Durability test of retro-reflecting materials for road signs at Nordic test sites - Ageing model for the retro-reflectivity after further exposure

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Introduction, summary and conclusions

This note is a continuation of the note "Durability test of retro-reflecting materials for road signs at Nordic test sites - Ageing model for retro-reflectivity after 6 years of exposure" by Kai Sørensen and Sven-Olof Lundkvist dated 2004. The note was also published as a paper in TEC in January 2005.

The previous note accounts for the road signs placed at 9 test sites in the Nordic countries, and for periodic measurements carried out since the signs were mounted in 1997 and for an ageing model explanation of the degradation of the values of the coefficient of retrorereflection R_A.

The model operates with a percentage degradation of R_A values given by the product of two factors, of which one represents a load called "equivalent exposure" and the other represents a sensitivity to loads called "degradation rate". The loads are individual for the test sites, while the sensitivities are individual for the retroreflective materials represented by samples on the signs.

Some of the conclusions were that:

- the loads are widely different at the different test sites
- some materials are more sensitive to the loads than other materials, i.e. they degrade faster.

The overall conclusion is that testing at a single test site provides results that are meaningful also for other locations in the sense that the degradation rates can be found at a test site at any location.

The measurements continued for some more years, one to six more years for the different test sites, giving ages of the signs ranging from 7 to 11 years at the final measurements. It is the purpose of this note to account for the further degradation of R_A values and in particular to verify if the above-mentioned conclusions are valid after longer exposures.

The test sites and the R_A values of the samples are accounted for in section 1.

As a starting point in analysing the data, the average levels of retroreflection at the different test sites are considered in section 2. It seems that the final measurements represent an accelerated loss of retroreflection, but this is not quite certain as stated later.

The data is then analysed by means of ageing models as accounted for in section 3. Ageing models are considered in general in 3.1, while the linear model used after 6 years of exposure is explained in 3.2 and an exponential type of model in 3.3. It is claimed that the exponential model is best suited when losses of retroreflection are high such as for the final data.

Accordingly, the exponential model is used for the data after 6 years of exposure as accounted for in 3.4 and also for the final data as accounted for in 3.5.

There is an indication that the degradation rates stay constant, or at least that the relative distribution between the materials do not change much. In other words, the materials that lost the most R_A value during the first six years keep on loosing the most during the following years.

There is also an indication that the equivalent exposures, as measured by exposure factors of the models, do not stay constant, i.e.: that they perhaps change with time. However, this is not certain as firm evidence requires measurements of a high accuracy, better than 5 %. It is not possible without investigation to say if the handheld retroreflectometers represent such an accuracy, or if variation of the calibration levels induce false changes of the exposure factors.

On one hand, it is practical for the implementation of sign management systems that the degradation rates stay reasonably constant over long period of time and that the equivalent exposures seem not to change much, or at least not very strongly.

On the other hand, it has taken a long time to test the particular materials that were applied on the signs. Some of these materials are no longer on the market, some are but under different trade names, and some may have been modified in a way that affects durability.

An example of a material that has probably been modified more than once is the 3M 3200 Engineering Grade material. This material did show a severe degradation even after a few years. However, it was claimed by the 3M company that this particular version was on the market in a short period only and that is probably true.

Therefore, materials change as quickly as it takes to test their long term durability. In view of this, a simple bench testing of materials was established at a single location and has been in use for about 5 years.

1. Test sites and R_A values of the samples

The test sites, 9 in total at different locations in the Nordic countries, were established in 1997, each with 4 identical test signs (only two at Reykjavik, and only two being used at Frederiksborg) placed along a representative road. Close to some of the test sites, a reference site was established with a reference sign at a convenient location, where it is not exposed to nearby road traffic.

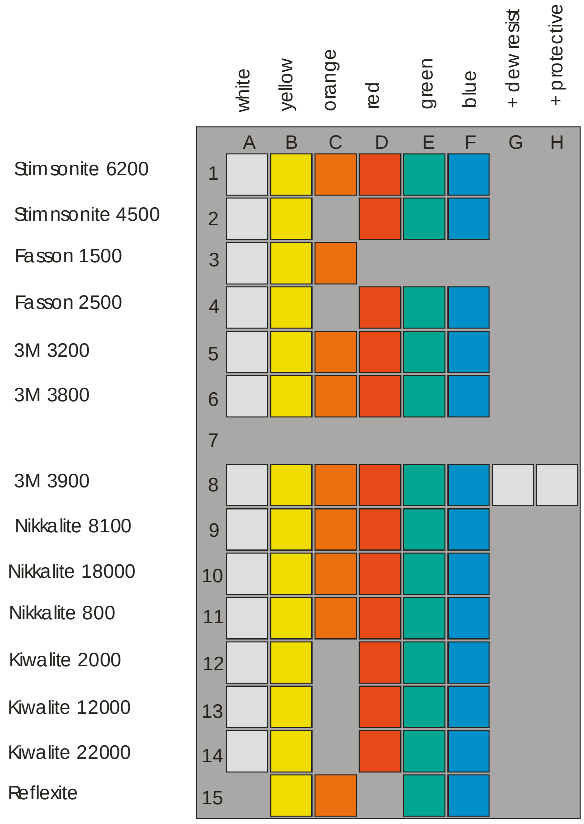
A test or a reference sign has samples of retro-reflecting materials placed in a matrix so that a row has a particular type of material in different colours, and so that the colours are aligned in columns. Accordingly, a location on one of these signs reflects a particular type and colour, which is referred to as a 'material' in the following. Refer to figure 1.

