Measuring methods for the daylight properties of microprismatic sheeting materials

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Summary and conclusions

The 45°/0° geometry, as widely used for the measurement of the daylight properties of ordinary materials, is introduced in section 1. This geometry is also used for the glass beaded retroreflective sheeting materials, and without any particular problems, refer to section 2.

However, microprismatic sheeting materials possess a type of reflection, called 'sparkle', which causes problems in the use of the 45°/0° geometry for these materials - the geometry may or may not activate sparkle so that the details of the geometry can affect the resulting daylight properties of particular materials. Refer to section 3.

It is discussed how the 45°/0° geometry can be redefined, so as to avoid problems in the use for microprismatic sheeting materials. It is concluded, however, that it is better to replace the 45°/0° geometry with the diffuse/0° geometry, and preferably to define the diffuse/0° geometry so that results are approximately the same for glass beaded sheeting materials. Refer to section 4.

Results of measurements with the diffuse/0° geometry are provided in section 5. There is some indication that the measuring gate should have been larger so as to avoid contribution from surface reflection and retroreflection. The gate was 150 mm diameter in a 500 mm diameter photometric sphere, and should probably be increased to 200 mm. However, the results for the two geometries are similar for two glass beaded sheeting materials, while the diffuse/0° geometry certainly leads to sound results for microprismatic sheeting materials.

1. Measurement of daylight properties of ordinary materials

The daylight properties of ordinary materials is expressed by the luminance factor Y (or β) and the chromaticity co-ordinates (x, y) as measured in D65 illumination. Measurements and specifications are conventionally based on the 45°/0° geometry, implying that illumination is at 45° to the surface and that measurement is at 0° viewing angle, i.e. perpendicular to the surface. Refer to figure 1.

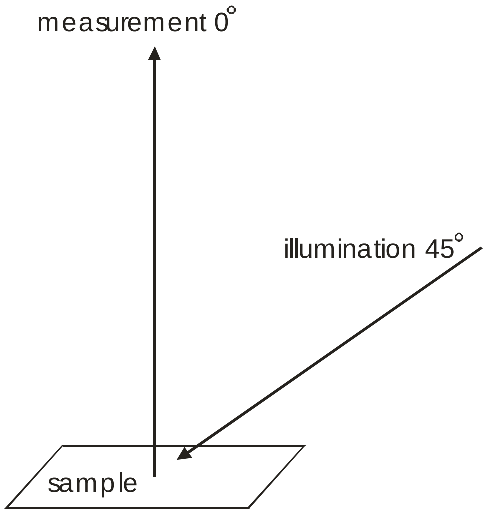
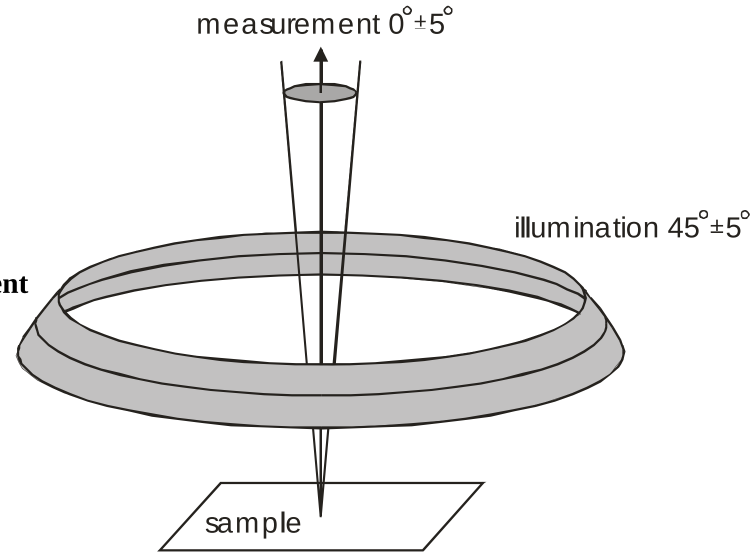


Figure 1: The 45°/0° measuring geometry.

Many ordinary material have some shininess due to surface reflection, which is often broadened by scattering in texture of the surfaces. However, due to the wide separation of 45° of the angles of illumination and measurement, the surface reflection does mostly not contribute to the results of the measurements, so that only the component of light that has penetrated through the surface - to become reflected in the material itself - contributes.

This component of light is often scattered to the extent of becoming approximately diffuse. Because of this, the actual details of the geometrical arrangement do not influence the results of the measurement to any important degree and, therefore, the specifications for the 45°/0° geometry are liberal in order to allow for different instrumentation. The illumination must have its centre at 45°, but the beam can be fairly wide, up to ±5°, and it can occupy the whole circumference. Measurement can also be in a beam of a width up to ±5°. Refer to figure 2.

Figure 2: Angles allowed for illumination and measurement in the 45°/0° measuring geometry.



For range measurements in laboratory conditions, it is natural to illuminate a sample from a single light source at a distance from the sample, and to do measurement with a colorimeter at a distance from the sample as well. This corresponds to illumination and measurement in fairly narrow beams, such as illustrated in figure 1.

Some specialized equipment reproduces range measurement in a more compact geometry, so that beams are broader, but still pretty narrow. A Hunter D25 45°/0° instrument has this arrangement, although is uses 2 lamps opposite to each other on the 45° circumference.

