A durability test of retro-reflecting materials for road signs at Nordic test sites

Kai Sørensen and Sven Olof Lundkvist, May 2004

Durability test of retro-reflecting materials for road signs at Nordic test sites

A durability test of retro-reflecting materials for road signs is being carried out at nine test sites at different locations in the Nordic countries. The test sites were established in 1997 by the NMF group, a voluntary Nordic research cooperation. The RA values (coefficient of retro-reflection) of the samples of the retro-reflecting materials have been measured in the 0,33°/5° geometry (0,33° observation and 5° entrance) on a regular basis since 1997. The measurements have been performed by local people with locally used instruments.

In the autumn of 2003, measurements were done by a single person using a single and well tested instrument, resulting in 'reference' set of data with less variation than on previous occasions that is particularly well suited for analyses such as presented in this article. The test sites and the RA values of the samples are introduced in an analysis carried out in steps resulting in an ageing model showing that the load of exposure differs from test site to test site and that the RA values of the materials degrade at different rates. The model is further discussed and the implications of the model are considered.

TEST SITES & RA VALUES OF THE SAMPLES

The test sites, nine in total at different locations in the Nordic countries, were established in 1997, each with four 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 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. A location on one of these signs accordingly 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 location of the test sites is shown in figure 3.

The RA 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. These measurements were performed by local people with locally used instruments.

On each occasion, the resulting RA values of the materials of a sign are provided in a table that reflects the matrix arrangement of the materials on the sign. In the autumn of 2003, measurements were done by a single person using a single and well tested instrument, resulting in a 'reference' set of data with less variation than at previous occasions that is particularly well suited for analyses which follows.

The roads used for the test sites 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 RA values would reflect this orientation (in particular that the values of materials facing south would decrease faster than the 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 RA values.

The above does not imply that the RA values of samples of a particular material are the same for all the test signs at a particular site. The variation is in fact far from small, but as it cannot clearly be related to external agents, it is assumed to be random of nature. Likely causes are measuring uncertainties and variations from sample to sample of the same material.

Therefore, the four tables of RA 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 RA values for each material. This results in nine tables of RA values, one for each of the test sites. The additional tables of RA values for the five reference signs bring the total number up to 14.

These 14 tables are the results of the reference measurements to be considered in the following. During this consideration it has to be taken into account that the values of these tables must themselves be subject to some uncertainty due to the above-mentioned variations.

The standard deviation of single RA values can be estimated by standard methods, when comparing RA values for test signs at the same test site. For white materials, the estimated standard variation is 9% as an average for all the types of materials. For most of the other colours, the percentage standard variation is somewhat higher.

The simplest way to represent the 14 tables of RA values is to represent them all by a single table of average RA values. The assumption behind this approach would be that all the tables reflect equal conditions of exposure, and that variations between RA values of the tables are just random, carrying no information.

This approach is tested in figure 4, where the actual RA values of the 14 tables are plotted against the average RA values. Only RA values for white samples are plotted in order to keep the figure simple – if RA values for all colours were plotted details would be hidden by overlap of symbols.

Figure 4 shows a considerable scatter, at least by a factor of two, which indicates that a single table of average RA values does not provide a good representation of the actual RA values.

This probably indicates conditions of unequal exposure for the 14 tables, a matter that is discussed in the following section.

REPRESENTATION BY RESCALED AVERAGE RA VALUES

When accepting that the 14 tables of actual RA values represent different conditions of exposure, the next approach would be to still represent them all by the single table of average RA values, but simultaneously allow that the scale of this table is changed in each case.

The assumption behind this approach would be that all materials are equally sensitive to exposure, for instance that the actual RA values all degrade by 5% at a given exposure. Since exposure and degradation differ between the 14 tables,

Figure 3: Approximate locations of the test sites.

Figure 4: Actual RA values versus average RA values for white samples.
these are in different scales, but proportions between RA values within a table are assumed to be the same (apart from random variation).

The scale of a table of RA values is represented by the average of the RA values within the table. Actually, the geometrical mean of the RA values within the table is used instead of the simple average in order to place the same emphasis on all materials, with low or high RA values.

Accordingly, the single table of average RA values represents a table of actual RA values, when it is first brought into the same scale.

The approach is tested in figure 5, where the actual RA values of the 14 tables are plotted against the rescaled average RA values. As for figure 4, only RA values for white samples are plotted in order to keep the figure simple. Figure 5 does show less scatter than table 4. This is assumed to prove that the 14 tables represent unequal states of exposure.

However, the scatter shown in figure 5 is still considerable. There is in fact a strongly significant interaction between the test site and the type of material (for each colour), which shows that the variation in figure 5 is larger than random variation.

This may indicate that the different materials are not equally sensitive to exposure; ie that some materials degrade faster than other materials. This is discussed in the next section.