The arrangement of test signs at a test site is illustrated in figure 2, while the locations of the test sites is shown in figure 3.

The R_A values (coefficient of retro-reflection) of the samples have been measured in the 0,33°/5° geometry (0,33° observation and 5° entrance) on a regular basis. With one exception, these measurements were performed by local people with locally used instruments. The exception is the measurements done in the autumn of 2003 by a single person using a single and well tested instrument. These are the values that were used for the ageing model after 6 years of exposure.

At each occasion, the resulting R_A values of the materials of a sign are provided in a table that complies with the matrix arrangement of the materials on the sign.

Figure 1: A test sign with 76 samples arranged in rows and columns.



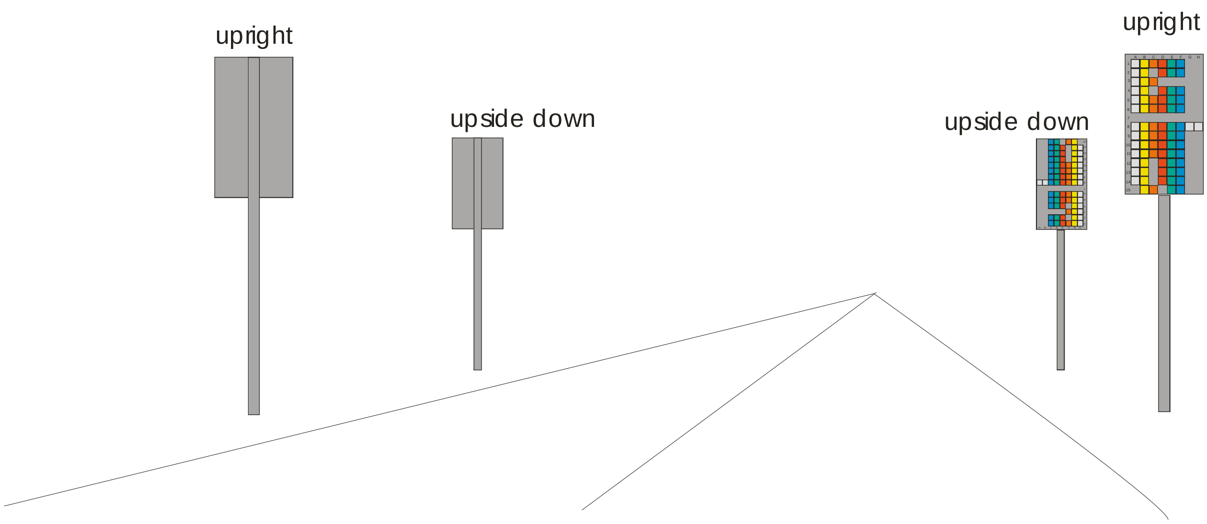


Figure 2: Four test signs mounted at a road at a test site.

Figure 3: Approximate locations of the test sites.

The roads were selected with the approximate direction north-south (except at Reykjavik), with two signs facing south and two signs facing north. It was expected that the R_A values would reflect this orientation (in particular that the R_A values of materials facing south would decrease faster than the R_A values of materials facing north), but there is no significant effect. At Reykjavik, the two signs face respectively east and west, towards and away from the dominant direction of wind; with no significant effect on the R_A values either.

Therefore, the four tables of R_A values for the four test signs at a particular test site (only two at Reykjavik and Frederiksborg) are represented by a single table with average R_A values for each material. This results in 9 tables of R_A values, one for each of the test sites. The additional tables of R_A values for the 6 reference signs bring the total number up to 15.

The set of tables resulting after the final measurements at each location are considered in the following. The ages at these measurements are accounted for in table 1.

Table 1: Age at final measurements.

Test site	Age at final measurement
Røros	10 years
Rovaniemi	8 years
Gamleby	9 years
Reykjavig	7 years
Vanda	8 years
Linköping	9 years
Arendal	8 years
Frederiksborg	11 years *)
Ribe	11 years
*) the reference signs was only 8 years old at the final measurement.	

