Durability test of retro-reflecting materials for road signs at Nordic test sites from June 1997 to September 2002

draft report January 2004

Abstract

A durability test of retroreflecting materials for road signs was initiated by the NMF group, a voluntary Nordic research co-operation, to commence in 1997. This reports provides a status after 5 years of exposure in the autumn of 2002. The test is continued in order to further explore the functional life of retroreflecting road signs.

One of the aims of the test is to obtain realistic functional lives for retroreflecting road signs for use in practical models for planning and maintenance.

Samples of those materials that were on the market/used in the Nordic countries, and with colours as used in these countries, were mounted on test signs. These were mounted at representative roads in groups of 4 to form test sites at 9 locations of different climatic and traffic conditions (only 2 test signs at Reykjavik in Iceland). Additional test signs, called reference signs, were mounted in connection with some of the test sites at large distances from the road so as to be exposed to the load of climate only.

The coefficient of retroreflection R_A in the 0,33°/5° geometry (0,33° observation and 5° entrance) has been measured on a regular basis. The exposure during the 5 years period has caused:

- no clear difference of R_A values between the test signs at a test site, including no clear effect of the orientation north/south (east/west on Iceland)
- significant changes of the R_A values, mostly losses, that depend on the test site, the type of material and the colour
- losses of R_A values for the test signs mounted at roads as compared to the reference signs.

One of the test sites in Norway seems to provide little load of climate and traffic. The other test sites may be divided into two groups representing medium load and heavy load.

Some combinations of material and colour are more susceptible to the loads than other combinations. The prominent case is the material 3M 3200, which at most test sites shows large losses of R_A values for the colours white and red.

Measurements of the luminance factor and chromaticity with D65 illumination and the 45°/0° geometry were added later and carried out on a less regular basis. A non-exposed test sign stored in darkness was used to represent the initial condition.

Both in the initial condition and after exposure, the luminance factor values of glass beaded materials comply with minimum requirements of EN 12899-1 for road signs in use. The comparison cannot be carried out for microprismatic materials, that are excluded from the scope of the present version of EN 12899-1.

In most cases of glass beaded materials, the chromaticity does not change much from the initial condition to the condition after exposure, and the chromaticity points lie within the relevant colour boxes for road signs in use of EN 12899-1. In a few cases, the chromaticity points move out of the respective boxes after exposure.

For the microprismatic materials, the chromaticity points are compared to the colour boxes of HI materials of EN 12899-1. Some of the points do lie outside of the respective boxes or move out during exposure. For the white microprismatic materials, this may be due to the 'sparkles' that are particular to these materials, when using the 45°/0° test geometry.

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1. Introduction

The test of retroreflecting materials for road signs was initiated by the Nordic NMF group (title in Scandinavian language, translates to Nordic meeting for improved road equipment) to commence in 1997. NMF is a voluntary research co-operation with participation by institutes and road authorities in Denmark, Finland, Norway, Iceland and Sweden.

The aims of the test are:

- to obtain realistic functional lives for retroreflecting road signs for use in practical models for planning and maintenance
- to decide if durability testing in one or more sites can provide results that are representative for all of the area of the Nordic countries.

On this background, the following elements were selected as the basis for the investigation:

- test sites are established in all 5 Nordic countries at 1 or 2 locations per country

- all climatic zones are to be represented by the locations of the test sites
- the test should include all retroreflecting materials that are on the market/used in the Nordic countries
- samples of the materials are mounted on signs that are placed like usual road signs at representative roads, so that they are exposed to normal loads of climate and traffic
- the signs are surveyed at least once per year by measurement of the coefficient of retroreflection R_A ($cd \cdot lx^{-1} \cdot m^{-2}$) in a representative geometry, and the test is to be continued for at least 5 years in order to provide clear results.

The materials and the test signs are introduced in section 2.1.

The materials include glass beaded materials, both of the enclosed and the encapsulated lens types, and microprismatic materials. As a matter of convenience, the materials are described by the abbreviations EG (Engineering Grade, enclosed lens type), SEG (Super Engineering Grade, also of the enclosed lens type, but with a somewhat improved performance), HI (High Intensity, encapsulated lens) and PM (microprismatic).

The materials include the colours used in the Nordic countries, except that some of the colours are missing for some of the materials. The colours are white, yellow, orange, red, green and blue.

The test sites, 9 in total, are introduced in section 2.2. Additional reference signs were mounted in connection with 5 of the test sites at locations, where they are exposed only to the load of climate in order to isolate the influence of climate.

Some important durations of outdoor exposure are 3 and 5 years. Natural weathering in a 3 year period is foreseen as part of initial type testing of retroreflective road signs with regard to CE marking. Warranty or guaranty systems often operate with a 5 year period.

A report after 3 years of exposure was made available in VTI meddelande 912 - 2001 'Åldring av retroreflekterande folier för vägmärken - Resultat efter 3 års exponering' (in Swedish). This report includes test results after 5 years of exposure. It has been decided to continue the test in order to further explore the functional life of retroreflecting road signs.

The measuring program is introduced in section 2.3.

R_A values were measured with Retrosign 4000 instruments at most test sites. These instruments, as produced by DELTA, work in the 0,33°/5° geometry (0,33° observation and 5° entrance). This geometry is normally used for inspection of installed road signs in Europe, it is prescribed in connection with natural weathering in EN 12899-1 'Fixed vertical road signs - Part 1: Fixed signs' and with factory production control in prEN 12899-4 'Fixed vertical road signs - Part 4: Factory production control.

> NOTE: EN 12899-1 also prescribes a second geometry 0,33°/30°for the purpose of natural weathering. This geometry can be used by Retrosign 4000 in addition to the 0,33°/5° geometry, but was not considered for this test because it did not appear in the draft of EN 12899-1 that was available at that point in time.

At the test site at Reykjavik, R_A values were measured with an instrument produced by Gamma Scientific. This instrument works formally in the same geometry as mentioned above, but with the modification that the observation is not in a single direction, but in directions forming an annular ring about the illumination direction.

Section 3 provides an introduction to the measured R_A values. The R_A values show more variation than expected and the calibration level varies to some extent between the instruments. These uncertainties led to a decision that all the signs were to be measured by a single person using a well tested and calibrated reference instrument. This took place during the autumn of 2003 - after 6 years of exposure - resulting in a set of reference data.

These reference data are not directly applicable for this report, which relates to 5 years of exposure. However, the reference data provide a better basis for statistical analyses regarding the influence of various factors, and therefore the general conclusions for the reference data are used for this report as well - assuming that the general trends are the same after 5 or 6 years of exposure. These conclusions are found in a draft report with the title 'Åldring av retroreflekterende folier, Funktionen efter 6 år' (in Swedish), autumn 2003.

The R_A values for the initial condition are considered in section 4, the R_A values after exposure in section 5 and the R_A values of the individual materials in section 6.

Measurements of the luminance factor and the chromaticity were added at the Danish test sites in the year 2000, and later at the other test sites, using Gardner Color-guide instruments with D65 illumination in the 45°/0° geometry. These measurements are according to EN 12899-1. A non-exposed test sign stored in darkness was used to represent the initial condition. The results of these measurements are considered in section 7.

Conclusions are given in section 8.

2. The test sites

2.1 Materials and test signs

The suppliers of retroreflecting materials in the Nordic countries were contacted and informed about the test prior to delivery of the materials. The company Nor-skilt purchased the materials and produced the test signs, including the posts.

The sign face of the test signs has 15 rows of positions reserved for 15 different material types, and 8 columns of positions reserved for different colours or coatings of the material types.

The positions leave space for 10×10 cm^2 samples backed by aluminium substrates as for normal road signs. Not all positions were used, because materials or colours were not available at that point in time. The sign faces came to look as shown in figure 1. The size of the sign faces is 162×90 cm^2. The signs were mounted with the lower edge at 250 cm above the ground.

The product types are indicated in figure 1 and a description is given in table 1 as well.

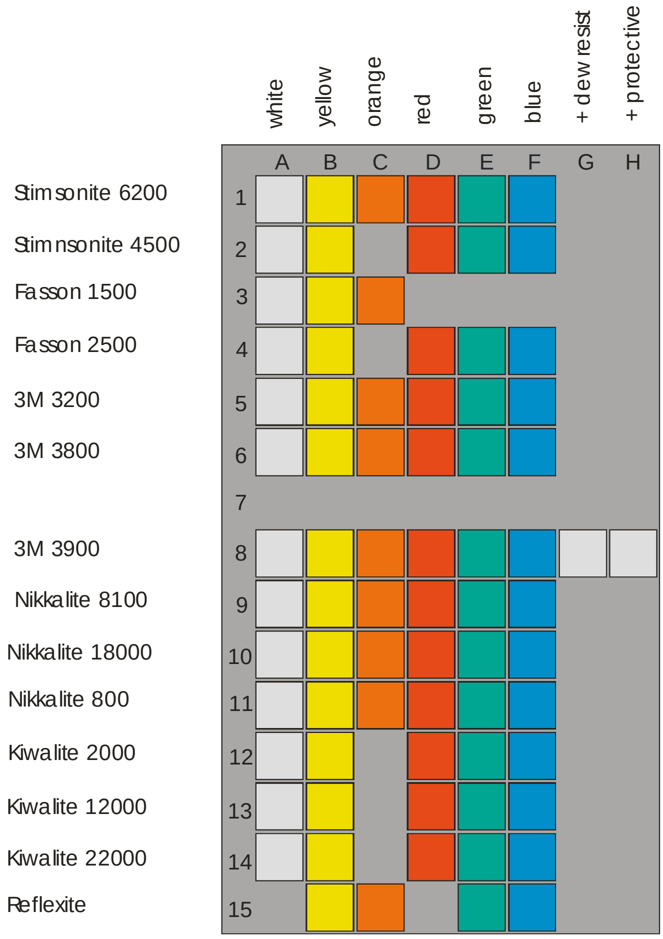


Figure 1: Sign face of a test sign and materials included.

NOTE 1: Different materials of the same colour do actually appear visually widely different, some of the orange colours for instance look brownish.

Table 1: Product types included on the test signs. Colours are white, yellow, orange, red, green and blue, when available.

Row No.	Trade name of material	Further description	Code
1	Stimsonite 6200*)	Microprismatic	PM
2	Stimsonite 4500*)	Microprismatic, metallized	PM
3	Fasson 1500	Enclosed lens	EG
4	Fasson 2500	Enclosed lens	SEG
5	3M 3200	Enclosed lens	EG
6	3M 3800	Encapsulated lens	HI
7	(empty row)		
8	3M 3990**)	Microprismatic	PM
9	Nikkalite 8100	Enclosed lens	EG
10	Nikkalite 18000	Enclosed lens	SEG
11	Nikkalite 800	Encapsulated lens	HI
12	Kiwalite 2000	Enclosed lens	EG
13	Kiwalite 12000	Enclosed lens	SEG
14	Kiwalite 22000	Encapsulated lens	HI
15	Reflexite	Microprismatic	PM

*) Stimsonite is now part of Avery Dennison and Stimsonite 6200 is called T-7500, while Stimsonite 4500 is called T-4500.
**) Additional samples are for the colour white with dew resist overlay film (actually 3M type 3970 instead of 3M type 3990) and with 1150 protective overlay film

2.2 Test sites

Two test sites were arranged in each of the countries Denmark, Finland, Norway and Sweden, each with four test signs mounted at a road as shown in figure 2. In order to compensate for possible influence of the height position on the action of dirt and traffic, the two signs at the same side are mounted respectively upright and upside down.

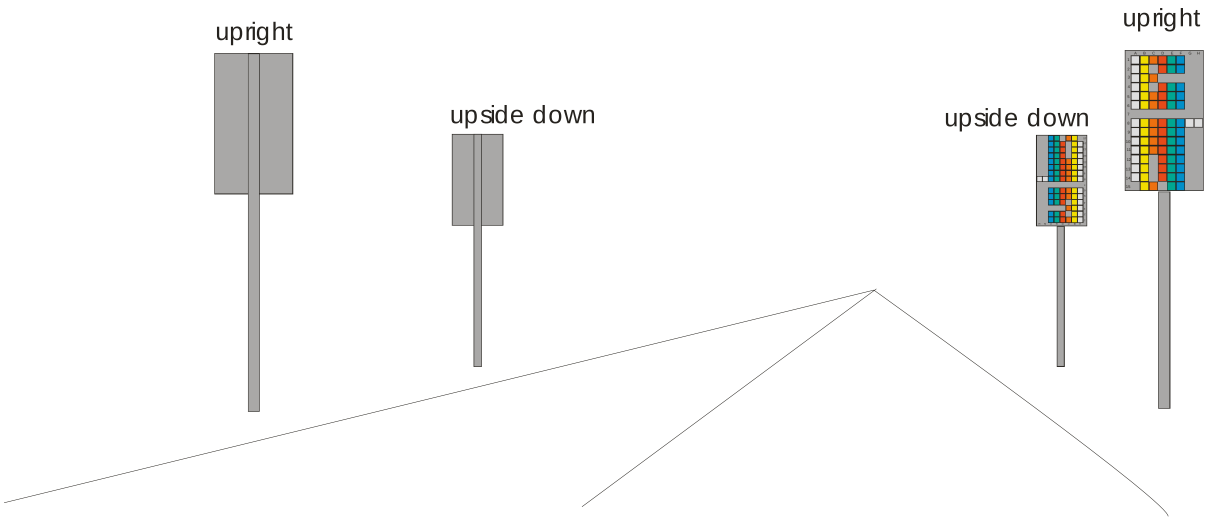


Figure 2: The test sites, except the one in Iceland, have four test signs mounted at a road.