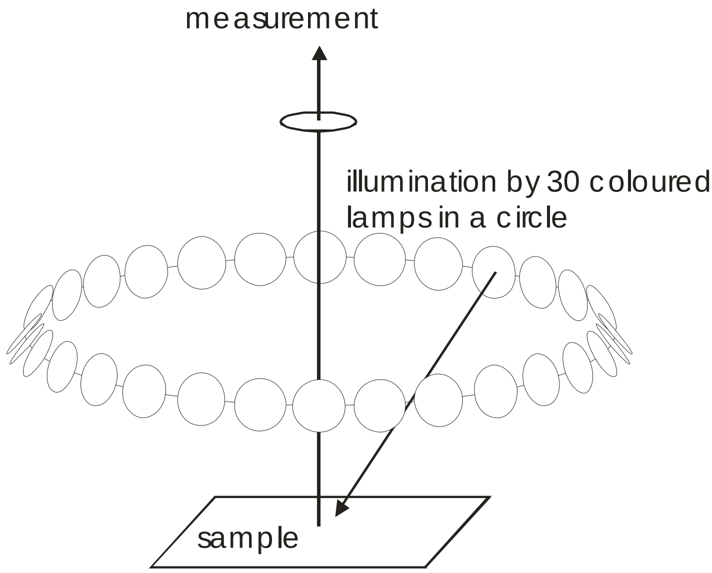
Other instruments use a larger number of lamps on the 45° circumference in order to establish an approximation to rotational symmetry. Such illumination may be called 'circumferential'.

The LabScan 6000 instrument is an example of this having 16 sensors (this instrument uses the 0°/45° geometry instead of the 45°/0° geometry - the two are considered to be equivalent).

Another example is the Gardner 45°/0° Color-guide, which has 30 lamps as shown in figure 3. These lamps actually have a number of different colours and therefore present a less good approximation to rotational symmetry than the number of lamps would indicate. Both the illumination beams and the measurement beam seem to have the full width of ±5°.

Some instruments have illumination from the complete circumference, which may be called 'annular' and may be assumed to provide the best approximation to rotational symmetry. An example is the BFC450 45°/0° instrument.

Figure 3: A particular portable equipment uses 30 coloured lamps in a circle at 45°.



2. Use of the 45°/0° measuring geometry for glass beaded sheeting materials

Glass beaded retroreflective sheeting materials (of the types enclosed or encapsulated lens) show an additional component of reflected light, namely the component of retroreflected light. This component is not included in measurements by the 45°/0° geometry as retroreflection makes itself felt only, when directions of illumination and measurement are separated by angles up to a few degrees only.

Apart from the retroreflected component, which is not included in the measurement in the 45°/0° geometry, glass beaded sheeting materials behave much like ordinary materials. There may be some surface texture, but not enough to let the surface reflection contribute, and the scattering of light is strong and without particular features so as to provide approximate diffusion.

> NOTE: The mechanisms of scattering of light in glass beaded sheeting materials are not the same as for ordinary materials, and may be of some complexity, but result nevertheless in a similar large scattering/diffusion.

Therefore, the 45°/0° geometry has been applied for glass beaded sheeting materials for many years without particular problems, and has become the conventional geometry for the measurement of the daylight properties of these materials.

For instance the Gardner 45°/0° Color-guide illustrated in figure 3 works well for glass beaded sheeting materials. In order to demonstrate this, measurements have been made for one glass beaded sheeting material of each of the two technologies used for glass beaded sheeting materials. The two technologies are respectively enclosed lens and encapsulated lens, here represented by white samples of respectively 3M Engineering Grade and 3M High Intensity.

Measurements were done with the Gardner 45°/0° Color-guide in rotations of 0°, 30°, 60° ... 360° with respect to the datum axes of the two samples. The results are presented in figures 4 and 5 in terms of the luminance factor Y and the chromaticity expressed by $z = 1-x-y$ and $y-x$ instead of the chromaticity co-ordinates x and y directly. This has the advantage that the colour box for white in EN 12899-1 can be declared by the conditions 0≤z≤0,04 and 0,29≤y-x≤0,39, so that compliance with the colour box can be verified directly in figures 4 and 5.

The figures 4 and 5 show that the luminance factor does not vary significantly with the rotation angle. The same applies for the chromaticity, which stays solidly within the colour box.

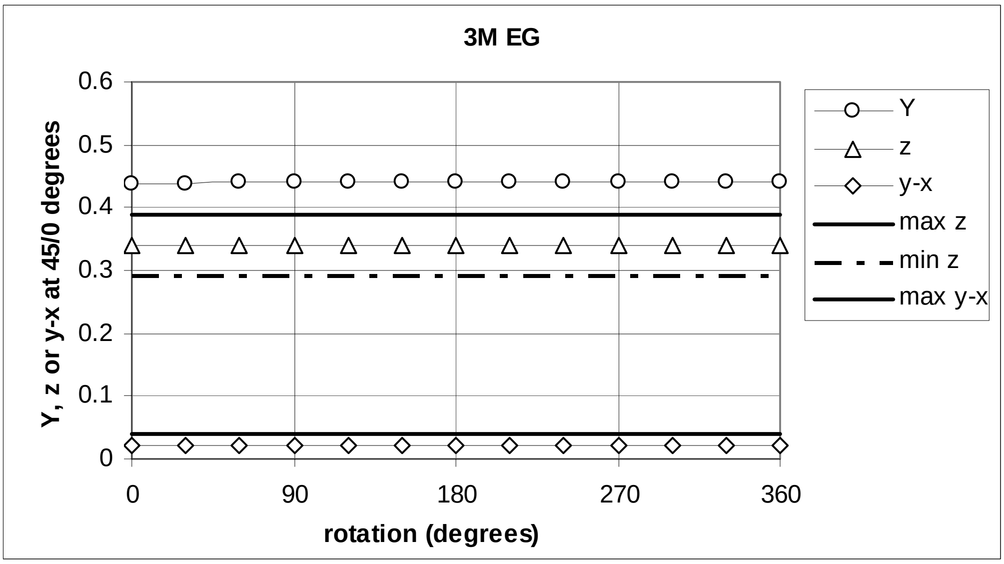


Figure 4: Luminance factor Y and chromaticity expressed by z and y-x of an enclosed lens material measured with a Gardner 45°/0° Color-guide in different rotations.