For comparison, the tables after 6 years of exposure are included into the consideration.

2. The average level of retroreflection

The remaining level of retroreflection of a table is represented by the average of the R_A values of the table.

However, the simple average is not used, as this would make samples with high R_A values dominate. Such are in particular white samples of the microprismatic technology. Instead, the average of $\ln(R_A)$ values is calculated, and this average is turned into an average R_A value by applying the exponential function. This kind of average is equally sensitive to a percentage loss of retroreflection, whether the percentage loss is for a small or a large R_A value.

The averages are set in proportion to the initial average, as determined for signs not yet exposed. The results are shown in figures 4 and 5 for respectively 6 years of exposure and final data.

Figures 4 and 5 show that some test sites, for instance the test site at Røros, had small losses of R_A after 6 years of exposure, but bigger losses after of a few additional years. It might be that a material can sustain a some threshold exposure without showing significant loss of R_A, and that the loss sets in when the exposure exceeds that threshold.

This matter is further considered in the following without, however, any firm conclusion.

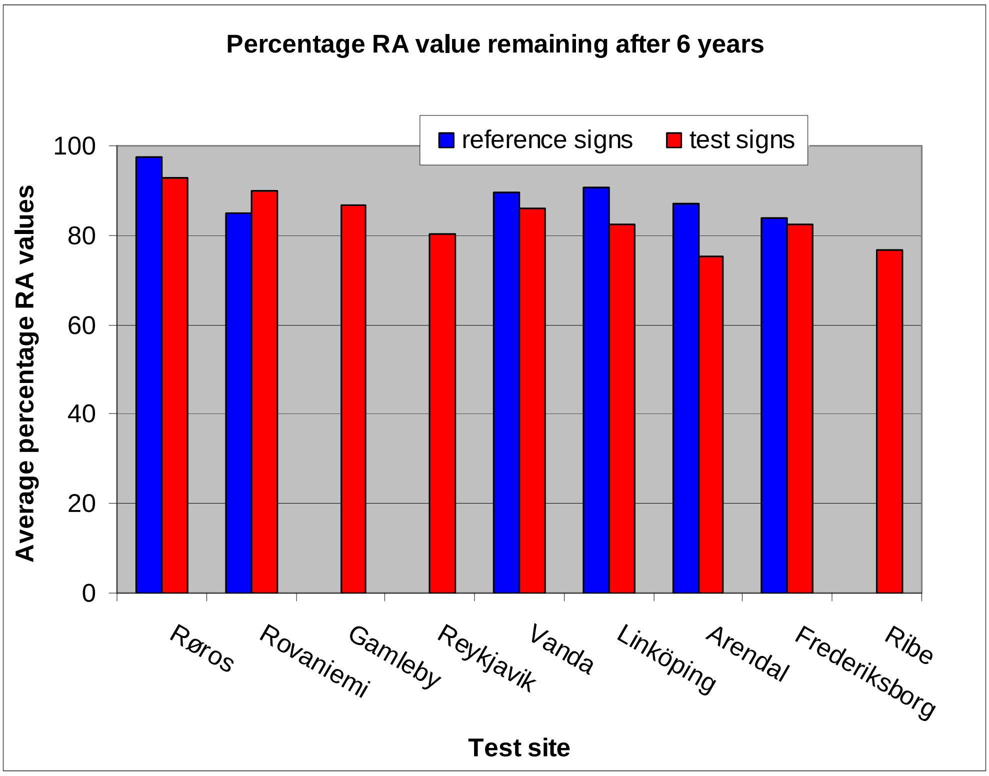


Figure 4: Percentage R_A values remaining after 6 years of exposure.