The roads run approximately north-south, so that the signs at one road side face approximately south, while the signs at the other road side face approximately north. A comparison of these two orientations may provide information of a possible detrimental effect of irradiation from the sun.

The test signs are exposed to loads of both climate and traffic. Some of these test sites include an additional reference sign placed in the open air and facing south at a convenient location far from roads, so as to be exposed to the load of climate only.

In Iceland, only one test site was arranged, with only one sign at each road side, and with no reference sign. The two road signs were turned upside down every four months in order to eliminate possible influence of the position in height relative to the road surface. The two signs face respectively west and east, these two directions being selected because east is known to be the main weathering direction, with more rain and wind than other directions. The wind sometimes carries sand particles, causing erosion that can be seen on different types of constructions.

The locations of the test signs are indicated on the map in figure 3. Further description of the test sites is given in table 2

Figure 3: Approximate locations of the test sites.

Table 2: Locations of the test sites.

Country	Location	Number of signs	Road location
Denmark	Frederiksborg	4+reference	Frederikssundsvej, 5 km South of Frederikssund
	Ribe	4	Ribe-Esbjerg, 15 km North of Ribe
Finland	Vanda	4+reference	Close to the Helsingfors airport
	Rovaniemi	4	Finnish lapland
Iceland	Reykjavik	2	East of Reykjavik
Norway	Arendal	4+reference	Arendal-Kristianssand, 9 km South of Arendal
	Røros	4+reference	Røros-Trondheim, 13 km North of Røros
Sweden	Linköping	4+reference	At Sjögestad, 15 km North of Linköping*)
	Gamleby	4	3 km South of Gamleby
*) moved to this location from a location near Linköping after a graffiti attack in 1998			

The latitudes of the test sites range from 55,4° at Ribe to 66,5° (the polar circle) at Rovaniemi. Climates range from a relatively mild, coastal temperate climate in Denmark to an inland sub-arctic climate in the Finnish lapland at Rovaniemi. Some sites are close to the coast, Ribe to the North Sea, Arendal to the Skagerak and Gamleby to the Baltic sea, while other sites are at a good distance from coasts.

The roads are all two-lane roads. Traffic ranges from low at Røros with an ADT of approximately 1500 to high at Frederiksborg with an ADT of approximately 15000.

Winter maintenance involves snowploughing and application of salt, sand or salt/sand mixture at all the locations. Sand is not used in Denmark, but to an increasing degree the further to the north. However, neither salting nor sanding is used at Røros.

The test signs are maintained in the manner normally used for road signs at the particular locations. At Frederiksborg, Ribe and Røros, road signs are normally not washed. At Linköping and Gamleby, signs are washed at intervals using a brush and water with a detergent. At Arendal, signs are cleaned with a high pressure jet of hot water with an additional washing at spring using a brush and water with a detergent. At Reykjavik, signs are cleaned with a detergent and low pressure cold water the day before measurements. At Røros, there is no washing or cleaning of the signs as part of regular maintenance - only removal of dirt in a few cases in connection with measurements using a dry cloth.

The test site at Røros is particular in a couple of respects. The abrasion load of the signs is probably low, as the traffic is low, winter maintenance does not include sanding or salting, and there is no washing of the signs as a part of regular maintenance. The UV load may on the other hand be high, as the signs are in a location free of shadows, fairly high above sea level, and in a landscape covered with snow much of the year. Temperature goes down to -40 C in winter and up to 30 C in summer.

The test signs were mounted in June 1997 with, however, some samples being added during the summer of 1997.

2.3 Measuring program

The coefficient of retroreflection R_A as defined in among else CIE 54.2 was measured in the 0,33°/5° geometry (0,33° observation and 5° entrance) with Retrosign 4000 instruments except for the use of a Gamma Scientific instrument on Iceland.

The R_A measurements were carried out during the autumn, first in 1997 and then the following years. At the Norwegian and Danish test sites, additional R_A measurements were carried out shortly after the test signs were mounted in June 1997, and then during spring the following years. These additional measurements were stopped at the Norwegian test sites after a couple of years, but are still carried out at the Danish test sites.

It is an agreement that the test signs are washed the day before measurement. However, no washing was carried out at Røros, only occasional cleaning with a dry cloth.

Measurement of the luminance factor and chromaticity were added at the Danish test sites in the year 2000 using a Gardner Color-guide instrument with D65 illumination and the 45°/0° geometry. Such measurements were added at the Swedish test sites later on using a Minolta CR 331C.

In order to compensate for the lack of initial measurements of the luminance factor and chromaticity, these measurements were later carried out on a test sign, which has been kept stored in dark, indoor conditions.

2.4 Signs with coated samples at Frederiksborg

The samples of two of the signs at Frederikssund, one at either side of the road, were coated with a clear paint used by the county of Frederiksborg on road signs for protection against graffiti. The coating seems to cause a loss of retroreflection, as the average R_A value of the samples on these signs is approximately 6% lower than the average R_A value of the samples on the other signs. This applies as well for the new condition as for the condition after exposure. The loss in retroreflectivity is not constant for the different types of sheeting materials, being larger for SEG types of materials than for the other types.

These two signs with coated samples are excluded from further discussion, leaving only two signs at the test site at Frederikssund, and a reference sign, to be considered.

2.5 Signs with graffiti at Linköping

The signs at Linköping, excluding the reference sign, were exposed to graffiti late in 1998. The lower parts of all four signs were covered, affecting some positions in rows 12 to 15 on two of the signs, and some positions in rows 1 to 4 on the other two signs (those in inverted positions).

The graffiti was removed, the signs were moved to another location, and the measuring program was continued.

3. Introduction to the retroreflectivity (R_A) values

3.1 Variation of measured R_A values

Figure 4 shows the R_A values for a particular EG material as a function of time for the test signs at the Danish test sites.

The general impression provided by figure 4 is one of gradual decrease of the R_A value as an average for the signs, but with fairly large variations for the individual signs, larger than might have been expected.

As the R_A values of EG materials are known to depend on temperature and humidity, one might speculate if not some of the variability is caused by weather conditions at the actual time of measurement.

The speculation is not promising in view of figure 4, as the curves for signs at Frederiksborg should then vary in some concert with each other, and the same should apply for the curves for the signs at Ribe - but this does not seem to be the case.

The speculation may be further tested by inspection of the results for a HI material, as the R_A values of these materials are known to be relatively stable in view of temperature and humidity. However, the diagram for a HI material, which is shown in figure 5, shows as much variation as figure 4. Another attempt to establish the influence of temperature and humidity was made by measuring one of the signs once per day in a period, while simultaneously recording the temperature and the humidity. There was no obvious correlation between R_A values and weather data (the data are not shown).

Therefore, temperature and humidity is probably not the major source of variation of measured R_A values.

Uncertainty of measurement should of course be considered a source of variation. However, it is hard to believe that EG and HI materials were not measured with a fairly low uncertainty in view of:

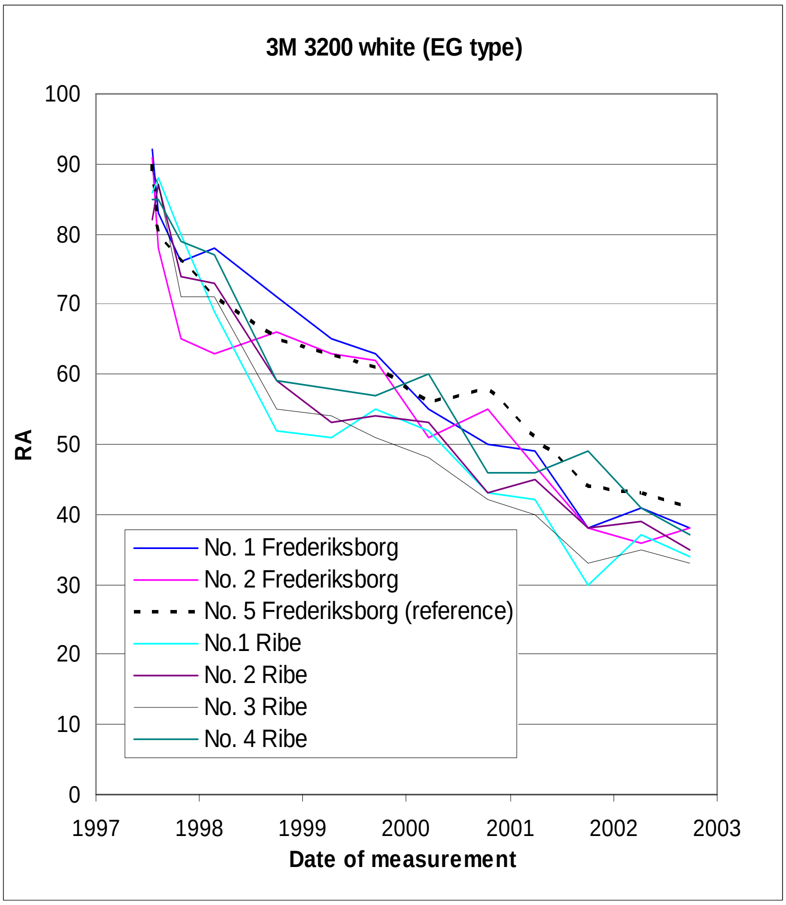
- the same instrument was used for all the measurements of R_A values at Frederiksborg and Ribe
- the calibration standard for this particular instrument was recalibrated prior to each set of measurements
- a tool was used to provide the same measuring spot from time to time
- the R_A values of EG and HI materials do not depend strongly on the angle and the orientation of the instrument during measurement

Therefore, some other source may have caused significant variation. It may be speculated that this source is residual dirt on the road signs, even though they were washed the day before measurement in all cases. The source may also be some long term effect of weather, like accumulation of moisture in the sheeting materials.

A priory, it can be expected that some PM materials show even larger variations of R_A values than for EG and HI materials. The patterns of the retroreflected beams of these materials are subject to changes with exposure and weather condition, and the patterns are complex in some cases making measurements less accurate. The diagram for a particular PM material, which is shown in figure 6, does reveal a large variation.

It must be accepted that there is significant variation of individual R_A readings, for which the reason is not known.

Figure 4: R_A values for a particular EG material at the Danish test sites.



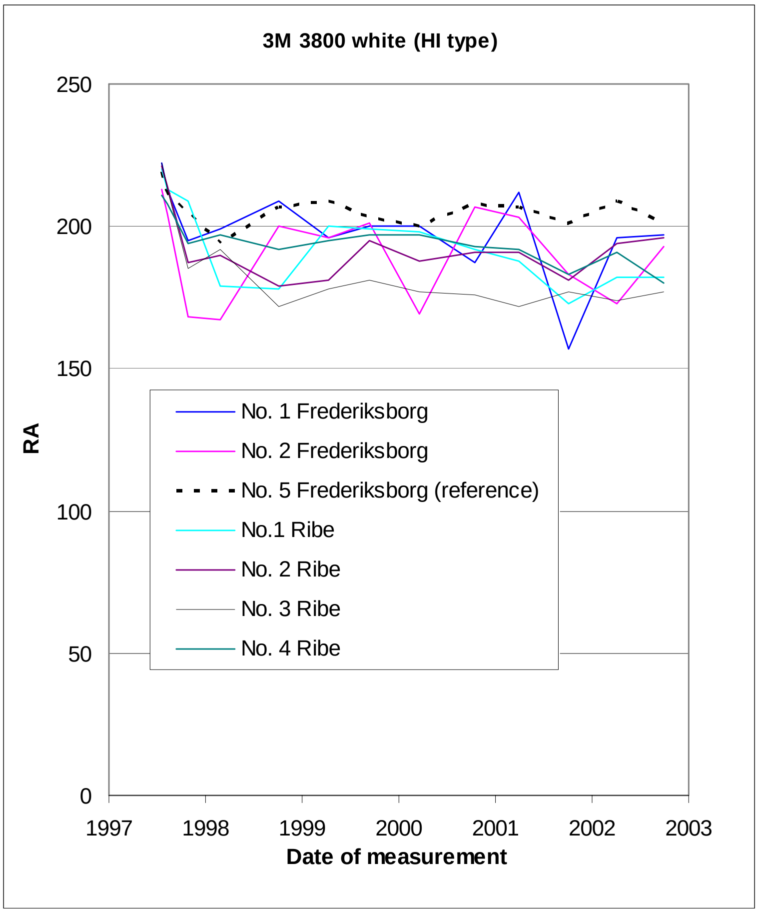


Figure 5: R_A values for a particular HI material at the Danish test sites.