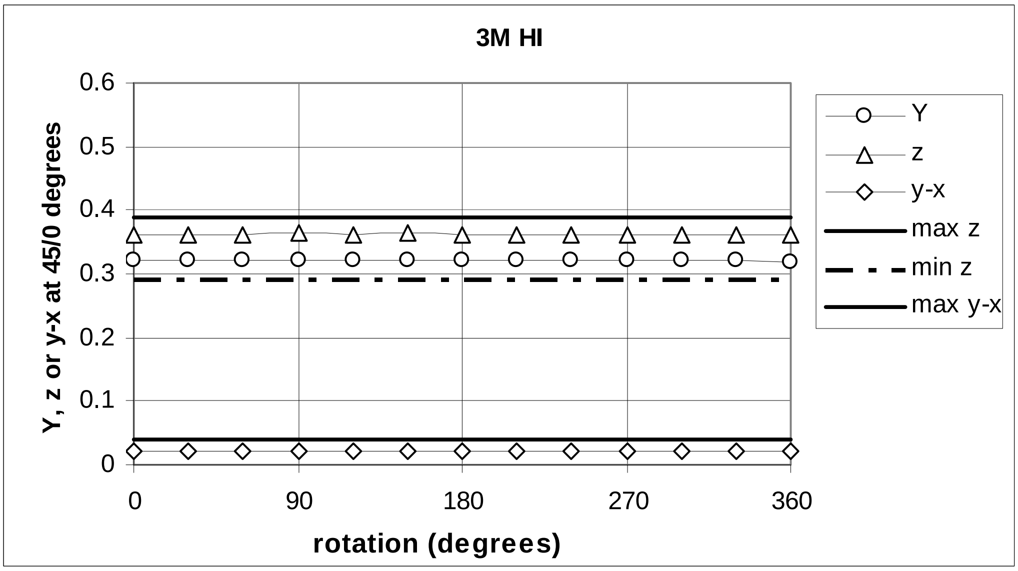


Figure 5: Luminance factor Y and chromaticity expressed by z and y-x of an encapsulated lens material measured with a Gardner 45°/0° Color-guide in different rotations.

3. Use of the 45°/0° measuring geometry for microprismatic sheeting materials

Microprismatic sheeting materials - at least the existing types - show the same types of reflection as glass beaded sheeting materials, but also some additional types of reflection that are created by complex paths of light within the prism layer.

The paths involve several total internal reflections in prism surfaces or in the backside of the surface of the prism layer.

Some paths involve only such total internal reflections and lead to reflection in the same direction as for mirror reflection. These paths act to give an apparent increase of the surface reflection, which in total can become quite high (for instance 15% for a white sheeting material) depending on the particular sheeting material and the direction of incident light. It is to be noted, however, that this component of reflected light has the colour of the sheeting material, while the light reflected in the surface is without colour.

Some paths involve also a transmission from one prism to a neighbour prism, this producing a colour effect - like in a Newton prism - that may be termed 'sparkle'. The conditions for sparkle depend on the particular sheeting material and the direction of incident light.

The above-mentioned kind of mirror reflection does not add to measurements in the 45°/0° geometry. However, sparkle may add, because existing microprismatic sheeting materials have their most powerful sparkle in some illumination directions at or about 45°, when observed at 0°.

In laboratory range measurements with narrow beams, it is likely that sparkle is not activated. If sparkle is activated, on the other hand, results of measurements are strongly affected. For a white sheeting material, the luminance factor value may become high and the chromaticity may be changed to show almost any colour of the rainbow.

If measurements are made with specialized equipment using wider beams, in some cases with circumferential or annular illumination, it is likely that sparkle is activated, but the effect is less, because the sparkle is mixed with a larger component of light reflected in normal ways.

The effect has been tested for the Gardner 45°/0° Color-guide for four white microprismatic sheeting materials in the same way as for glass beaded sheeting materials as discussed in the previous section.

The results, which are shown in figures 6, 7, 8 and 9, show significant variation with the rotation angle, both for the luminance factor and for the chromaticity. The chromaticities of two 3M materials are clearly outside of the colour box for white at some rotations. The chromaticity of the Nippon Carbide material varies significantly, but may perhaps stay just inside the colour box at all rotations. The variations are less for the Avery Dennison material.

The variations shown in figures 6, 7, 8 and 9 occur, because the Gardner 45°/0° Color-guide has a relatively poor approximation to rotational symmetry. The variations are not, on the other hand, excessive, because the instrument uses wide beams. Other instruments would show smaller or larger variations depending on the arrangment of lamps and on the beam widths. Refer to the introduction od some instruments in section 2.