REPRESENTATION OF AN AGEING MODEL

An actual RA value from one of the 14 tables is labelled RA(i,j,k),

where i = 1,2,3 ... refers to the rows in a table corresponding to different types of materials

j = 1,2,3 ... refers to the columns in a table corresponding to different colours of the materials

and k = 1,2,3 ... refers to the 14 tables of actual RA values

The ageing model assumes that each of the RA(i,j,k) values can be approximated by a model value obtained from the following equation:

\[ RA_{model}(i,j,k) = RA_{average}(i,j) - F(k) 	imes D(i,j) \]  

\[ \text{(equation 1)} \]

where \[ RA_{model}(i,j,k) \] are the model values that approximate RA(i,j,k),

\[ RA_{average}(i,j) \] are the average values of RA(i,j,k) F(k) are exposure factors, one for each of the 14 tables of actual RA values

and \[ D(i,j) \] are factors expressing degradation rates of the different materials.

Equation 1 shows that the ageing model allows for unequal degradation rates of the materials as well as for unequal states of exposure, by means of respectively the table of degradation rates \[ D(i,j) \] and the exposure factors \[ F(k) \].

All the factors \[ D(i,j) \] and \[ F(k) \] are determined so that the model values \[ RA_{model}(i,j,k) \] fit as well as possible to the actual RA(i,j,k) values. The criterion is that the RMS (root-mean-square) difference between the two sets of values is minimum.

The actual procedure, which has been used, is to determine the exposure factor values \[ F(k) \] in an iterative trial and error procedure, with recalculating of the exposure factor values \[ D(i,j) \] for each change of the factor values \[ F(k) \]. The exposure factor values \[ F(k) \] actually converge quite quickly, and therefore the scale of the exposure factors \[ F(k) \] can be approximated by a model value obtained from the following equation:

\[ RA_{model}(i,j,k) = RA_{average}(i,j) - F(k) 	imes D(i,j) \]  

\[ \text{(equation 1)} \]

The results of the ageing model are indicated in figure 6, where the actual RA(i,j,k) values are plotted against the model RA(i,j,k) values. As for figures 4 and 5, only RA values for white samples are plotted in order to keep the figure simple. Figure 6 does show less scatter than figures 4 and 5. This is assumed to prove that the different materials are not equally sensitive to exposure; ie that some materials degrade faster than other materials.

The question is if the scatter shown in figure 6 is solely due to random variation, or if some of it indicates some deficiency in the ageing model. The standard deviation of random variation for single readings of RA values is 9% according to section 1 (for white materials). The standard deviation of single readings with respect to the predictions of the ageing model is slightly higher, but this is significant at a low level.

Therefore, the ageing model does provide a good representation of the measuring data, but probably does not account for all variations between test sites.

Further interpretation of the ageing model

Signs at the Røros site suffered little degradation. For the reference sign at Røros to 2,19 for the test signs at Ribe.

The RA table for the initial condition can also be put on this scale (by applying the model), and corresponds to -3.8, so that the width of the total range is 6.

After adjusting the above-mentioned range to 0 to 6 it instead of -3.85 to 2.19, the equivalent exposure at the different sites are as shown in figure 9.

With this scale of the exposure factors, the degradation rates are in the scale of loss of RA value per year of equivalent exposure. If converted to a percentage of the average RA values, the degradation rates appear as in table 1. The table of average RA values is shown in table 2.
IMPLICATIONS OF THE MODEL

The details of the ageing model should probably not be taken too seriously. The model is linear in nature, assuming a constant loss of retro-reflectivity year by year (refer to equation 1), where a percentage decrease might be more natural and might fit the measuring data slightly better. Further, the estimates of the exposure factors, figure 9, and of the degradation rates, table 1, are liable to be associated with considerable uncertainty. However, the model is interesting in that it shows a number of features, which are undoubtedly true.

The equivalent exposure is widely different at the different test sites in the Nordic countries and some thought should be given to what factors determine this. With the exception of the test site at Frederiksborg, the equivalent exposure is less for the reference signs than for the test signs, which indicates that road conditions lead to additional degradation. A probable cause could be abrasion by particles carried in the wake of vehicles. Røros, which has little traffic and a road covered by snow during winter, has the lowest equivalent exposure.

It may be that there is less exposure to global radiation with higher latitudes, and thereby less degradation. A comparison of figure 3 with figure 9 would indicate some correlation between latitude and equivalent exposure. The correlation is most clear for the reference signs, refer to figure 10.

It may also be that closeness to a salt water sea has an influence by means of salt carried by the wind. The test sites at Ribe and Arendal both have high equivalent exposures; they are close, respectively, to the North Sea and the Skagerrak.

Washing the signs may also be a factor. The signs were never washed at Røros.

In any case, the model does show that the expected life, or the degradation of RS values, depends on the location of the road signs. The matter that the model can include both test signs and reference signs seems to indicate that the two kinds of exposure affect the proportions of the RS values in a table in at least approximately the same manner.

Materials with high degradation rates should not be used at locations with high equivalent exposures.

If a permanent test site is introduced in the Nordic countries, it should for practical reasons be placed at a location with a high equivalent exposure, so as to keep the test as short as possible.

Authors details