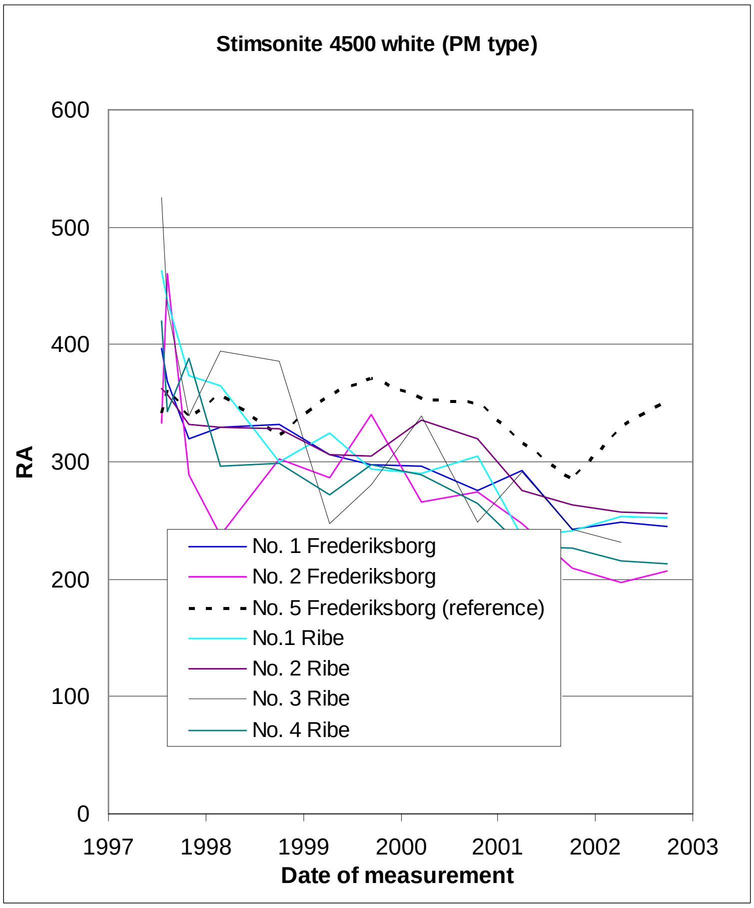


Figure 6: R_A values for a particular PM material at the Danish test sites.

3.2 Calibration of the instruments and reference measurements in 2003

It might also be suspected that the instruments did not necessarily have the same level of calibration. These levels were compared for some of the instruments a couple of times during the 5 year period, where differences of a couple of percent were found.

However, a decision was made that all the signs were to be measured by a single person using a well tested and calibrated reference instrument. This took place during the autumn of 2003 resulting in a set of reference data.

At the same time, a set of 3M HI type 3800 samples were used to compare readings with the reference instrument and locally used instruments. The readings are provided in table 3a, while table 3b provides percentage deviations from readings with the reference instrument. The percentage deviations are not large as seen from an engineering point of view, but large enough to disturb the analyses in an investigation like this one.

> NOTE: A set of 3M type 3990 samples were used as well to compare readings with the different instruments. These results are not indicated in table 3 as they lead to roughly the same conclusions as for the above-mentioned set of samples.

For this reason it was decided to use the general conclusions of the statistical analyses performed for the reference set of data for this report as well. These conclusions are found in a draft report with the title 'Åldring av retroreflekterende folier, Funktionen efter 6 år' (in Swedish), autumn 2003. Refer to section 5 of this report for the general conclusions.

Table 3a: Readings of R_A ($cd \cdot lx^{-1} \cdot m^{-2}$) for a set of samples with locally used instruments.

samples						
3M HI of the following colours:	Frederiksborg and Ribe (reference)	Vanda	Reykjavik	Arendal	Røros	Linköping and Gamleby
white	208	205	215	213	220	205
yellow	172	173	177	181	186	170
red	45	46	45	50	54	44
blue	18	16	20	16	16	17
green	41	38	43	37	38	40
average	96,8	95,6	100	99,4	102,8	95,2
geometrical mean	65,3	63,0	68,2	64,8	66,9	63,6

Table 3b: Percentage deviations of readings of R_A .

samples						
3M HI of the following colours:	Frederiksborg and Ribe	Vanda	Reykjavik	Arendal	Røros	Linköping and Gamleby
white	reference	-2,5%	+3,4%	+2,4%	+5,8%	-1,4%
yellow	reference	+0,6%	+2,9%	+5,2%	+8,1%	-1,2%
red	reference	+2,2%	0%	+11%	+20%	-2,2%
blue	reference	-11%	+11%	-11%	-11%	-5,6%
green	reference	-7,3%	+4,9%	-9,8%	-7,3%	-2,4%
average	reference	-1,2%	+3,3%	+2,7%	+6,2%	-1,6%
geometrical mean	reference	-3,5%	+4,4%	-0,8%	+2,5%	-2,6%

4. Retroreflectivity (R_A) values for the initial condition

For each test or reference sign, a table of R_A values is established for the initial condition using the earliest measured R_A values. For the Danish and Norwegian signs, R_A values were measured for most of the materials in June 1997, while R_A values for the remaining materials were measured late summer 1997. Other signs were measured late in the summer of 1997.

The geometrical mean R_A values of the tables are given in table 4. The table also contains geometrical mean R_A values for the condition after exposure, refer to section 5.

The geometrical mean R_A values for the initial condition are also illustrated in figure 7, which shows the values in the same sequence as used in table 4, and with columns for reference signs shown in a slightly deviating colour.

> NOTE 1: The geometrical mean R_A value is used to represent a table in order to place the same emphasis on samples with large or small R_A values. Simple average R_A values would place high emphasis on samples with large R_A values, and thereby on white samples as compared to samples of other colours and on PM samples as compared to samples of other general types.

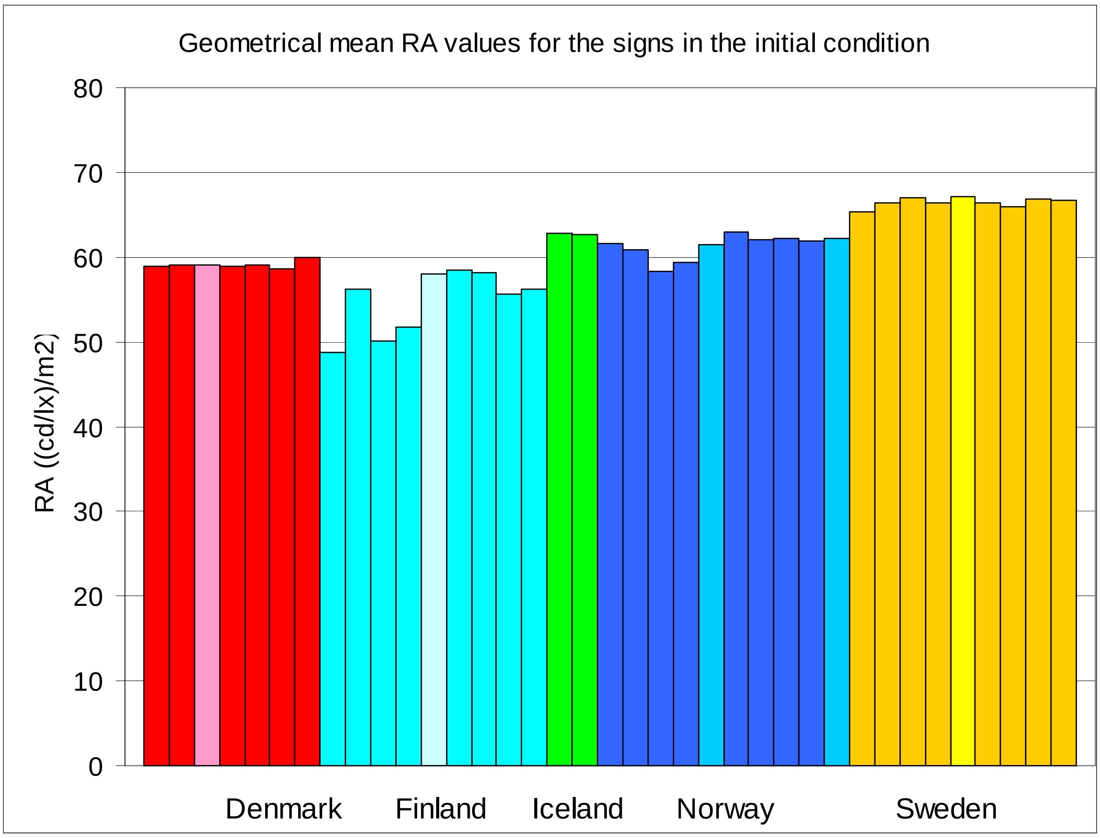


Figure 7: Geometrical mean R_A values ($cd \cdot lx^{-1} \cdot m^{-2}$) for the test and reference signs in the initial condition.

Table 4: Geometrical mean R_A values ($cd \cdot lx^{-1} \cdot m^{-2}$) for the test and reference signs.

Test site	Initially	After exposure
Denmark		
Frederiksborg No. 1	58,9	54,2
Frederiksborg No. 2	59,1	50,4
Average	59,0	52,3
Frederiksborg reference	59,1	53,9
Ribe No. 1	59,0	48,2
Ribe No. 2	59,0	52,1
Ribe No. 3	58,6	48,2
Ribe No. 4	60,0	48,8
Average	59,2	49,3
Finland		
Vanda No. 1	48,8	54,1
Vanda No. 2	56,2	54,5
Vanda No. 3	50,0	53,0
Vanda No. 4	51,7	54,6
Average	51,7	54,1
Vanda reference	58,1	55,5
Rovaniemi No. 1	58,4	55,1
Rovaniemi No. 2	58,2	54,5
Rovaniemi No. 3	55,7	55,3
Rovaniemi No. 4	56,3	54,8
Average	57,2	54,9
Iceland		
Reykjavik No. 1	62,8	54,8
Reykjavik No. 2	62,6	52,1
Average	62,7	53,5
Norway		
Arendal No. 1	61,6	51,7
Arendal No. 2	60,8	51,2
Arendal No. 3	58,3	48,4
Arendal No. 4	59,3	52,4
Average	60,0	50,9
Arendal reference	61,5	55,0
Røros No. 1	62,9	59,4
Røros No. 2	62,1	65,8
Røros No. 3	62,2	64,5
Røros No. 4	62,0	63,1
Average	62,3	63,2
Røros reference	62,2	67,1
Sweden		
Linköping No. 1	65,3	49,2
Linköping No. 2	66,3	47,5
Linköping No. 3	66,9	48,6
Linköping No. 4	66,3	51,9
Average	66,2	49,3
Linköping reference	67,1	57,5
Gamleby No. 1	66,4	55,3
Gamleby No. 2	66,0	53,5
Gamleby No. 3	66,8	55,8
Gamleby No. 4	66,6	57,1
Average	66,5	55,4

Table 4 and figure 7 show unexpected large variations between the test signs. The geometrical mean R_A values of the signs in Denmark, Iceland and Norway agree with each other within a few percent. However, the geometrical mean R_A values of the Finnish test signs are lower than in the above-mentioned countries and show variation between them. The geometrical mean R_A values of the Swedish test signs are higher than in the above-mentioned countries. The percentage standard deviation of the geometrical mean R_A values of all the signs is as high as 8,2%.

When considering a particular type of sheeting material, some variation between the signs can be expected, as the R_A value may show variation even within the same roll of the material. However, the above-mentioned variations are consistent in the sense that a sign with a high geometric mean R_A has to some extent high R_A values for all the samples of the sign.

Therefore, the variations are most probably not true, but reflect some source of bias.

A closer look at the R_A values for the Finnish signs show that the R_A values measured a year later are higher than the initial values, and that the R_A values even stay higher in the following years for several of the materials. This is in contradiction with the results for the other test signs and indicates that the initial R_A values of the test signs in Finland, in particular those at Vanda, are too low.

It may also be suspected that the initial R_A values for the Swedish test signs are too high.

However, speculations are not helpful, the possible sources of bias cannot be established, and there is a need to decide how to represent the initial condition.

The more scientific method would be to use all of the tables of R_A values measured initially for all the signs. However, it is not reasonable that this should provide a good picture of the initial condition in view of the variations between the signs and test sites. Among else, conclusions regarding the development of R_A values with exposure would be different for the Finnish signs (R_A values would tend to increase) than for the other signs.

Instead, a single table of initial R_A values has been established, refer to table 5, where the R_A value in a particular position is the geometrical mean of the R_A values in the same positions in the tables for the individual signs. It could be argued that the tables of R_A values for the Finnish signs and perhaps the Swedish signs should be omitted, when forming the single table of initial values. However, it has been chosen to include all the tables - which by the way results in roughly the same table of R_A values as if these tables were omitted.

> NOTE 2: In this case, simple averages could have used instead of geometrical means, as the individual R_A values are fairly equal. However, geometrical means are used in this case as well to provide consistency with the use of geometrical means to represent the overall level of tables.

The geometrical mean R_A value for this table is 60,5 $cd \cdot lx^{-1} \cdot m^{-2}$, which is the average of the geometrical mean R_A values for the individual tables.