The variations show that the 45°/0° measuring geometry is not suitable for microprismatic sheeting materials, at least not directly. The matter is discussed further in the next section.

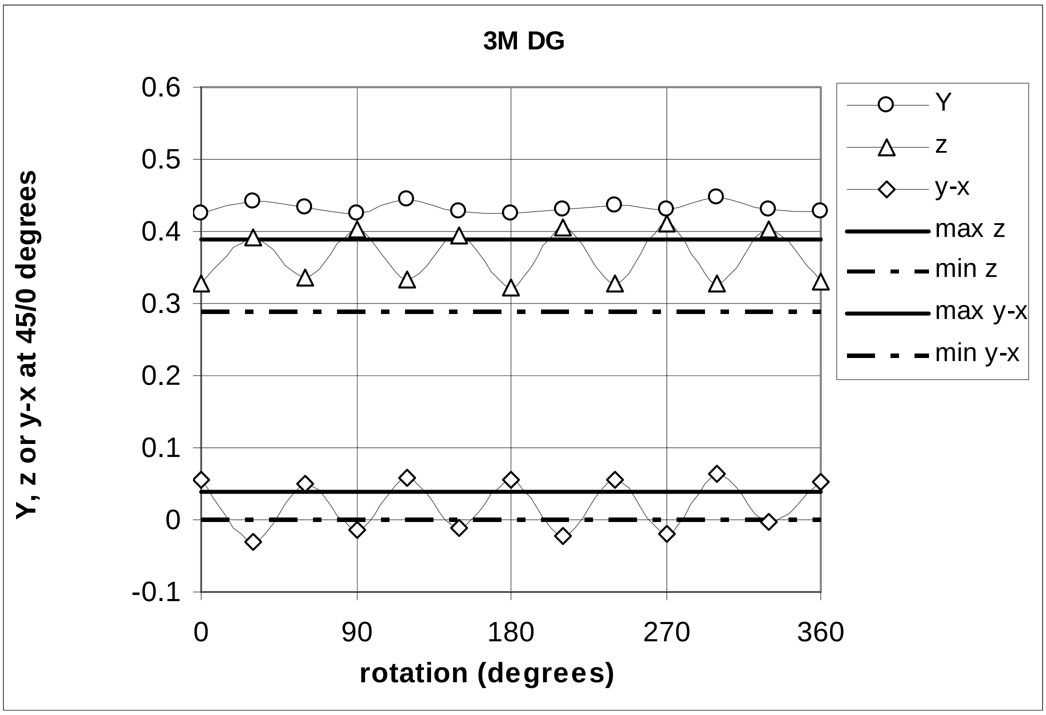


Figure 6: Luminance factor Y and chromaticity expressed by z and y-x of a 3M microprismatic material (often called Diamond Grade or LDP) measured with a Gardner 45°/0° Color-guide in different rotations.

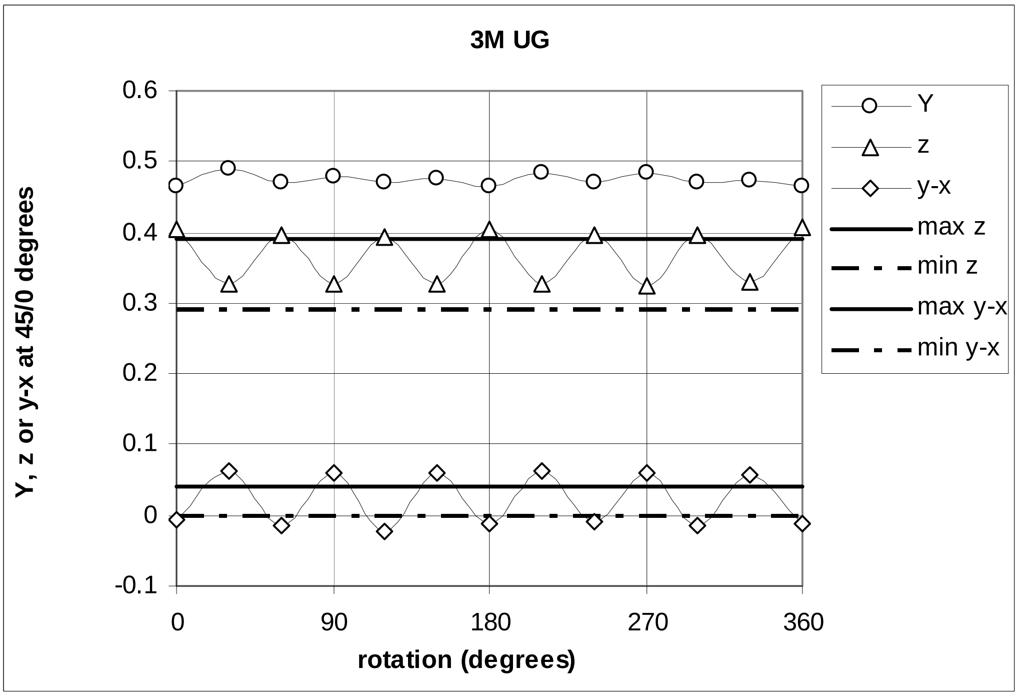


Figure 7: Luminance factor Y and chromaticity expressed by z and y-x of a 3M microprismatic material (often called Urban Grade or VIP) measured with a Gardner 45°/0° Color-guide in different rotations.