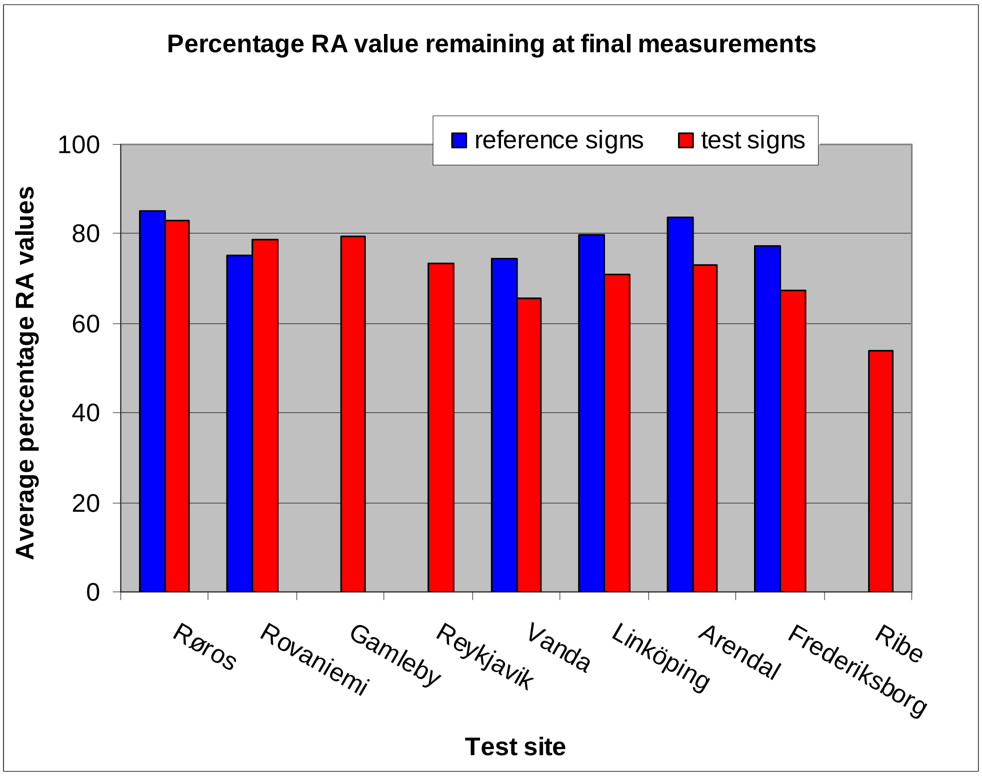


Figure 5: Percentage R_A values remaining at the final measurements.

3. Representation by ageing models

3.1 General about ageing models

An ageing model uses a formula that provides model R_A values which represent the measured R_A values. The formula contains some parameters that account for loads and sensitivities to loads. These parameters are adjusted so that the model R_A values are as close a match to the measured R_A values as possible.

If the match is good, the model is assumed to provide reliable results for the degradation of the retroreflection. The results are expressed by the parameter values.

The measured R_A values include both the initial R_A values for the road signs in the new condition and the R_A values after a particular exposure.

Since all the samples were cut from the same pieces of sheeting materials, the initial R_A values are assumed to be the same for all test sites. These values may be derived as averages for initial measurements to be provided in a single table with rows corresponding to different types of materials and columns corresponding to different colours of the materials. Refer to figure 1.

The measured R_A values at a particular exposure are provided in one table for each of the 9 test sites and one table for each of the 6 reference signs; 15 tables in total.

The initial R_A values are labelled $R_{A,initial}$ (i,j), where i = 1, 2, 3 … refers to rows and j = 1, 2, 3 … refers to columns in the table. The measured R_A values after exposure are labelled R_A(i,j,k), where k = 1, 2, 3 … refers to the different tables.

The model must in principle provide values that match both the initial R_A values and the R_A values after exposure. These are labelled respectively $R^*_{A,initial}$ (i,j) and R^*_A(i,j,k).

3.2 The linear model used after 6 years of exposure

The ageing model used after 6 years of exposure assumes a linear loss of retroreflection given by:

$$R^*_A(i,j,k) = R^*_{A,initial}(i,j) - F(k)\times D(i,j) \qquad \text{(equation 1)}$$

where F(k) are exposure factors, one for each of the 15 tables of R_A values
and D(i,j) is a table of factors expressing degradation rates for the different materials.

As the loss of R_A values is expressed by the product of two factors, it is necessary to choose the scale of one of the factors.

This was done for the scale of F(k), which was set so that the value is 6 for the test site with the largest loss of retroreflection (this was the test site at Ribe). The factor values can then be understood as equivalent years of exposure (compared to the test site at Ribe).

With this scale of F(k), the other factor D(i,j) can be understood as the loss of R_A value per equivalent year of exposure. The values were represented by 100*D(i,j)/ $R_{A,initial}$ (i,j) as percentage losses of R_A values.

NOTE: The values $R^*_{A,initial}$ (i,j) can be set so that they accurately equal $R_{A,initial}$ (i,j). However, initial values often change quickly in the first period of time and, therefore, it is not important to provide an accurate match to those values. Instead, it was chosen to set the $R^*_{A,initial}$ (i,j) values so that an average table R^*_A(i,j) matches an average table R_A(i,j) accurately, where the average tables are averages for the 15 tables of respectively R^*_A(i,j,k) and R_A(i,j,k). In any case, $R^*_{A,initial}$ (i,j) was a good match to $R_{A,initial}$ (i,j).

The factors F(k) and D(i,j) were set so that the standard deviation between R^*_A(i,j,k) and R_A(i,j,k) becomes minimum. The standard deviation itself is a measure of the quality of the match, which was good. Refer to the previous note or the paper.