The use of table 5 to represent the initial condition does imply that the variation of the overall level of the individual tables has been eliminated. It is reasonable to eliminate this variation, as it is too large to be considered real (this is the variation with the above-mentioned standard deviation of 8,2%).

This use of table 5 also implies that proportions of the R_A values within the individual tables have been replaced by the single set of proportions reflected by table 5. This corresponds to a further elimination of variation of individual R_A values with standard deviations as given in table 6.

Some of this variation is due to uncertainty of measurement or other unknown sources; refer to the discussion in section 3.1. Table 6 shows that the standard deviations are fairly small for some of the materials, in particular glass beaded sheeting materials of the general types EG, SEG and HI; the average value is approximately 7% (computed as RMS average). For these, uncertainty of measurement is probably a main contributor to the variation.

However, variations are fairly large for some of the microprismatic materials (refer to rows 1, 2 and 15 and position 8G); the average value is approximately 22% (computed as RMS average). For these, variations between samples of the same material and colour play a role. It is an approximation to eliminate such variation.

Table 5: Geometrical mean R_A values for the initial condition ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F	G	H
1 (PM)	628	503	240	175	77,8	61,0		
2 (PM)	427	263		69,2	81,3	30,1		
3 (EG)	76,3	46,2	24,2					
4 (SEG)	116	77,0		29,8	26,4	9,2		
5 (EG)	86,3	47,8	29,6	18,9	11,9	8,2		
6 (HI)	218	178	80,5	54,8	38,3	16,6		
7								
8 (PM)	366	320	344	80,2	67,7	29,0	506	308
9 (EG)	96,1	66,7	52,9	20,0	17,0	5,4		
10 (SEG)	139	98,2	29,5	25,5	21,6	9,4		
11 (HI)	224	126	86,5	28,6	43,9	15,3		
12 (EG)	103	79,9		30,7	18,3	7,3		
13 (SEG)	133	94,9		31,2	29,2	8,4		
14 (HI)	204	139		38,2	28,2	14,7		
15 (PM)		245	161		80,9	54,8		

Table 6: Standard deviation of R_A values for the initial condition (%).

	A	B	C	D	E	F	G	H
1 (PM)	7,2	6,7	12,7	10,6	11,8	17,5		
2 (PM)	19,0	27,5		16,7	26,7	13,4		
3 (EG)	4,2	10,6	8,5					
4 (SEG)	4,4	6,7		7,9	6,4	11,8		
5 (EG)	4,5	5,2	6,1	9,3	6,0	7,9		
6 (HI)	4,6	5,4	4,3	8,8	5,1	6,1		
7								
8 (PM)	5,5	5,1	9,4	8,0	7,3	9,5	26,9	6,1
9 (EG)	4,4	6,0	3,9	10,4	3,6	9,1		
10 (SEG)	4,5	6,8	6,2	5,0	6,6	4,6		
11 (HI)	9,9	7,7	5,9	7,7	4,5	9,5		
12 (EG)	5,1	7,1		6,9	9,3	12,5		
13 (SEG)	5,5	6,0		6,5	6,3	9,9		
14 (HI)	3,6	5,0		5,9	6,3	13,9		
15 (PM)		27,1	33,3		47,3	22,7		

5. Retroreflectivity (R_A) values after exposure

5.1 Average effects of exposure

The condition after exposure is represented by a table of R_A values for each of the test or reference signs measured in the autumn of 2002.

The geometrical mean R_A values of the tables are given in table 4 together with the similar values for the initial condition. These R_A values are also illustrated in figure 8 in the same sequence as used in table 4, and with columns for reference signs shown in a slightly deviating colour.

Most of the signs are seen to have geometrical mean R_A values well below the value of 60,5 $cd \cdot lx^{-1} \cdot m^{-2}$ for the initial condition, refer to section 4.

For the test signs, the geometrical mean R_A value is 54,1 $cd \cdot lx^{-1} \cdot m^{-2}$, which corresponds to an average loss of R_A value during exposure of 10,6%. For the reference signs, the geometrical mean R_A value is 57,8 $cd \cdot lx^{-1} \cdot m^{-2}$, which correspond to an average loss of retroreflection of 4,5%.

However, underneath those average figures, there is a strong dependence on the actual materials, their colours and the test site. This is illustrated by small losses of R_A values for some cases, or even gains, and losses of up to approximately 60% for other cases.

It is striking feature that some of the Norwegian signs, those at Røros, do not show a decrease of geometrical mean R_A values, but rather an increase in some cases.

The investigation of calibration levels in 2003, refer to section 3.2, indicates that the instrument used at Røros may have resulted in R_A values that were too high by a few percent. However, even if a few percent were subtracted, the Røros R_A values would still be as high as for the initial condition.

This raises the question, if conditions at Røros are so favourable that 5 years of exposure does not cause any depreciation of the R_A values. This might well be the case in view of the particular conditions at the test site at Røros, refer to section 2.2. The materials were reported to look like new during the reference measurements in 2003.

The assumption of favourable conditions at Røros may be confirmed by the diagram of figure 9, which shows the development of R_A values for a particular EG material at the two Norwegian test sites. The R_A values show large decreases for the signs at Arendal - as for signs at other test sites - while the decrease is fairly small for the signs at Røros.

The graffiti attack at the test site of Linköping, refer to section 2.5, has to be considered as well. Figure 10 shows the development of R_A values for the samples of a white HI material on 5 signs, of which one of the samples was affected by graffiti while the other were not. The curve for the affected sample shows clearly a dip in R_A value, followed by an uncompleted recovery. Therefore, R_A values for samples affected by graffiti are excluded from the analysis.

This exclusion does not, by the way, change the geometrical mean R_A values for the signs at Linköping. The different materials seem to be affected differently by the graffiti followed by cleaning. Some materials have lower R_A values for those samples affected by graffiti, but some other materials - in particular some of the microprismatic materials - have higher values.

Some results of the analyses for the reference data from 2003, refer to section 3.2, are as follows:

- exposure to climate does lead to changes of the R_A values, a decrease in most cases (reference signs)
- simultaneous exposure to the road environment and climate does lead to additional changes, a larger decrease in most cases (test signs at the roads)
- the changes of R_A values depend on the test site location
- there is no effect of the orientation north/south of the test signs (all test sites except the test site on Iceland) and no effect of the orientation east/west (the test site on Iceland).

To the results may be added that there is no effect of the two rotations of the test signs, upright or upside down.

It is a bit surprising that the orientation north/south does not show an effect, as exposure to the sun for the south orientation was expected to have an effect. It might also be a surprise that the orientation east/west on Iceland does not show an effect, as exposure to the predominant wind direction was also expected to have an effect.

It is probably less surprising that there is no effect of the two rotations of the test signs. The two rotations were used so that no material should be placed low on all the signs, where more dirt might accumulate. The signs are probably mounted so high that dirt accumulation is not excessive in any case.

To these conclusions can be added that the position nearby a coast does not seem to have a clear detrimental effect, compare for instance the results for the test sites at Ribe and Frederiksborg, and for the test sites at Gamleby and Linköping - in both cases near and far from a coast.

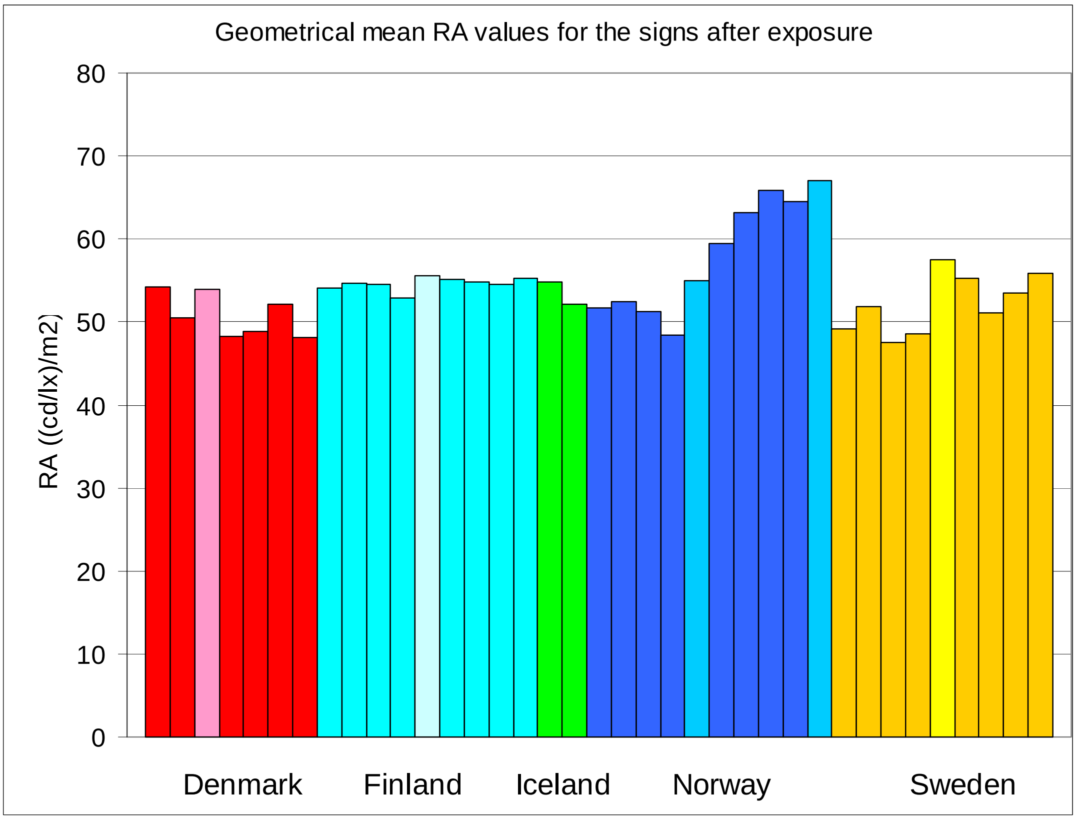


Figure 8: Geometrical mean R_A values ($cd \cdot lx^{-1} \cdot m^{-2}$) for the test and reference signs in the initial condition

Figure 9: R_A values for a particular white EG material at the Norwegian test sites.

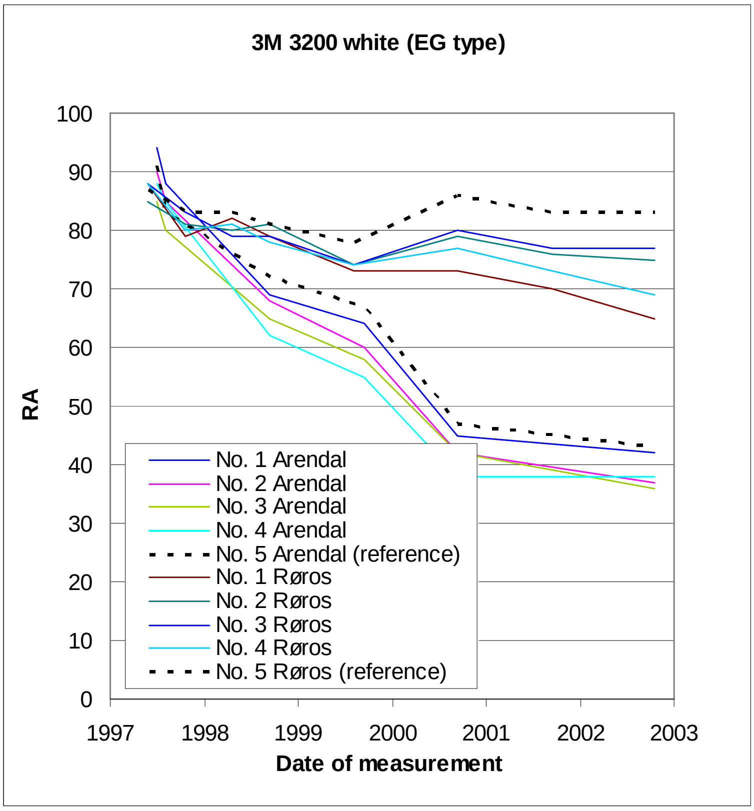
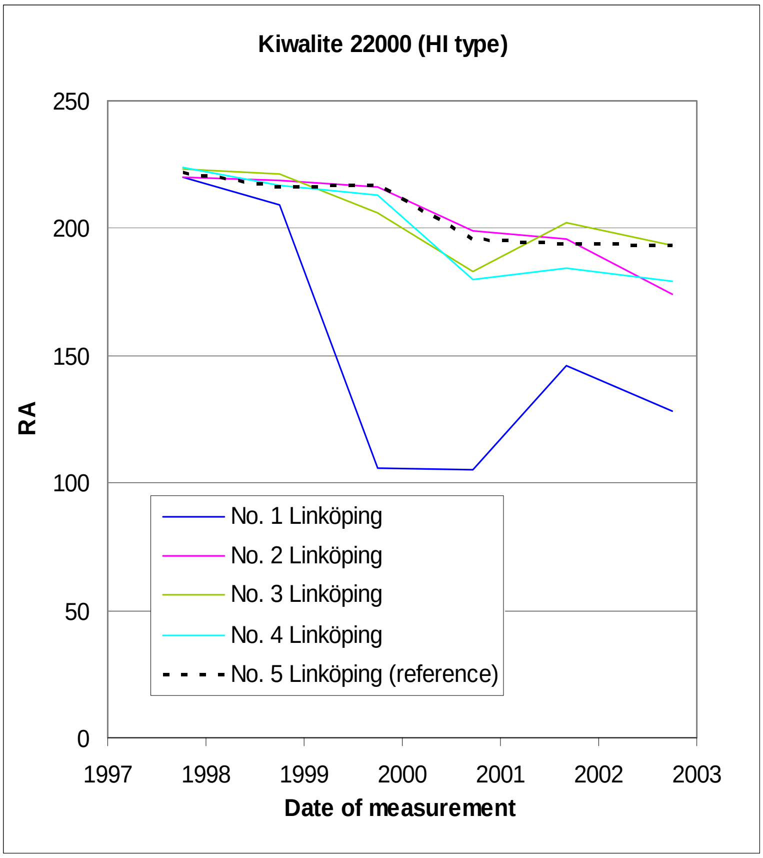


Figure 10: R_A values for a particular white HI material at the test sites at Linköping. The sample on sign No. 1 was affected by graffiti.