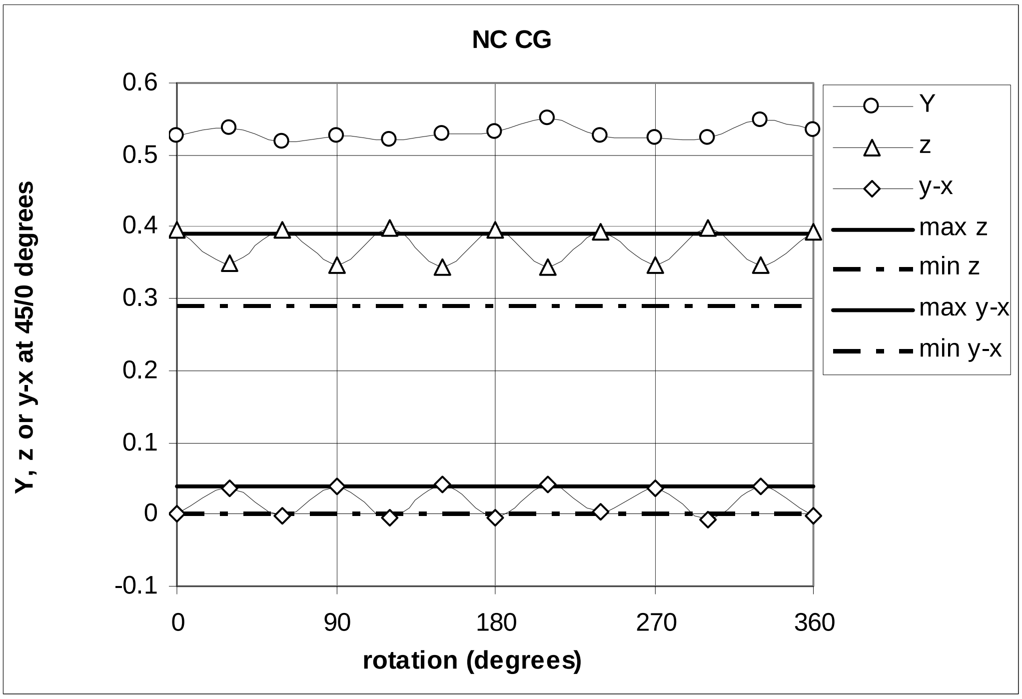


Figure 8: Luminance factor Y and chromaticity expressed by z and y-x of a Nippon Carbide microprismatic material (often called Crystal Grade) measured with a Gardner 45°/0° Color-guide in different rotations.

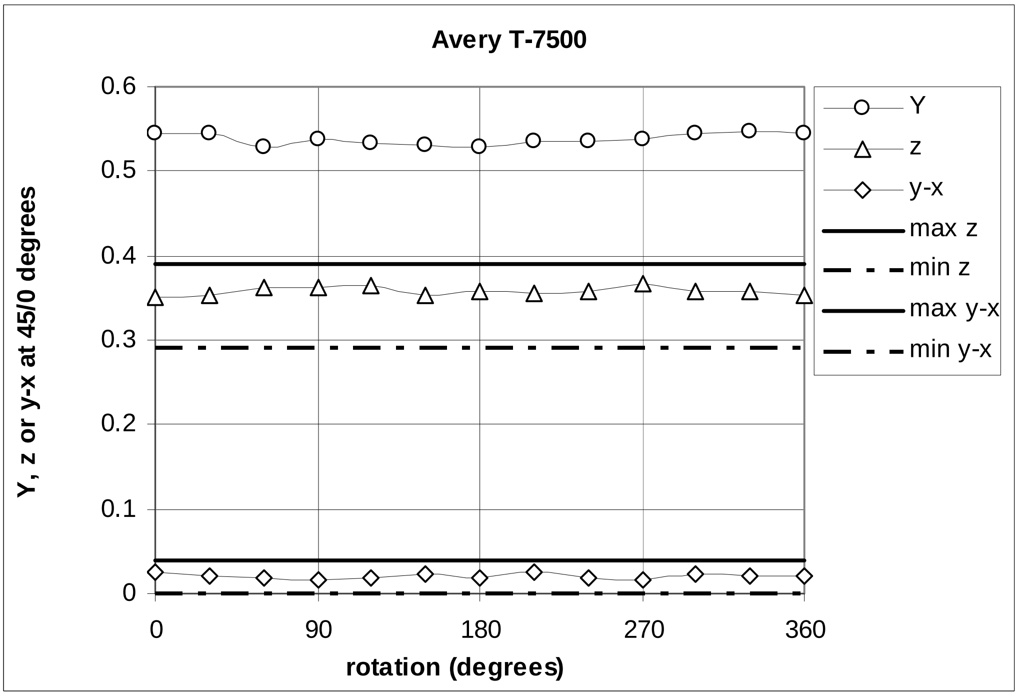


Figure 9: Luminance factor Y and chromaticity expressed by z and y-x of an Avery Dennison microprismatic material (T-7500) measured with a Gardner 45°/0° Color-guide in different rotations.

4. Discussion of he 45°/0° measuring geometry and proposal for an alternative diffuse/0° measuring geometry

The 45°/0° measuring geometry, as introduced in section 1, is permissive in terms of the details of the geometry.

In section 2 it is claimed that this geometry works well for glass beaded sheeting materials, and this is illustrated by some measurements using a particular portable instrument.

In section 3, on the other hand, it is pointed out that microprismatic sheeting materials have an additional type of reflection that is termed 'sparkle', and that this type of reflection may cause variation of the results of measurement with the details of the measuring geometry. Variations are illustrated by means of measurements with a particular portable instrument.

