9	9.5	6	9.5	6	7.5	4	10	9.5	10	5	9.5	5
36	POR	8.5	8	9.5	7.5	8.5	8	9.5	8	9	6	4	2	10	10	10	9.5	9.5	5.5
37	CAN	9.5	10	10	8	9.5	10	10	9	9	5	6	6	10	10	10	5	9.5	6.5
38	USA	9.5	10	6	5	9.5	10	6.5	7	5	4	4	1	10	10	5	5	9.5	4
39		8.5	8	9	8.5	8.5	8	9	8.5	7.5	6	4	4	10	9	9.5	5	9.5	5
	Type K	8.3	8.4	8.8	6.1					9.1	6.4	5.6	5.0						

Table 2.8: Type K: Supplementary evaluation of wood panels exposed in field for 8 years.

WOOD PANELS WITH OPAQUE STAIN (Type K)					
Site No	Country	Flaking	Checking (+sigmoid forms)	Algae	NOTES: K = flaking on knots. s/S = few/many sigmoid forms observed. F = fungi also in spots. Algae: a/A = few/many.
1	CZE	10	8		F
2		10	10		
3		10	5		F
4	FIN	8		A	Spots of alga
5		9 K	10		
6		9 K	10 S		
7	GER	10	10		
8		10	10		
9		10	10 S		
10		9.5 K	10		
11		10	10		
12		9.5 K	10 s		
13	ITA	10	8 S		
14		10	s		
15		10	9 s		
16		9,5		a	Dark because of fungi
17	NL	10	10	A	
18		10	s	A	Dark because of fungi
19		9,5	10	a	Yellow green stain
20		9 K	10	A	
21	NOR	10	8		F
22		10	9		F
23		9 K		a	F
24	SWE	10	10		
25		10	10		
26		9		A	
27	UK	10	9		F
28		10	10	a	F
29		8,5			
30		10	10	a	
31	SPA	10	5 S		
32		9	8 s		
33		10	7 s		
34	RU	9,5	7 s		
35	EST	10			
36	POR	9,5	s		Light yellow grey stain
37	CAN	9	10		F
38	USA	5 x			x:Mainly caused by one panel only
39		10			

Annex 3

Paint evaluation methods

1. General comments to the evaluation

The evaluation has followed international standards where standards have been available. All evaluations were made from three parallels.

We have chosen to follow the ASTM-standards since their standards cover most of the parameters evaluated. Even when ISO-standards were available the similar ASTM-standards were preferred. The ISO-standards were used for some rating with a transformation to the 1-10 scale. The transformation is shown in Table 1.

Table 1:

Rating ASTM	Rating ISO	Intensity of change
10	0	Unchanged
9	1	Very slight
8		
7	2	Slight
6		
5	3	Moderate (reparation may be needed)
4		
3	4	Considerable
2		
1	5	Severe

Some of the columns give descriptions of the deterioration pattern seen and special scales are made for these columns.

Since nearly all evaluations made for paint systems to some degree will be subjective, we have made coloured photo-standards for the rating using a selection of the exposed samples. The same series of samples will always be used and extensions will be made if necessary. This is done to prevent movements and changes in the rating scale.

2. Comments to the schemes and the parameters used

***General appearance** (ASTN D 1150-55)*

The rating shall give information about the overall picture of the test samples. To interpret the rating of the general appearance consideration must be taken to the rest of the evaluations made. At rating 5 action for special treatment or repainting may be taken. The parameter general appearance is mainly effected by the degree of dirt, especially in the beginning of the exposure. After some years, fungi and cracking tend to become more important.

We have considered this parameter as a visual one. That means with using the eye only.

Note that interpolation like 9.5. 8.5 and so on is used for the rating.

Dirt (ASTM D 3719-87)

Photostandards have been made for all four paint systems. Also this parameter we have considered as a visual one. So fungi will to some degree be included in the dirt evaluation if it is not easily seen to be fungi.

Chalking (ASTM 4214-82 and ISO 4628/6)

The test is made by use of tape (Scotch Magic no. 810). The tape (ca. 5 cm) was pressed against the painted surface and pulled off again. By sticking the tape on a black cardboard the chalking appeared and a reference system was made. When the rating 1 is reached, the tape cannot receive more "chalking", but the chalking, may still grow deeper in the surface of the sample. The three last evaluations we have used a black electrotape Scotch Super 88 sticked to a transparent plastic card, since we wished to have a more flexible tape for the test of the wood panels.