5.2 Interaction effects of exposure

Tables 7 with geometrical mean R_A values and 8 with standard deviations of R_A values are produced for the test signs (excluding reference signs) in the same way as tables 5 and 6 for the initial condition, refer to the section 4.

Table 8 is seen to contain larger standard deviation values than the similar table 6 for the initial condition. This indicates that R_A values of individual samples changed to different degrees from sign to sign.

The analyses of interaction effects for the reference data measured in 2003, refer to section 3.2, shed more light upon the above-mentioned matter. The variation is found between test sites, not between signs at the same test site. The analyses show that the R_A values of particular sheeting materials and colours deviate significantly between the test sites.

Additional analyses indicate that the deviations between test sites can be explained by differences in exposure between the test sites. The most light exposure is at the test site of Røros, where the R_A values of the materials are hardly affected after 6 years of exposure as compared to the initial conditions. The most heavy exposure, on the other hand, is at the test site of Ribe, where the R_A values of the materials are strongly affected, in most cases showing decreases. The R_A values of the materials at the other test sites are in between these extremes in such a way that they can be arranged in a sequence and even attributed 'equivalent numbers of years of exposure at Ribe'. Even the reference signs can be arranged this way.

For this reason, table 7 really describes the average conditions in the Nordic countries. These are best approached by the test site at Vanda, whose table of average R_A values for the test signs do actually match quite well to table 7.

Table 7: Geometric mean R_A values after exposure for test signs at the road ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F	G	H
1 (PM)	538	500	279	183	86,4	55,8		
2 (PM)	263	136		68,1	36,5	19,7		
3 (EG)	74,2	50,0	24,9					
4 (SEG)	105	64,8		39,5	20,7	7,1		
5 (EG)	45,8	36,2	29,9	8,1	10,5	4,7		
6 (HI)	200	165	86,9	50,1	33,0	15,7		
7								
8 (PM)	342	304	350	74,7	63,6	30,7	548	315
9 (EG)	86,5	61,0	47,7	17,3	14,6	4,3		
10 (SEG)	115	89,0	30,0	23,3	18,1	8,1		
11 (HI)	211	138	106	30,3	40,0	14,8		
12 (EG)	81,7	62,3		28,1	13,5	5,5		
13 (SEG)	115	79,2		28,0	23,4	6,2		
14 (HI)	188	133		39,0	25,6	13,3		
15 (PM)		383	174		115	55,5		

Table 8: Standard deviation of R_A values after exposure (%).

	A	B	C	D	E	F	G	H
1 (PM)	18,0	10,8	15,7	12,8	12,0	15,4		
2 (PM)	29,4	25,9		22,3	26,5	23,0		
3 (EG)	9,1	10,5	9,3					
4 (SEG)	10,9	13,5		9,3	16,3	15,3		
5 (EG)	18,5	9,3	6,5	15,6	8,5	19,2		
6 (HI)	3,7	4,5	17,3	7,1	5,9	7,4		
7								
8 (PM)	5,7	6,0	14,1	8,2	7,5	10,2	13,4	7,4
9 (EG)	8,9	10,5	5,9	12,7	9,0	19,1		
10 (SEG)	8,9	11,0	5,4	10,2	9,2	12,0		
11 (HI)	4,4	5,3	10,4	8,5	5,5	7,6		
12 (EG)	13,5	10,7		8,9	15,5	14,3		
13 (SEG)	5,9	11,2		6,8	8,5	16,7		
14 (HI)	7,2	8,2		13,7	9,6	12,7		
15 (PM)		30,7	36,7		28,8	44,4		

6. Retroreflectivity (R_A) of the individual materials

6.1 EG type materials

Tables 9 and 10 contain extracts of tables 5 and 7 for EG type materials, and table 11 shows the percentage losses of R_A values after exposure.

Table 9 for the initial condition shows increasing R_A values in the sequence from rows 3, 5, 9 and 12. In table 10 for the condition after exposure, this sequence is broken, because some materials show larger losses of R_A values than other materials, refer to table 11. The end result is that the R_A values are comparable for rows 3, 9 and 12 (Fasson 1500, Nikkalite 8100 and Kiwalite 2000), while R_A values are lower for row 5 (3M 3200) - in particular for white and red, but with the exception of blue.

Table 9: Initial R_A values for EG type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
3 : Fasson 1500	76,3	46,2	24,2			
5 : 3M 3200	86,3	47,8	29,6	18,9	11,9	8,2
9 : Nikkalite 8100	96,1	66,7	52,9	20,0	17,0	5,4
12: Kiwalite 2000	103	79,9		30,7	18,3	7,3

Table 10: R_A values after exposure for EG type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
3 : Fasson 1500	74,2	50,0	24,9			
5 : 3M 3200	45,8	36,2	29,9	8,1	10,5	4,7
9 : Nikkalite 8100	86,5	61,0	47,7	17,3	14,6	4,3
12: Kiwalite 2000	81,7	62,3		28,1	13,5	5,5

Table 11: Percentage loss of R_A values after exposure for EG type materials.

	A	B	C	D	E	F
3 : Fasson 1500	3%	-8%	-3%			
5 : 3M 3200	47%	24%	-1%	57%	12%	43%
9 : Nikkalite 8100	10%	9%	10%	14%	14%	20%
12: Kiwalite 2000	21%	22%		9%	26%	25%

6.2 SEG type materials

Tables 12 and 13 contain extracts of tables 5 and 7 for SEG type materials, and table 14 shows the percentage losses of R_A values after exposure.

The R_A values for the three SEG materials are roughly comparable both for the initial condition and for the condition after exposure. The values are higher than for EG type materials except for a couple of cases for orange and red.

The unusual feature is that the red Fasson 2500 material shows an increase after exposure (position 4D). The cause is probably paling of the red colour and is mentioned later in connection with chromaticity coordinates.

Table 12: Initial R_A values for SEG type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
4 : Fasson 2500	116	77,0		28,8	26,4	9,2
10: Nikkalite 18000	139	98,2	29,5	25,5	21,6	9,4
13: Kiwalite 12000	133	94,9		31,2	29,2	8,4

Table 13: R_A values after exposure for SEG type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
4 : Fasson 2500	105	64,8		39,5	20,7	7,1
10: Nikkalite 18000	115	89,0	30,0	23,3	18,1	8,1
13: Kiwalite 12000	115	79,2		28,0	23,4	6,2

Table 14: Percentage loss of R_A values after exposure for SEG type materials.

	A	B	C	D	E	F
4 : Fasson 2500	9%	16%		-37%	22%	23%
10: Nikkalite 18000	17%	9%	-2%	9%	16%	14%
13: Kiwalite 12000	14%	17%		10%	20%	26%

6.3 HI type materials

Tables 15 and 16 contain extracts of tables 5 and 7 for HI type materials, and table 17 shows the percentage losses of R_A values after exposure.

The R_A values for the three HI are roughly comparable both for the initial condition and for the condition after exposure. Some exceptions are, however, found for some of the colours, refer to the tables.

The R_A values are consistently higher than for EG and SEG type materials except for a couple of cases for red and green.

Table 15: Initial R_A values for HI type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
6 : 3M 3800	218	178	80,5	54,8	38,3	16,6
11: Nikkalite 800	224	126	86,5	28,6	43,9	15,3
14: Kiwalite 22000	204	139		38,2	28,2	14,7

Table 16: R_A values after exposure for HI type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
6 : 3M 3800	200	165	86,9	50,1	33,0	15,7
11: Nikkalite 800	211	138	106	30,3	40,0	14,8
14: Kiwalite 22000	188	133		39,0	25,6	13,3

Table 17: Percentage loss of R_A values after exposure for HI type materials.

	A	B	C	D	E	F
6 : 3M 3800	8%	7%	-8%	9%	14%	5%
11: Nikkalite 800	6%	-10%	-23%	-6%	9%	3%
14: Kiwalite 22000	8%	4%		-2%	9%	10%

6.4 PM type materials

Tables 18 and 19 contain extracts of tables 5 and 7 for PM type materials, and table 20 shows the percentage losses of R_A values after exposure.

The PM materials Stimsonite 6200 and 3M 3900 (rows 1 and 8) show moderate losses of R_A values, or small gains, after exposure. These materials thereby behave like most of the glass beaded materials. The material Reflexite (row 15) show large increases of R_A values for yellow and green.

The above-mentioned three materials have R_A values that are higher than for the other types of materials (EG, SEG and HI).

The material Stimsonite 4500 (row 2), on the other hand, show large losses of R_A values, except for red. The R_A values after exposure are comparable to those of HI materials.

An additional sample has a white material 3M 3970 with a dew resist overlay film in position 8G. The initial R_A value is 506 $cd \cdot lx^{-1} \cdot m^{-2}$, while the value after exposure is 548 $cd \cdot lx^{-1} \cdot m^{-2}$.

A further additional sample has a white material 3M 3990 with an 1150 protective overlay film in position 8H. The initial R_A value is 308 $cd \cdot lx^{-1} \cdot m^{-2}$, while the value after exposure is 315 $cd \cdot lx^{-1} \cdot m^{-2}$.

Table 18: Initial R_A values for PM type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
1 : Stimsonite 6200	628	503	240	175	77,8	61,0
2 : Stimsonite 4500	427	263		69,2	81,3	30,1
8 : 3M 3900	366	320	344	80,2	67,7	29,0
15: Reflexite		245	161		80,9	54,8

Table 19: R_A values after exposure for PM type materials ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
1 : Stimsonite 6200	538	500	279	183	86,4	55,8
2 : Stimsonite 4500	263	136		68,1	36,5	19,7
8 : 3M 3900	342	304	350	74,7	63,6	30,7
15: Reflexite		383	174		115	55,5

Table 20: Percentage loss of R_A values after exposure for PM type materials.

	A	B	C	D	E	F
1 : Stimsonite 6200	14%	1%	-16%	-5%	-11%	9%
2 : Stimsonite 4500	38%	48%		2%	55%	35%
8 : 3M 3900	7%	5%	-2%	7%	6%	-6%
15: Reflexite		-56%	-8%		-42%	-1%

6.5 Comparison to minimum requirements

EN 12899-1 supplies minimum R_A values for the initial condition for retro-reflective road signs with sheeting materials based on the glass bead technology of two classes Ref1 and Ref2. EG and SEG type materials belong to class Ref1, while HI type materials belong to class Ref2. For the particular measuring geometry used in this report, the minimum values are as indicated in table 21.

For warranty in a period that might be 5 years, or longer, some national road standards use minimum R_A values that are 80% of those provided in table 21. Such values are supplied in table 22.

Table 21: Minimum R_A values for the initial condition ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
EG and SEG	50	35	20	10	7	2
HI	180	120	65	25	21	14

Table 22: Typical minimum R_A values for warranty ($cd \cdot lx^{-1} \cdot m^{-2}$).

	A	B	C	D	E	F
EG and SEG	40	28	16	8	5,6	1,6
HI	144	96	52	20	16,8	11,2

The initial R_A values for EG, SEG and Hi type materials of table 5 all comply with the minimum R_A values for the initial condition of table 21.

The only remark is that a couple of the blue HI materials fail to meet the minimum requirement of 14 $cd \cdot lx^{-1} \cdot m^{-2}$ on some of the test signs; although the average values for all the test signs as given in table 5 do comply with the requirement. The materials are the Nikkalite 800 and the Kiwalite 22000 with average R_A values for the Danish test signs of respectively 13,9 and 12,4 $cd \cdot lx^{-1} \cdot m^{-2}$.

The R_A values after exposure for EG, SEG and Hi type materials of table 7 comply with the minimum R_A values for warranty of table 22.

The white EG material 3M 3200 fails to meet the minimum R_A value of 40 $cd \cdot lx^{-1} \cdot m^{-2}$ for the signs at the roads at the test sites of Frederiksborg, Ribe and Arendal. Average values for the test signs are respectively 38,0; 34,8 and 38,3 $cd \cdot lx^{-1} \cdot m^{-2}$.