Accordingly, the 45°/0° measuring geometry presents a problem in connection with use for microprismatic sheeting materials. There might be four methods to fix this problem:

A. by defining the test conditions
B. by requesting that the illumination is annular
C. by requesting that illumination and/or measurement use wide angular bands
D. by introducing diffuse illumination

Method A is assumed in a CUAP for Microprismatic retro-reflective sheetings, ETA Request No. 01.06/04 that will form the basis for CE marking of these materials in Europe. The requirement is simply that materials are measured with the datum mark upwards. This of course does not help at all, any variability of results can be expected.

Method B is the basis for an ASTM work item 'WK2896 Standard Test Method for Daytime Colorimetric Properties of Retroreflective Sheeting and Marking Material for Traffic Control and Personal Safety Applications using 45°:Normal Geometry'. It requires either that the instrument has annular illumination, or that measurements are averaged over several rotations of the sample with a sufficiently small angular step.

This is of course a complexity for range measurements in the laboratory, and for the use of non-annular instruments - in particular for in situ measurements on installed road signs. The number of rotations required would range from a few up to 50. However, the type of variations presented in the previous section would be averaged out.

The question is if method B is sufficient to ensure that measurements are representative for particular materials. To test this, the case of the 3M DG material used for figure 6, is considered. The average luminance factor value for the rotations used in figure 6 is 43%. Some additional results for three other types of instruments, also obtained with rotations of the instruments, has been supplied by Dennis Couzin, Avery Dennison (private correspondence), leading to the four values for four instruments illustrated in figure 10.

The four values of figure 10 (63%, 49%, 46% and 43%) show clearly that the instrument type has an influence. This particular sheeting material has sparkle at 45° illumination, or at illumination close to this angle, so that all the instruments activate this sparkle. The instruments, however, have use different widths of the illumination and/or observation beams, ranging from being quite sharp for the first instrument (Labsphere BFC 450) to being as broad as permitted for the last instrument (Gardner 45°/0° Color-guide). This means that the sparkle is mixed with diffuse/scattered light to an increasing degree in the sequence the instruments are listed, and therefore the luminance factor value decreases in this sequence.

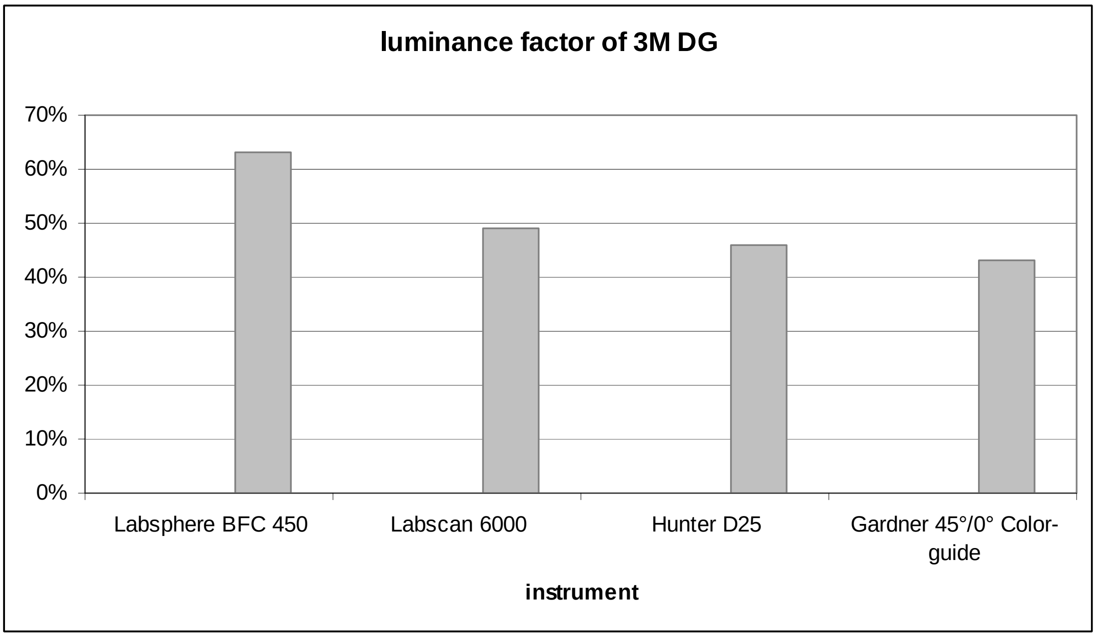


Figure 10: Luminance factor values obtained with four instruments according to method B (average for different rotations).

The total variation between the instruments is quite large, and therefore it is concluded that method B is not sufficient. Dennis Couzin has provided examples of even larger variations (not shown here).

Method C should be considered as an extension of method B, to use an annular illumination, and at the same time use illumination in a broad annular band (and perhaps also a broad observation beam). The philosophy is to make sure that sparkle is included in the measurement, and to 'drown' it in a much larger contribution by diffused/scattered light.

Method C actually works in principle, because sparkle is strong only when activated by a narrow beam of illumination, not when the beam is wide (a wide measurement beam also helps to wash out the sparkle). As an example, sparkle in roads signs with microprismatic sheeting materials can be observed only in sunshine, not in overcast daylight conditions.

Figure 2 shows that the 45°/0° measuring geometry does allow the use of method C, because both illumination and measurement can be in wide beams.