The results from the paint system G were used as a standard.

Fungus (ASTM D 3274-82 and ASTM D 4610-86)

The fungus-hyphae is small and we have made a special evaluation rating and photoreferences for inspection in the microscope.

Magnification used: 10-20
Inspected area: approximately 1.0 cm^2

Rating	Description of attack
10	No attack.
9.5	2-3 places with traces of fungus-hyphae.
9	Traces of fungus-hyphae several places.
8	Fungi in about 50% of the inspected areas.
7	Fungi can be seen in almost 100% of the areas. Low density.
6	Fungi all over the sample. Moderate amounts. 1–5 groups in each inspected area (by microscope).
5	More than 5 groups of fungi per inspected area.
4	The density of the hyphae groups is so high that little space is found between them.

It is sometimes difficult to distinguish between dirt and fungus since the fungus is of the black surface type. After we have started to use a transparent tape for moving a sample from the paint surface to a glass plate and use the microscope, distinguishing between fungus and dirt has become easier.

Flaking (ASTM D 772-86 and ISO 4628/5)
Cracking (ASTM D 661-86 and ISO 4628/4)
Checking (ASTM D 660-44 and ASTM D 660/87)

Some wood panels show types of checking, long line and sigmoid types, the sigmoid type is marked by "sig" in scheme. Such damages may be difficult to observe without the use of microscope.

Blistering near cut: Special scale (for painted metals only).

Rating	Defects
Open space	No blisters
(b)	Few blisters
b	Moderate amount
bB	Considerable amount
B	The area dominated by blisters

Flaking near cut: Special scale (for painted metals only).

Rating	Defects
Open space	No flacking
(f)	Slight flacking
f	Moderate flacking
fF	Considerable flacking
F	The area dominated by flacking

As a part of the evaluation of flacking, tape (Scotch Ruban Adhesif) was used to pull off the flacked area around the cut.

Rust in cut: Special scale (for painted metals only).

Rating	Defects
Open space	No rust
(r)	Slight corrosion
r	Moderate corrosion
rR	Considerable corrosion
R	Severe corrosion

Damage from cut (ASTM D 1654-79a) (for painted metals only).

Recording of loss of paint as mean creepage in mm from the cut is shown below. Differences in the corrosion attack are often seen and notes are often given.
Conversion from mm damage from cut to ASTM rating. The numbers in paranthesis represent a scale in mm of damage (creepage) from edge.
Creepage of the paintfilm from edge has been observed especially for the two last intakes of samples. This time we measured the creepage, and made a special rating scale (the numbers in paranthesis).

mm creepage from		
cut	edge	ASTM
0	(0)	10
>0–0.5	(–0.5)	9
>0.5–1.0	(0.6–1.0)	8
>1.0–2.0	(1.1–1.5)	7
>2.0–3.0	(1.6–2.0)	6
>3.0–5.0	(2.1–3.0)	5
>5.0–7.0	(3.1–5.0)	4
>7.0–10.0	(5.1–8.0)	3
>10.0–13.0		2
>13.0–16.0		1
>16.0		0

The codes used are:

d = discontinuous: Damages around the cut with parts without damages.
s = spotty: Occasional damages around the cut.

Gloss

Gloss instrument used: Glossmaster/Erichsen.

Measurements of the light reflection in % at 60° angle.

Measurements were made on unwashed surface.

For the painted steel systems, G and H, the results given are the mean value of three measurements. For the painted wood systems, I and K, the gloss is low and the rough surface give spread in the measured values. The panels have therefore not been measured for gloss the last years.

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ABSTRACT

The damage of the paint systems have been evaluated by using the well established ASTM-standards on samples exposed for one, two, four and eight years. The dose-response functions for the relation between the air pollutants and the damages have been established by means of two steps. The first step has been to define the lifetime for maintenance intervals for fungus growth on the surfaces, for the cracking of the paint systems for wood and for damage spread from a cut in the film for the paint systems for metals. The second step has been to establish the correlation between the lifetime and selected environmental parameters in a dose-response function by stepwise backward regression analysis.

NORWEGIAN TITLE

Nedbrytning av malinssystemer for tre, stål og galvanisert stål etter åtte års eksponering

KEYWORDS

Dose-response	Paint	Deterioration

ABSTRACT (in Norwegian)

* Classification		
	A	*Unclassified (can be ordered from NILU)*
	B	*Restricted distribution*
	C	*Classified (not to be distributed)*