A similar comparison cannot be carried out for PM type materials, as road signs with these materials are excluded from the scope of EN 12899-1. The PM type materials do meet the minimum requirements for HI type materials of tables 21 and 22.

7 Luminance factor and chromaticity (β and x, y coordinates)

7.1 The initial condition and the condition after exposure

A non-exposed test sign stored in darkness is used to represent the initial condition, while the signs at the roads at the test sites of Frederiksborg and Ribe after exposure are used to represent the condition after exposure.

7.2 Luminance factor values

Table 23 shows the luminance factor values for the non-exposed test sign, while table 24 shows the average luminance factor values of the signs at the test sites of Frederiksborg and Ribe after exposure.

EN 12899-1 provides minimum luminance factor values for the initial condition for retro-reflective road signs with glass beaded sheeting materials of two classes Ref1 and Ref2. EG and SEG type materials belong to class Ref1, while HI type materials belong to class Ref2. The minimum values are indicated in table 25.

A comparison of tables 23 and 25 shows that the EG, SEG and HI type materials in the initial condition comply with the minimum requirements in all cases. A comparison of tables 24 and 25 shows that this is true even after exposure. In most cases, differences between values of tables 23 and 24 are in fact small.

A similar comparison cannot be carried out for PM type materials, as road signs with these materials are excluded from the scope of EN 12899-1.

Table 23: Luminance factor values for a non-exposed test sign.

	A	B	C	D	E	F	G	H
1 (PM)	0,486	0,237	0,134	0,068	0,044	0,054		
2 (PM)	0,168	0,097		0,016	0,038	0,021		
3 (EG)	0,484	0,319	0,237					
4 (SEG)	0,469	0,340		0,100	0,074	0,034		
5 (EG)	0,426	0,359	0,253	0,077	0,054	0,024		
6 (HI)	0,312	0,214	0,161	0,038	0,065	0,028		
7								
8 (PM)	0,477	0,257	0,150	0,037	0,061	0,024	0,483	0,448
9 (EG)	0,487	0,327	0,200	0,100	0,054	0,023		
10 (SEG)	0,462	0,302	0,298	0,083	0,041	0,021		
11 (HI)	0,310	0,221	0,188	0,072	0,050	0,041		
12 (EG)	0,457	0,311		0,100	0,058	0,018		
13 (SEG)	0,456	0,318		0,091	0,045	0,016		
14 (HI)	0,283	0,191		0,069	0,065	0,038		
15 (PM)		0,203	0,089		0,040	0,024		

Table 24: Average luminance factor values for signs at Frederiksborg and Ribe after exposure.

	A	B	C	D	E	F	G	H
1 (PM)	0,496	0,324	0,156	0,065	0,060	0,061		
2 (PM)	0,191	0,118		0,027	0,047	0,036		
3 (EG)	0,469	0,354	0,228					
4 (SEG)	0,458	0,369		0,105	0,079	0,039		
5 (EG)	0,419	0,350	0,220	0,072	0,062	0,030		
6 (HI)	0,322	0,220	0,188	0,038	0,072	0,038		
7								
8 (PM)	0,509	0,280	0,179	0,035	0,070	0,035	0,504	0,464
9 (EG)	0,451	0,323	0,191	0,081	0,056	0,028		
10 (SEG)	0,441	0,301	0,175	0,074	0,045	0,028		
11 (HI)	0,310	0,237	0,199	0,067	0,059	0,047		
12 (EG)	0,426	0,307		0,083	0,061	0,025		
13 (SEG)	0,426	0,327		0,086	0,054	0,023		
14 (HI)	0,296	0,210		0,066	0,072	0,044		
15 (PM)		0,207	0,085		0,048	0,033		

Table 25: Minimum luminance factor values for new retro-reflective sheeting materials.

	A	B	C	D	E	F
EG and SEG	0,35	0,27	0,17	0,05	0,04	0,01
HI	0,27	0,16	0,14	0,03	0,03	0,01

7.3 Chromaticity

Table 26 shows the chromaticity co-ordinates x and y for the non-exposed test sign, while table 27 shows the average chromaticity coordinates of the signs at the test sites of Frederiksborg and Ribe after exposure.

EN 12899-1 provides colour boxes for retro-reflective road signs with glass beaded sheeting materials of two classes Ref1 and Ref2. EG and SEG type materials belong to class Ref1, while HI type materials belong to class Ref2. The colour boxes are provided for classes R1 and R2 that are applicable for respectively signs in use and new signs.

The chromaticity points according to table 26 for the initial condition are shown for EG, SEG and HI type materials together with the relevant colour boxes for class R1 (signs in use) in figures 11, 13 and 15 respectively. The points according to table 27 after exposure are shown for these materials in figures 12, 14 and 16 respectively.

Figures 11 and 12 for EG type materials show that the points do not shift much from the initial condition to the condition after exposure. It is concluded that the chromaticity is correct in all cases, even if the point for the colour orange for the EG material 3M 3200 seems to be out of the corresponding box for the initial condition.

Figures 13 and 14 for SEG materials lead to similar conclusions as mentioned above for EG materials. It may be that the point for the red Fasson material is out of the box for the condition after exposure. This material has an increase in the R_A value from the initial condition to the condition after exposure, which is consistent with a paling of the colour (refer to table 15).

Figures 15 and 16 for HI type materials again lead to similar conclusions, with the exception that the points for orange Nikkalite 800 and Kiwalite 22000 clearly move out the box after exposure.

It is reasonable, but not exactly correct, to compare the chromaticity points for PM type materials to the colour boxes for HI type materials, as EN 12899-1 does exclude road signs with PM type materials from the scope. Additionally, the 45°/0° test geometry used to measure the luminance factor and the chromaticity co-ordinates poses a problem for PM type materials, although it is being used. The problem is that the results of measurements depend on details of the measuring geometry, as 'sparkles' may or may not be activated. Just a rotation of the instrument, which does not violate the requirements for the geometry, can change results significantly and cause chromaticity points to move in or out of the respective boxes.

Nevertheless, the chromaticity points according to tables 26 and 27 are shown in figures 17 and 18 respectively.

Some of the points do lie outside of the respective boxes. For the white PM materials, this may be due to the above-mentioned sparkles. It is less likely that sparkles induce the points for green Stimsonite 6200 and Reflexite materials to be outside of the box. The points for red Stimsonite 6200 and 4500 materials move outside of the box after exposure; probably due to paling.

The Reflexite samples on the signs at Reykjavik show delamination between the coloured surface film and the underlying retroreflecting film, causing discolouration and grey areas, where the surface film is lost.

Table 26: Chromaticity co-ordinates x and y for a non-exposed test sign.

		A	B	C	D	E	F	G	H
1 (PM)	x	0,3084	0,5223	0,6035	0,5987	0,1892	0,1369		
	y	0,3315	0,4613	0,3839	0,3097	0,5069	0,1272		
2 (PM)	x	0,2812	0,5058		0,6459	0,1457	0,1508		
	y	0,3194	0,4768		0,3142	0,3717	0,1000		
3 (EG)	x	0,3076	0,4997	0,5381					
	y	0,3285	0,4728	0,3982					
4 (SEG)	x	0,3103	0,4927		0,6210	0,1375	0,1326		
	y	0,3331	0,4759		0,3427	0,4178	0,1199		
5 (EG)	x	0,3122	0,5056	0,5093	0,6372	0,1334	0,1381		
	y	0,3359	0,4721	0,3854	0,3350	0,4055	0,1042		
6 (HI)	x	0,3065	0,4318	0,5171	0,6456	0,1369	0,1422		
	y	0,3286	0,3984	0,3829	0,3209	0,4111	0,1271		
7									
8 (PM)	x	0,3081	0,5161	0,5891	0,6474	0,1252	0,1421	0,3110	0,3125
	y	0,3632	0,4738	0,3965	0,3122	0,4353	0,1218	0,3428	0,3637
9 (EG)	x	0,3087	0,5074	0,5779	0,5850	0,1234	0,1448		
	y	0,3308	0,4740	0,3962	0,3240	0,4371	0,1120		
10 (SEG)	x	0,3089	0,5091	0,5079	0,6176	0,1205	0,1416		
	y	0,3317	0,4739	0,3791	0,3249	0,4166	0,1066		
11 (HI)	x	0,3052	0,4750	0,4990	0,5758	0,1417	0,1483		
	y	0,3254	0,4719	0,3898	0,3302	0,4024	0,1323		
12 (EG)	x	0,3112	0,5064		0,5960	0,1262	0,1490		
	y	0,3346	0,4809		0,3314	0,4049	0,1129		
13 (SEG)	x	0,3119	0,5090		0,6113	0,1387	0,1504		
	y	0,3350	0,4789		0,3328	0,4356	0,1084		
14 (HI)	x	0,3054	0,4973		0,5701	0,1547	0,1451		
	y	0,3262	0,4716		0,3215	0,3908	0,1317		
15 (PM)	x		0,4740	0,5516		0,1296	0,1484		
	y		0,4892	0,4131		0,3471	0,1310		

Table 27: Average chromaticity co-ordinates x and y after 5 years of exposure.

		A	B	C	D	E	F	G	H
1 (PM)	x	0,3110	0,5072	0,5686	0,5698	0,2043	0,1444		
	y	0,3292	0,4711	0,3917	0,3162	0,4643	0,1390		
2 (PM)	x	0,2977	0,4844		0,5751	0,1682	0,1598		
	y	0,3232	0,4755		0,3218	0,3743	0,1306		
3 (EG)	x	0,3068	0,4852	0,5457					
	y	0,3286	0,4755	0,3988					
4 (SEG)	x	0,3134	0,4736		0,5689	0,1583	0,1414		
	y	0,3358	0,4795		0,3495	0,4113	0,1328		
5 (EG)	x	0,3149	0,4982	0,5301	0,6173	0,1510	0,1476		
	y	0,3371	0,4730	0,3940	0,3315	0,4036	0,1178		
6 (HI)	x	0,3072	0,4360	0,4732	0,6045	0,1486	0,1508		
	y	0,3296	0,4037	0,3805	0,3175	0,4079	0,1405		
7									
8 (PM)	x	0,3061	0,5114	0,5728	0,6120	0,1428	0,1534	0,3129	0,3099
	y	0,3431	0,4718	0,4057	0,3123	0,4130	0,1335	0,3445	0,3467
9 (EG)	x	0,3123	0,4956	0,5625	0,6088	0,1419	0,1540		
	y	0,3330	0,4764	0,3927	0,3293	0,4247	0,1292		
10 (SEG)	x	0,3128	0,4978	0,5521	0,6045	0,1436	0,1523		
	y	0,3345	0,4750	0,3766	0,3283	0,4104	0,1301		
11 (HI)	x	0,3051	0,4542	0,4738	0,5685	0,1552	0,1498		
	y	0,3266	0,4795	0,4014	0,3301	0,3998	0,1426		
12 (EG)	x	0,3153	0,4994		0,6128	0,1484	0,1630		
	y	0,3395	0,4792		0,3341	0,4010	0,1375		
13 (SEG)	x	0,3166	0,5014		0,6111	0,1558	0,1625		
	y	0,3406	0,4776		0,3353	0,4134	0,1354		
14 (HI)	x	0,3048	0,4894		0,5905	0,1581	0,1502		
	y	0,3260	0,4748		0,3288	0,3926	0,1422		
15 (PM)	x		0,4622	0,5185		0,1521	0,1588		
	y		0,4823	0,4149		0,3494	0,1411		

Figure 11: Chromaticity of non-exposed EG type materials.

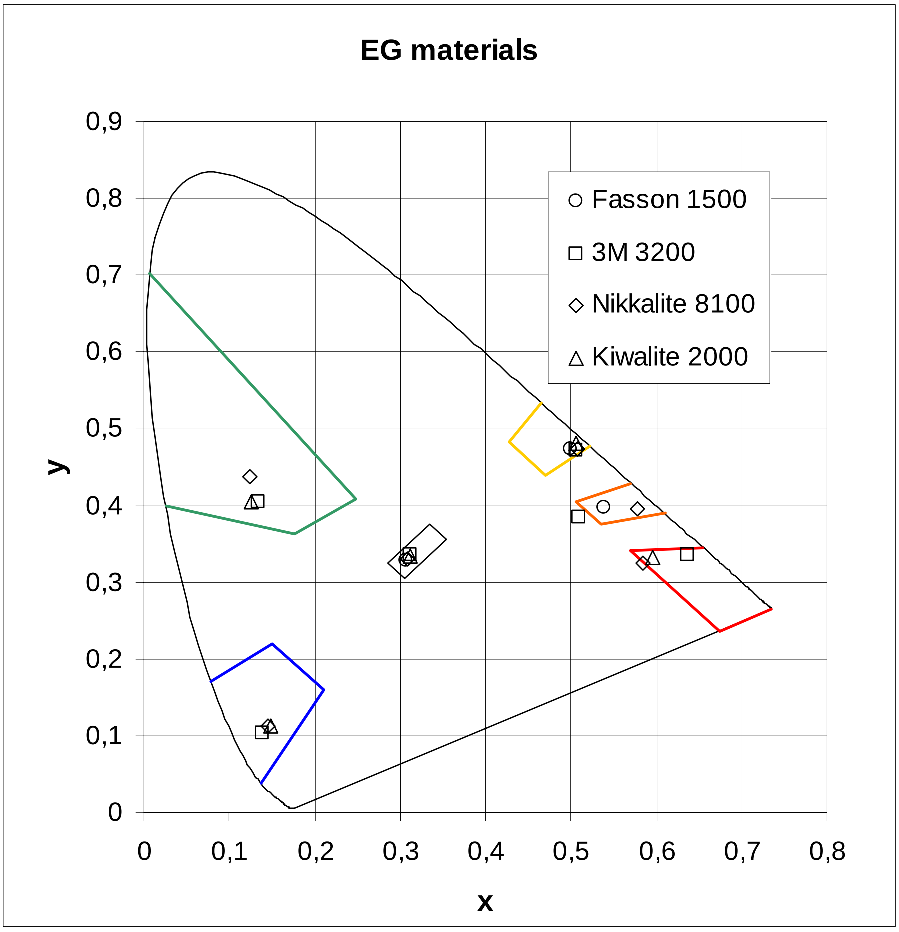


Figure 12: Chromaticity of EG type materials after exposure.