3.3 An exponential model

In the previous note and the paper it was hinted that a linear model was probably not the best, because some of the materials showed large decreases of R_A values already after 6 years.

Figure 4 shows that the average decrease was approximately 25% at some of the test sites. However, some materials show smaller of larger decreases corresponding to losses per year up to 16%.

It is not likely that losses stay constant year after year as a fixed percentage of the initial value as this would mean that zero or even negative retroreflection is reached after a number of years. It is more likely that the annual loss is a fixed percentage of the present value corresponding to an exponential decrease.

Assume that a linear model is given by $R^*_A = 1-L$, where L is the relative loss, while an exponential model is given by $R^*_A = e^{-L}$. When L is much smaller than 1, e^{-L} roughly equals 1-L and the two models give approximately the same results. When L is not small, on the other hand, the exponential model predicts higher values that the linear model.

Therefore, when losses become big, an exponential model may be preferable to a linear model.

The linear model was actually applied to the final data, but did not results in a good fit in general, and a poor fit for materials with big losses. Therefore, the following exponential model was applied instead:

$$R^*_A\,(i,j,k) = R^*_{A,initial}\,(i,j)\times e^{-F(k)\times D(i,j)} \qquad \text{(equation 2)}$$

When applying the natural logarithm to both sides of the model equation, it turns into $\ln(R^*_A\,(i,j,k)) = \ln(R^*_{A,initial}\,(i,j)) - F(k)\times D(i,j)$. It is then clear that this model can be handled in the same way as the linear model, just by working in $\ln(R_A)$ values instead of R_A values. The essential differences lie in the above-mentioned exponential decrease instead of a linear decrease, and that small R_A values are given as much weight as large R_A values.

3.4 Use of the exponential model for the data after 6 years of exposure

This model was first tested on the data after 6 years of exposure. The match between model R_A and measured R_A values is illustrated for white materials in figure 6, while the exposure factors are shown in figure 7 and the degradation rates in table 2.

These results may be compared to those of the linear model (which are not shown) with the conclusion that they are quite similar, but with some changes. These, on the other hand, are probably caused by the above-mentioned change of focus away from the larger R_A values.

It is to be noted that the exposure factors are converted so as to be per year of exposure, instead of per 6 years as in the previous note. The conversion is done simply by dividing the resulting factors by 6, as the resulting model value is the same if 1/6 of the degradation is applied 6 times instead of applying the full degradation once. The degradation rates are in percent for each unit of the load factor.

Finally, the initial values used in the model are shown in table 3.

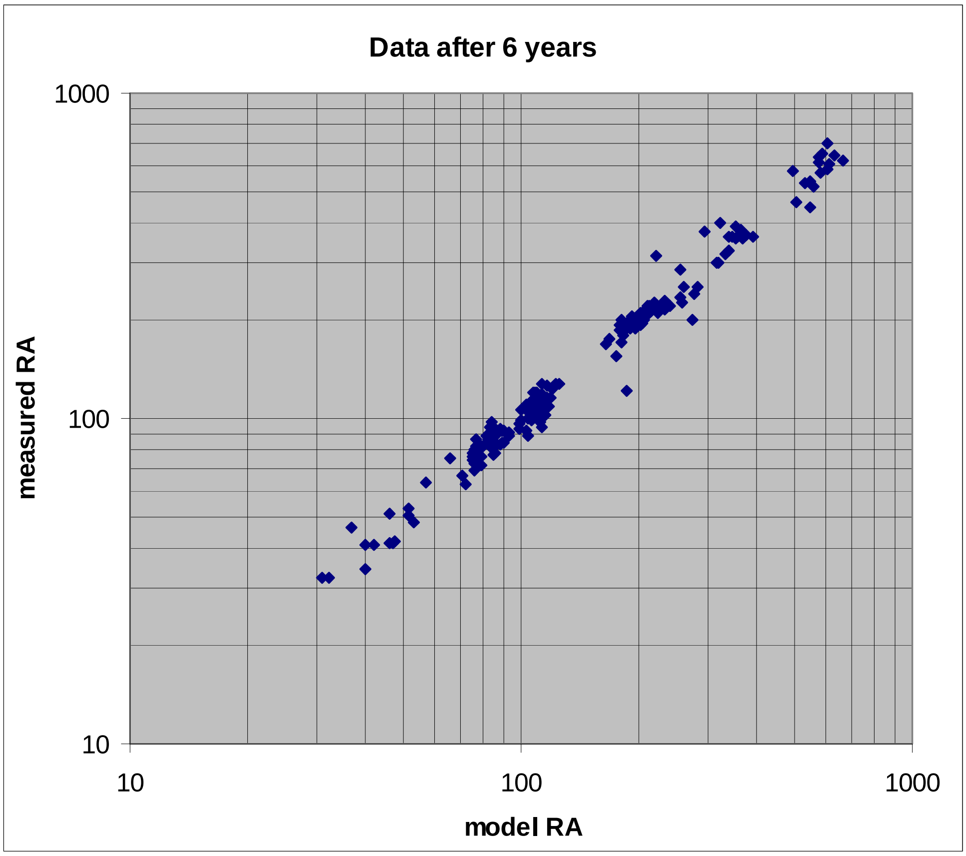


Figure 6: Match between exponential model R_A and measured R_A values for white materials after 6 years of exposure.