There has been some experimentation with method C in the USA. However, this method does have a serious drawback, namely that it is not easy to establish illumination (and possibly measurement) in wide beams. This would in particular be difficult in laboratory range measurements, and some existing instruments could not be used.

Method D is a further step in the same direction as method C, as diffuse illumination corresponds to the broadest possible band of illumination and the most effective 'drowning' of sparkle. The method has the advantage that diffuse illumination is practicable and that geometries using diffuse illumination are already established.

The principle of diffuse illumination is illustrated in figure 11. A sample is exposed to illumination from a hemisphere of uniform luminance above the plane of the sample. Measurement takes place through a gate in the equipment that produces the diffuse illumination.

Figure 11 shows only a hemisphere, but a complete photometric sphere can be used as shown in figure 12. Another use of a photometric sphere is shown in figure 13, where a sample is placed at a gate into the sphere, while measurement takes place through another gate.

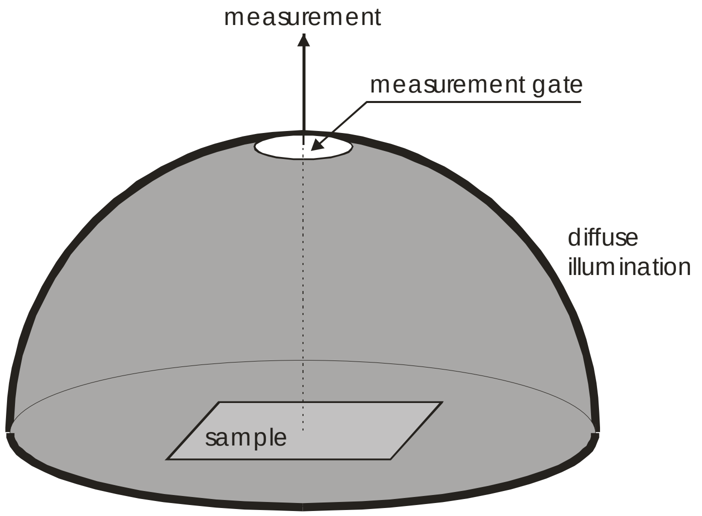


Figure 11: In diffuse illumination, a sample is exposed to illumination from a hemisphere above the plane of the sample of uniform luminance.

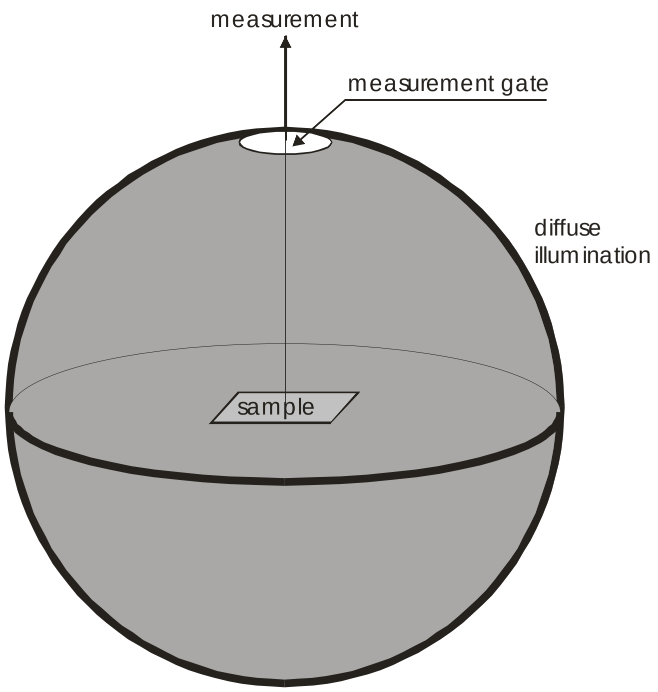


Figure 12: In practice diffuse illumination can be established in a photometric sphere, where the upper part obtains uniform illuminance by illumination from a light source in the lower part.

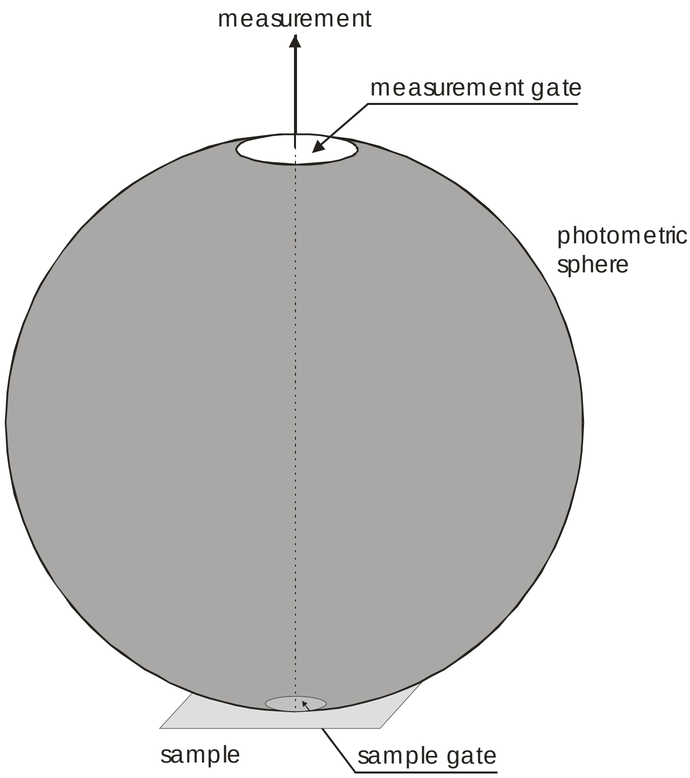


Figure 13: Diffuse illumination can also be established through a sample gate of a photometric sphere.