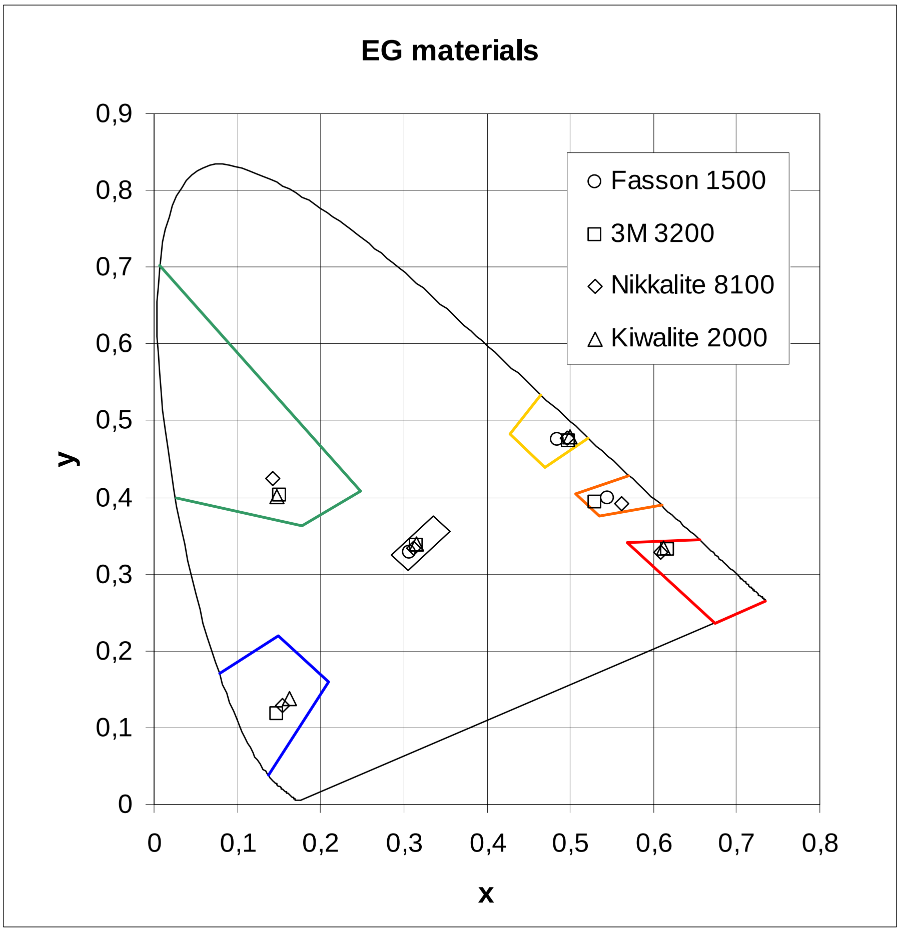


Figure 13: Chromaticity of non-exposed SEG type materials.

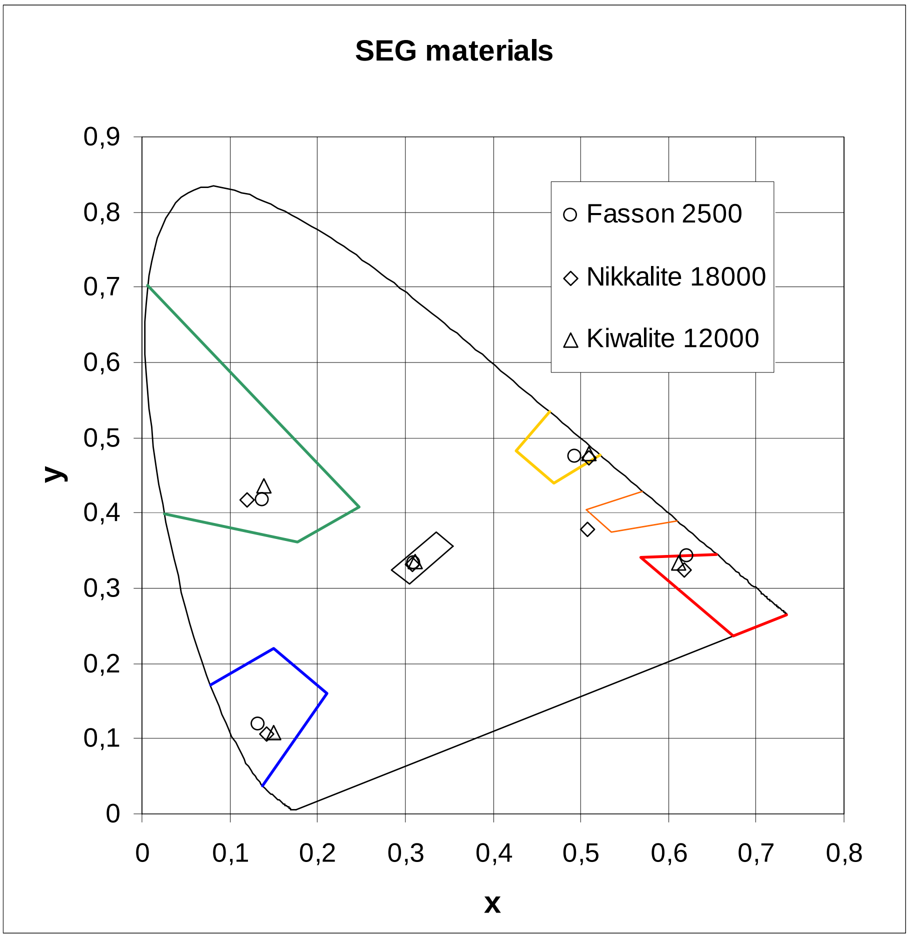


Figure 14: Chromaticity of SEG type materials after exposure.

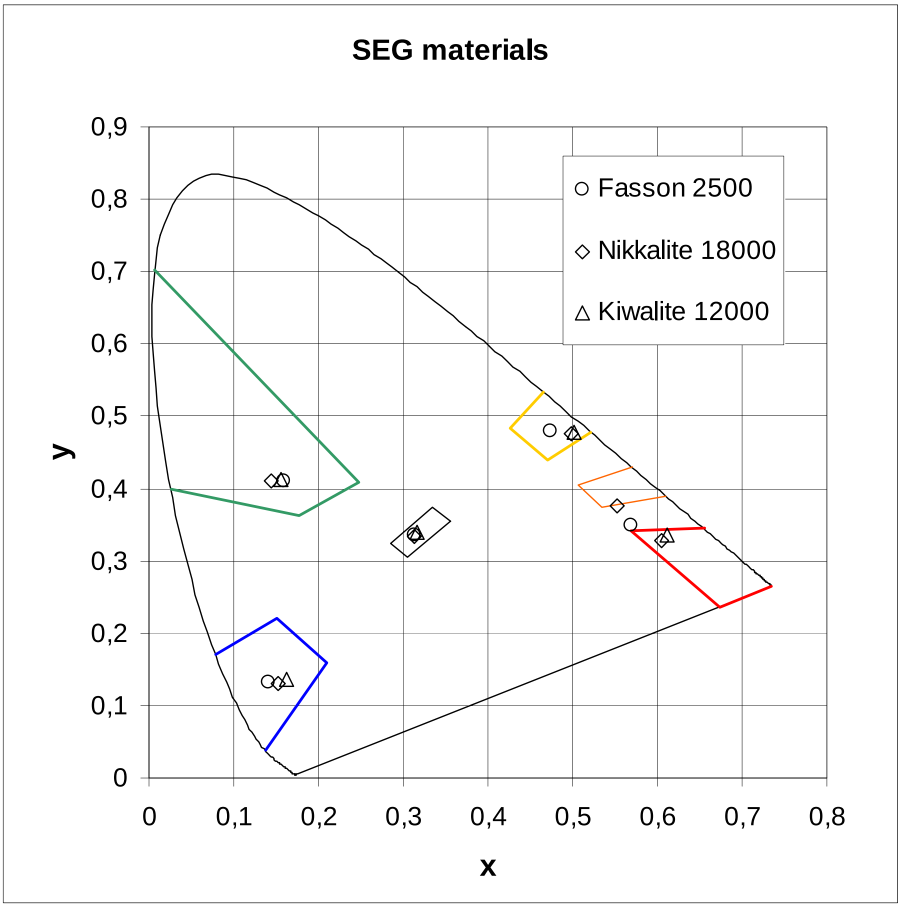


Figure 15: Chromaticity of non-exposed HI type materials.

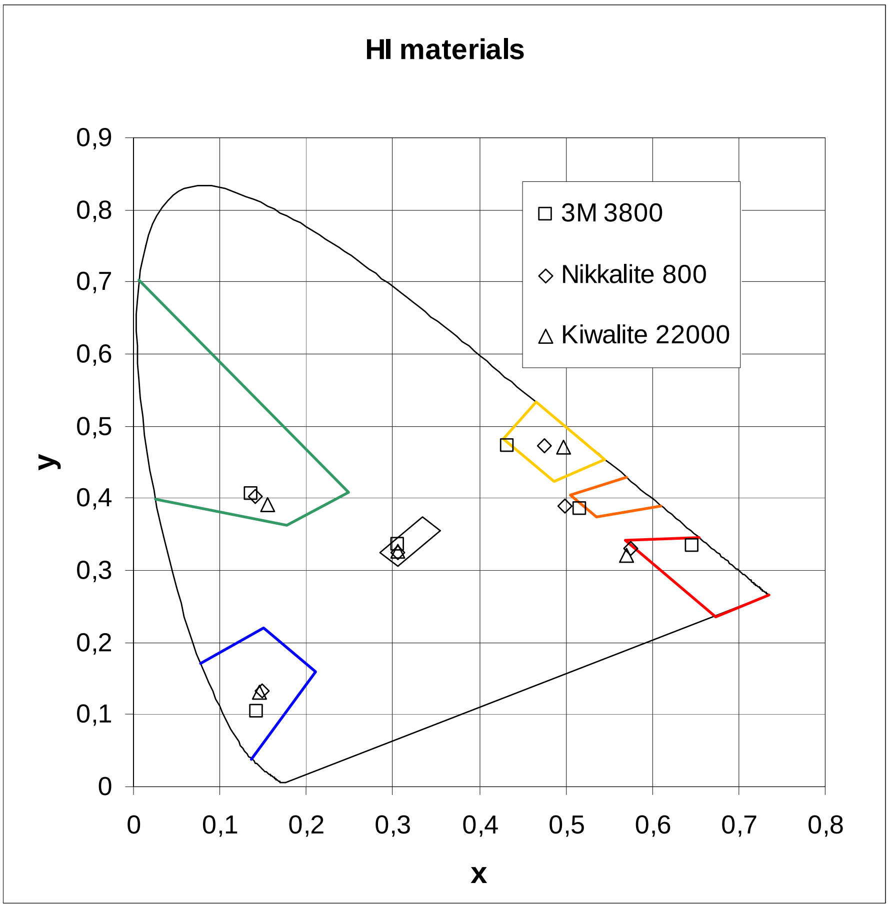
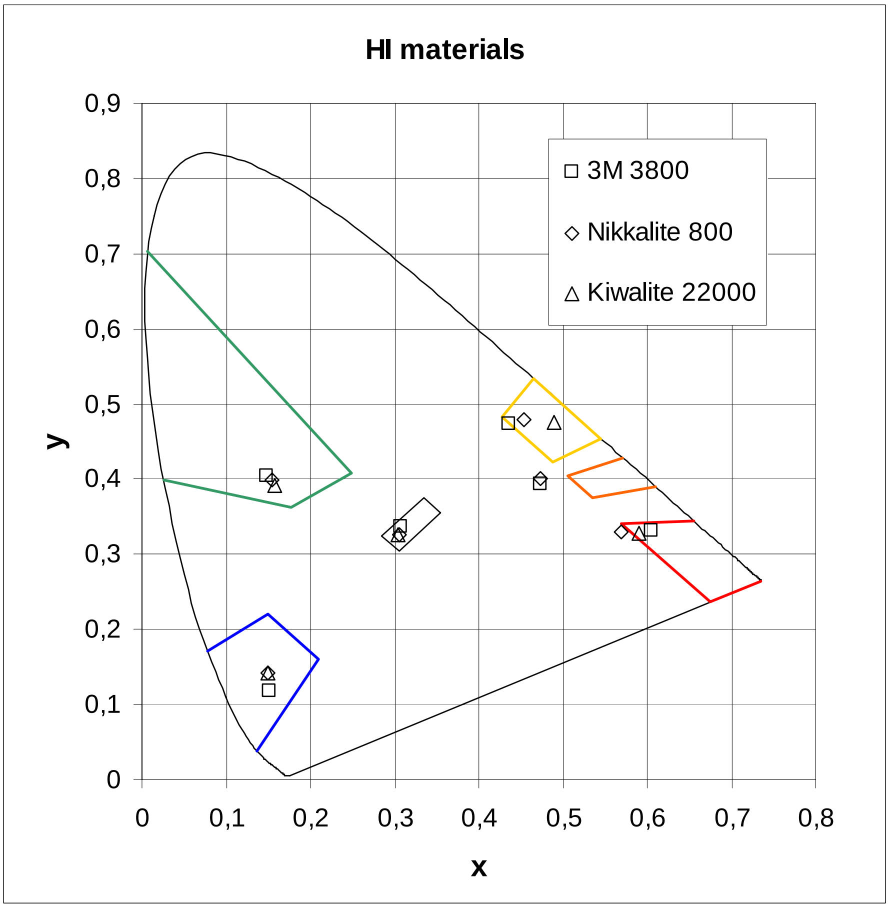


Figure 16: Chromaticity of HI type materials after exposure.