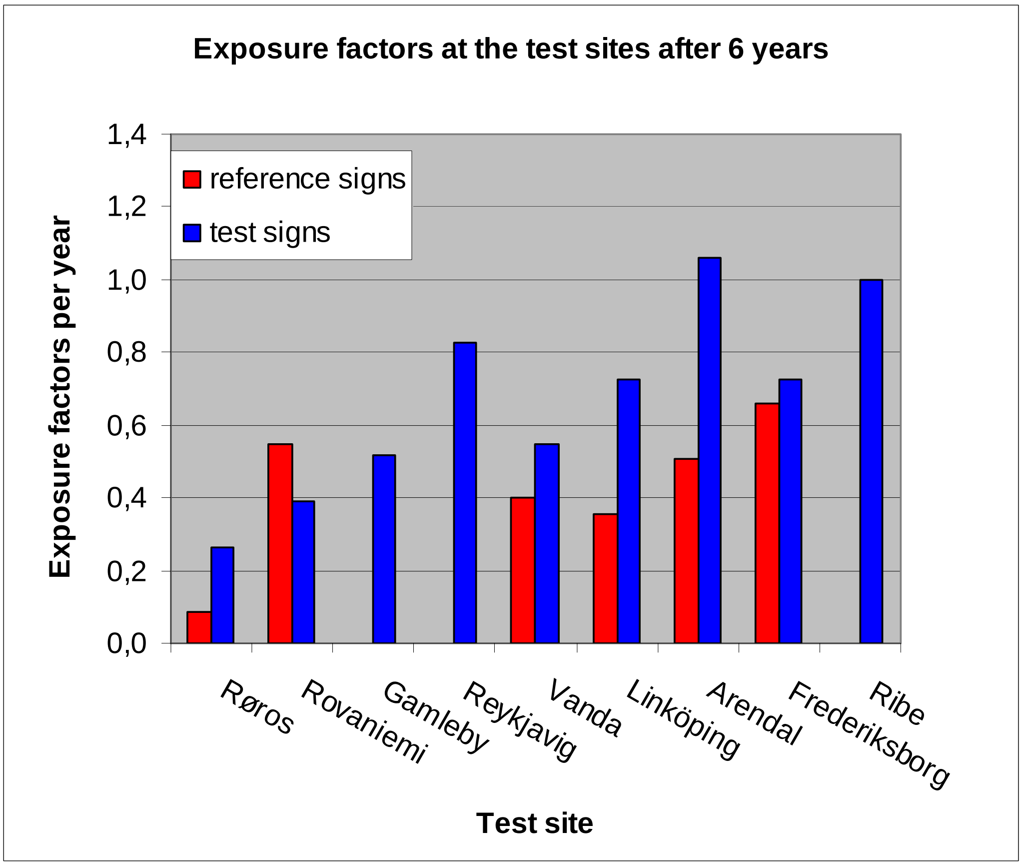


Figure 7: Exposure factors for the exponential model after 6 years of exposure.

Table 2: Degradation rates in percent for the exponential model after 6 years of exposure.

	A	B	C	D	E	F	G	H
1. Stimsonite 6200 (PM)	5,2	3,7	5,9	4,3	5,2	4,3		
2. Stimsonite 4500 (PM)	9,0	13,0		7,4	12,5	9,2		
3. Fasson 1500 (EG)	0,5	-1,4	1,2					
4. Fasson 2500 (SEG)	2,2	2,1		0,6	6,0	4,0		
5. 3M 3200 (EG)	13,8	8,3	2,0	11,1	2,8	13,1		
6. 3M 3800 (HI)	3,7	3,5	4,5	3,2	6,3	5,8		
7. (empty row)								
8. 3M 3990 (PM)	3,8	4,3	4,5	5,4	4,4	5,4	8,1	-1,3
9. Nikkalite 8100 (EG)	2,8	3,7	3,8	4,2	3,4	2,5		
10. Nikkalite 18000 (SEG)	2,9	2,2	2,5	4,7	1,9	2,4		
11. Nikkalite 800 (HI)	2,9	2,3	3,7	3,3	3,7	4,2		
12. Kiwalite 2000 (EG)	6,0	8,3		4,5	6,4	7,8		
13. Kiwalite 12000 (SEG)	4,2	3,5		4,9	5,4	5,8		
14. Kiwalite 22000 (HI)	4,0	2,8		3,6	4,0	4,2		
15. Reflexite (PM)		-3,9	5,3		0,3	2,0		

Table 3: Initial R_A values used for the exponential model after 6 years of exposure.