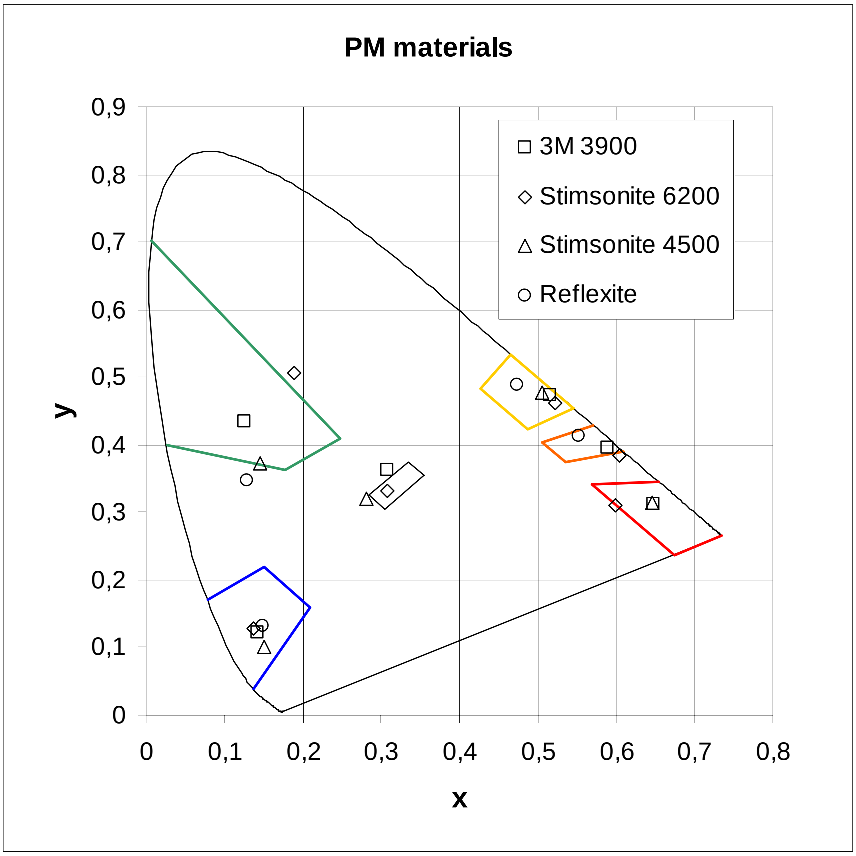


Figure 17: Chromaticity of non-exposed PM type materials.

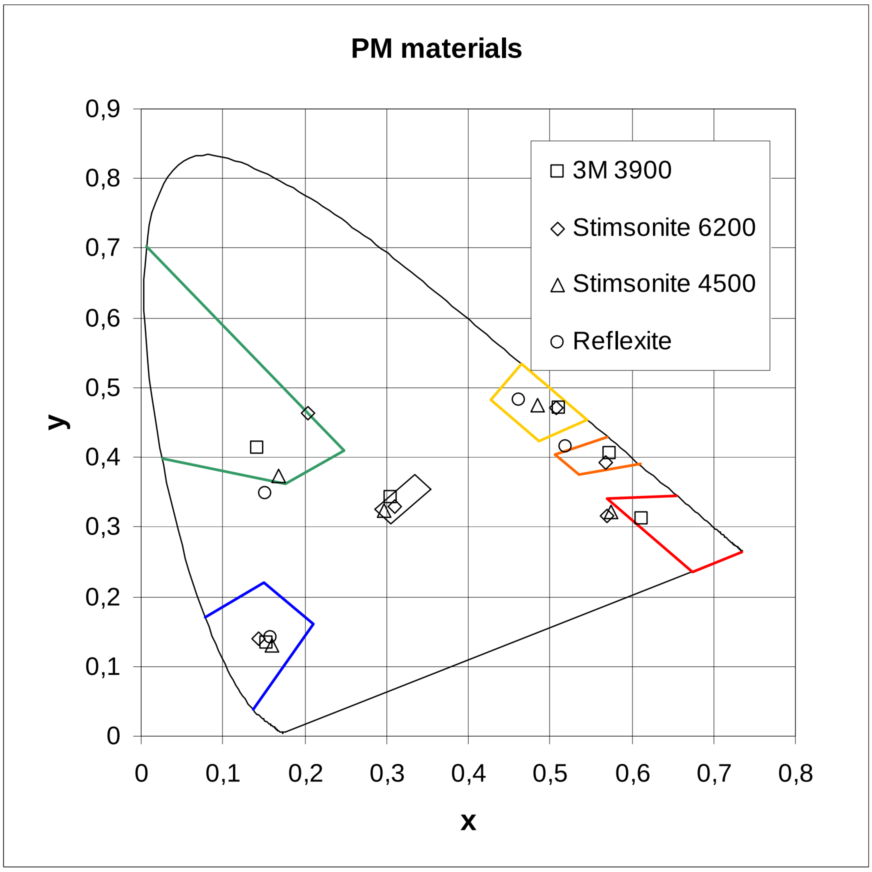


Figure 18: Chromaticity of PM type materials after exposure.

8 Conclusions

8.1 Conclusions regarding retroreflectivity (R_A)

Some results of the analyses for the reference data from 2003, refer to section 3.2, are as follows:

- exposure to climate does lead to changes of the R_A values, a decrease in most cases (reference signs)
- simultaneous exposure to the road environment and climate does lead to additional changes, a larger decrease in most cases (test signs at the roads)
- the changes of R_A values depend on the test site location
- there is no effect of the orientation north/south of the test signs (all test sites except the test site on Iceland) and no effect of the orientation east/west (the test site on Iceland).

To the results may be added that there is no effect of the two rotations of the test signs, upright or upside down.

For the initial condition, the geometrical mean R_A value is 60,5 $cd \cdot lx^{-1} \cdot m^{-2}$ (including test signs and reference signs). For the condition after 5 years of exposure, the geometrical mean R_A value is 57,8 $cd \cdot lx^{-1} \cdot m^{-2}$ for the reference signs and 57,8 $cd \cdot lx^{-1} \cdot m^{-2}$ for the test signs placed at roads.

This implies that the load of climate alone, as pertinent for the reference signs, caused an average loss of 4,5%. The load of traffic and climate, as pertinent for the test signs, caused an average loss of R_A value of 10,6%.

However, underneath those average figures, there is a strong dependence on the actual materials, their colours and the test site. This is illustrated by small losses of R_A values for some cases, or even gains, and losses of up to approximately 60% for other cases.

To these conclusions can be added that the position nearby a coast does not seem to have a clear detrimental effect, compare for instance the results for the test sites at Ribe and Frederiksborg, and for the test sites at Gamleby and Linköping - in both cases near and far from a coast.

The R_A values of EG, SEG and HI type materials are roughly comparable with each other within each type of material, and compare roughly as expected between the types with increasing R_A values in the above-mentioned sequence.

The outstanding exception is the EG type 3M 3200, which shows substantial losses of R_A values with exposure for most of the colours, in particular white and red, for which they end up with much lower R_A values than the other EG materials.

Two PM materials show large changes of R_A values with exposure. The two other PM materials show changes along the same lines as the glass beaded materials. The 3M 3970 with dew resist overlay film shows an increase of R_A values.

In the initial condition, the R_A values of glass beaded materials comply with minimum requirements of EN 12899-1 for new road signs, with the exception of small deviations for a couple of blue materials at some test sites.

After exposure, the R_A values of glass beaded materials comply with the 80% of the above-mentioned minimum requirements, that are often used for warranty purposes after 5 years. The exception is the EG type 3M 3200, which fails for white and red at some of the test sites.

The poor performance of the 3M 3200 is regrettable as this is the sheeting type that is used the most for road signs in some on the Nordic countries.

A comparison to minimum requirements cannot be carried out for PM materials, that are excluded from the scope of EN 12899-1.

8.2 Conclusions regarding luminance factor and chromaticity (β and x, y coordinates)

Measurements of the luminance factor and chromaticity were added to the measuring program first at the Danish test sites at Frederiksborg and Ribe in the year 2000, and later at other test sites, but carried out most systematically at the Danish test sites.

A non-exposed test sign stored in darkness is used to represent the initial condition, while the test signs at the Danish test sites are used to represent the condition after exposure.

Both in the initial condition and after exposure, the luminance factor values of glass beaded materials comply with minimum requirements of EN 12899-1 for road signs in use. The comparison cannot be carried out for PM materials, that are excluded from the scope of EN 12899-1.

For the glass beaded materials, the chromaticity does not change much from the initial condition to the condition after exposure. Observed changes might in most cases be due to measuring uncertainty.

The chromaticity points lie within relevant colour boxes of EN 12899-1 for road signs in use for all materials in the initial condition, but move out of these in a few cases after exposure. One of the cases is the red Fasson 2500, probably due to paling as the R_A value increases after exposure. Two other cases are the orange Nikkalite 800 and Kiwalite 22000.

For the microprismatic materials, the chromaticity does not change much from the initial condition to the condition after exposure either. The chromaticity points are compared to the colour boxes of HI materials of EN 12899-1, although this is not exactly correct as EN 12899-1 excludes road signs with PM materials from the scope.

Some of the points do lie outside of the respective boxes. For the white PM materials, this may be due to the 'sparkle' that is particular to PM materials for the 45°/0° test geometry. It is less likely that 'sparkle' induce the points for green Stimsonite 6200 and Reflexite to be outside of the box. The points for the red materials Stimsonite 6200 and 4500 move outside of the box after exposure; probably due to paling.

8.3 Overall conclusions

Most of the products show good durability in the weather and climate conditions of the Nordic countries, and are likely to show moderate change in performance during the normal lifetime of a road sign.

A requirement for retroreflection of 80% of the initial minimum value, as often used for warranty purposes after 5 years, is unsatisfactory as a material that looses 60% of the retroreflection in some cases (EG type 3M 3200) may sometimes qualify, even when products that show little loss are available.

The interaction between material, colour and test site of the R_A values after 5 year exposure should at first glance be assumed to mean that one test site cannot represent another test site.

In a wider sense, the conclusion would be that one test site does not provide results that are representative for all of the area of the Nordic countries.

However, the underlying reason for the above-mentioned interaction may be that the loads of exposure are different at the different test sites. Consider for instance the 3M 3200 and 3800 materials of the colour white. At Røros, where the load is obviously light, none of these materials loose much R_A value. At another test site, where the load is more heavy, it shows up that the first material is more sensitive to the load than the second. At for instance Ribe, the first material looses more than 50% of the initial R_A value, while the second looses only approximately 15%.

Therefore, the balance between two materials may turn up differently at two test sites, and this may be what causes the above-mentioned interaction.

If this is the case, one test site can in fact provide results that are representative for all of the area of the Nordic countries. But this is to be understood in the way that a short exposure (say 1 year) is representative for a location with a light load from climate and traffic (for instance Røros), while a longer exposure (say 5 years) is representative for a location with a heavy load (for instance Ribe).

Assuming that the load at a particular test site is reflected by the geometrical mean of the R_A values of the test signs at the test site, then the load is rather heavy at Frederiksborg, Ribe, Arendal and Linköping, less heavy at Vanda, Rovaniemi, Reykjavik and Gamleby, and light at Røros. The key factors may be the latitude and some measure of abrasion.