	A	B	C	D	E	F	G	H
1. Stimsonite 6200 (PM)	684	585	352	212	109	71		
2. Stimsonite 4500 (PM)	338	197		85	56	28		
3. Fasson 1500 (EG)	77	48	26					
4. Fasson 2500 (SEG)	114	70		40	27	8		
5. 3M 3200 (EG)	70	47	32	11	12	8		
6. 3M 3800 (HI)	227	183	109	55	44	21		
7. (empty row)								
8. 3M 3990 (PM)	400	351	407	90	82	42	705	307
9. Nikkalite 8100 (EG)	94	71	54	20	17	5		
10. Nikkalite 18000 (SEG)	124	93	32	26	20	9		
11. Nikkalite 800 (HI)	235	150	126	33	48	19		
12. Kiwalite 2000 (EG)	102	83		32	17	8		
13. Kiwalite 12000 (SEG)	128	87		32	29	9		
14. Kiwalite 22000 (HI)	211	144		44	32	17		
15. Reflexite (PM)		328	235		131	69		

3.5 Use of the exponential model for the final data after 7 to 11 years of exposure

The exponential model was applied to the final data in two ways. First the degradation rates were fitted to provide the best possible match to the measured R_A values, and then the degradation rates shown in table 2, as obtained for the data after 6 years of exposure, were used.

The match was somewhat better in the first case than in the second case, but not by much. This is taken as an indication that the degradation rates stay constant, or at least that the relative distribution between the materials do not change much. In other words, the materials that lost the most R_A value during the first six years keep on loosing the most during the following years.

The initial values shown in table 3 were used in both cases. Only the second case, using fixed degradation rates, is considered in the following.

The match between model R_A and measured R_A values is illustrated for white materials in figure 8, while the exposure factors are shown in figure 9.

The match is not as good as for the data after 6 years. However, it is to be recalled that the data after 6 years were obtained with a single retroreflectometer used by a single person, while the final data were obtained with different retrorefletometers used by different people. Therefore, some additional scatter may be due to variation of the calibration levels of the different retroreflectometers. A few outliers may be due to simple mistakes.

In any case, the match is not bad in view of the large variations among materials and test sites.

The exposure factors are again converted so as to be expressed per year of exposure by dividing the resulting factors with the years of exposure as given in table 1. Because of this, the exposure factors can be compared with those obtained after 6 years, compare figures 7 and 9.

The factors are in most cases larger for the final data than for the data after 6 years. This is in agreement with the observation in section 2 that some test sites show increased losses of retroreflection in the last years.

The exposure factors increase the most at the two Finnish test sites at Rovaniemi and Vanda. This increase reflects an average loss of retroreflection of approximately 10 % over a two year period. There may be a natural explanation for this in terms of weather, or it may be due to a lower level of calibration of the retroreflectometer used in Finland. A difference of the calibration level as small as 5 % would explain the increase.

NOTE: In 2003 the Finnish signs were measured with both the Finnish retroreflectometer and the retroreflectometer used at all test sites. There was no significant difference in the level of calibration.

Apart from this, it is not easy to see a clear change of pattern in the exposure factors. A cautious conclusion is that they may or may not have changed.

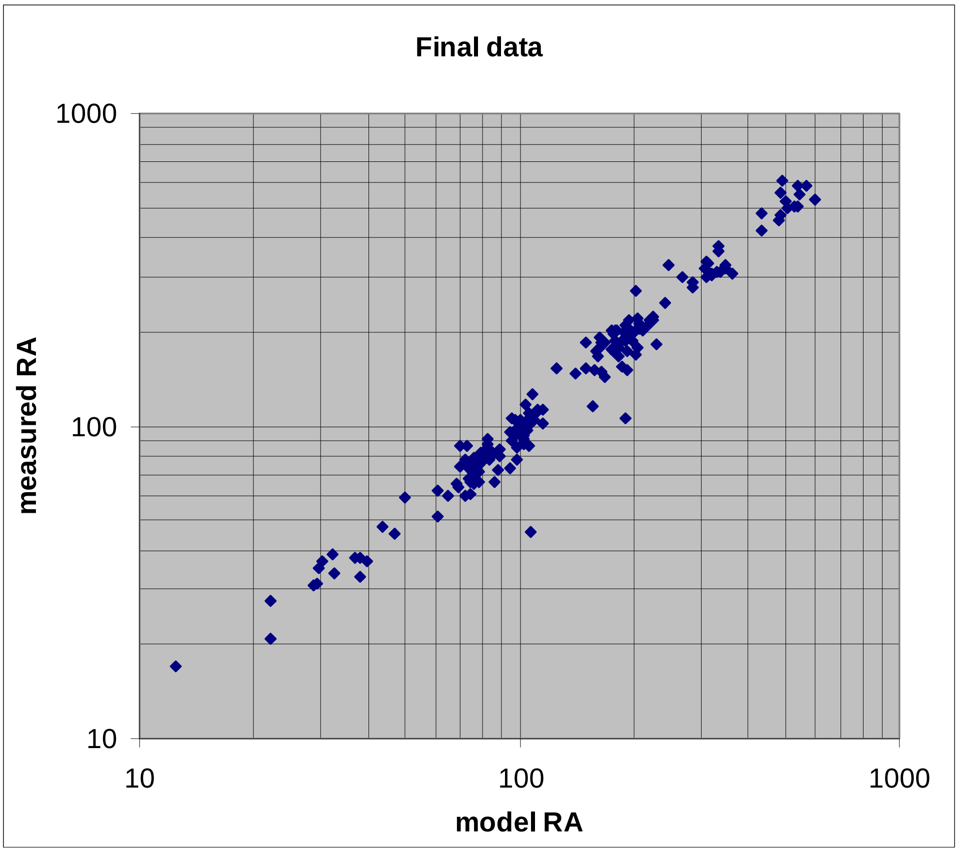


Figure 8: Match between exponential model R_A and measured R_A values for white materials for the final data.

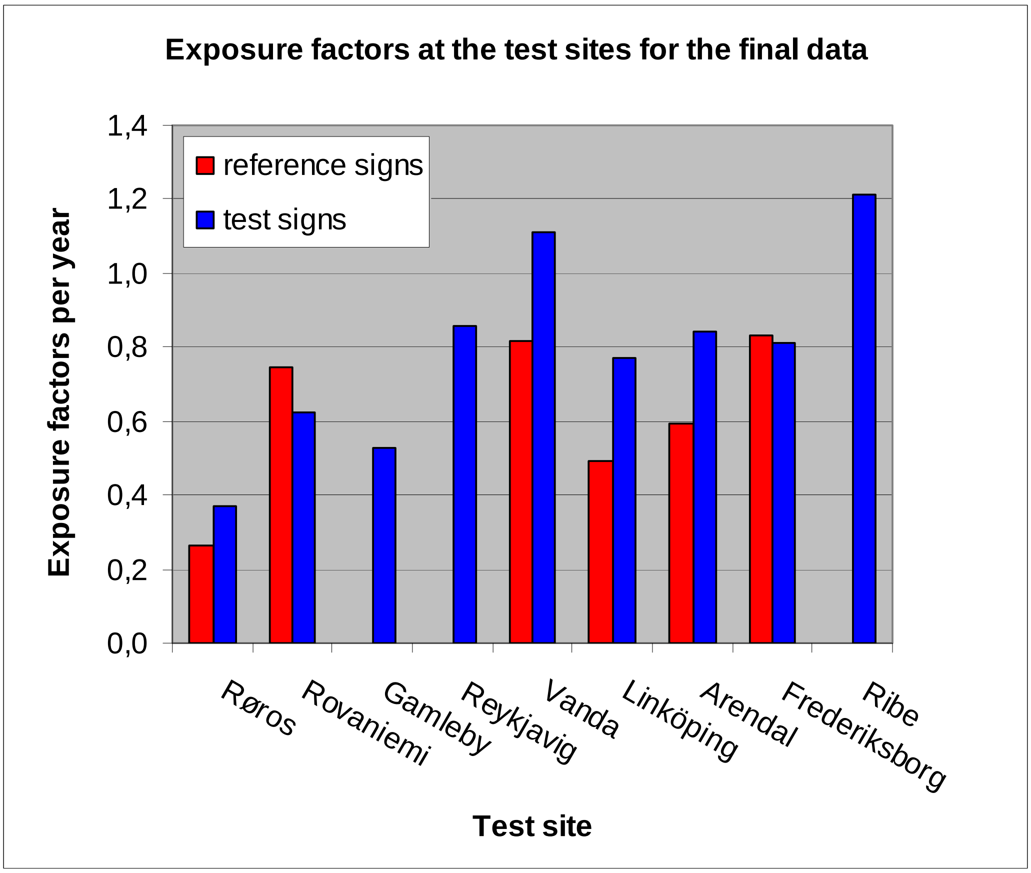


Figure 9: Exposure factors for the exponential model for the final data.