Diffuse illumination in the full range from 0° to 90° entrance angle will activate both surface reflection and retroreflection, causing a considerable raise of the luminance factor value considerably and also influencing chromaticity as compared to results obtained with the 45°/0° measuring geometry.

In daylight conditions, the sign face of a road sign does show surface reflection (of the sky or some other part of the surrounding) and it does show retroreflection (of the surroundings of the driver - his car and some of the road surface) - this is the reason that white parts of a sign face do look white and not grey as would be implied by the value of the luminance factor. This argument could lead to a discussion of the relevance of different measuring methods, but there is some advantage in excluding the above-mentioned types of reflection, as it is done in the 45°/0° measuring geometry.

Therefore, diffuse illumination should be used in such a way that surface reflection and retroreflection do not contribute. Assuming measurement at 0°, this is a question of using a sufficiently large measuring gate, leading to a dark surrounding in which the colorimeter is placed.

> NOTE: The alternative would be to use measurement at 8°, as both the diffuse/0° and the diffuse/8° geometries are established in practice. However, use of measurement at 8° would require not only a sufficiently large measuring gate in order to exclude retroreflection, but also a large gate at -8° opposing the measuring gate in order to exclude surface reflection. The diffuse/0° geometry is the more simple of the two, and has the additional advantages of providing rotational symmetry and of maintaining the 0° measurement of the 45°/0° measuring geometry.

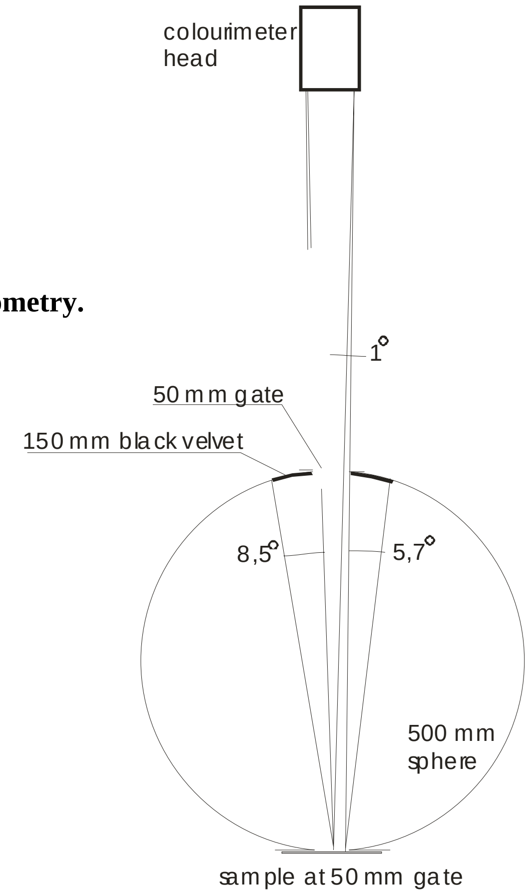
In conclusion, methods A and B are not sufficient, while methods C and D could work leaving a choice between the two. The most clear decision is to introduce diffuse illumination according to method D, i.e. to introduce the diffuse/0° measuring geometry instead of elaborating on the 45°/0° measuring geometry. In doing so, the diffuse/0° measuring geometry should be defined so that surface reflection and retroreflection do not contribute. This matter in considere din the next section

5. Measurements in the diffuse/0° measuring geometry

Measurements in the diffuse/0° geometry were carried out with a 500 mm photometric sphere with two gates as illustrated in figure 11. Both gates have a diameter of 50 mm, but an inlay of a ring of black velvet cloth at the measurement gate simulates a diameter of 150 mm of this gate. Measurements were with a spectrocolourimeter calibrated against a reference with known values of Y, x and y at this particular measuring geometry.

The spectrocolourimeter was placed approximately 500 mm outside of the measurement gate, it has an entrance pupil of approximately 70 mm, was used with a 1° measuring field and was focussed at a distance of 500 mm behind the sample gate. The geometry is shown in figure 14, which also indicates the reserve against surface reflection is approximately 8,5° (i.e. surface reflection does not contribute unless scattering by surface texture exceeds 8,5°), while the reserve against retroreflection is approximately 5,7° (i.e. retroreflection does not contribute unless retroreflection is to larger observation angles than 5,7°).

Figure 14: Measuring set-up for the diffuse/8° geometry.



Measurements were carried out for the two glass beaded sheeting materials (3M EG and HI) mentioned in section 2 and the four microprismatic sheeting materials mentioned in section 3. Not only white samples, but also samples of the colours of yellow, red, blue and green were used.

Results for the two glass beaded sheeting materials are compared for the two geometries, 45°/0° and diffuse/0°; for the luminance factor Y in figures 15 and for the chromaticities in figure 16.

Figure 15 shows that the Y values are higher for the diffuse/0° geometry than for the 45°/0° geometry. Additionally, figure 16 shows that chromaticities correspond to a bit less saturated colours for the diffuse/0° geometry than for the 45°/0° geometry in some cases, refer to the colour blue for both materials. This might imply that the reserves mentioned in section 4 are not quite sufficient to suppress the surface reflection.

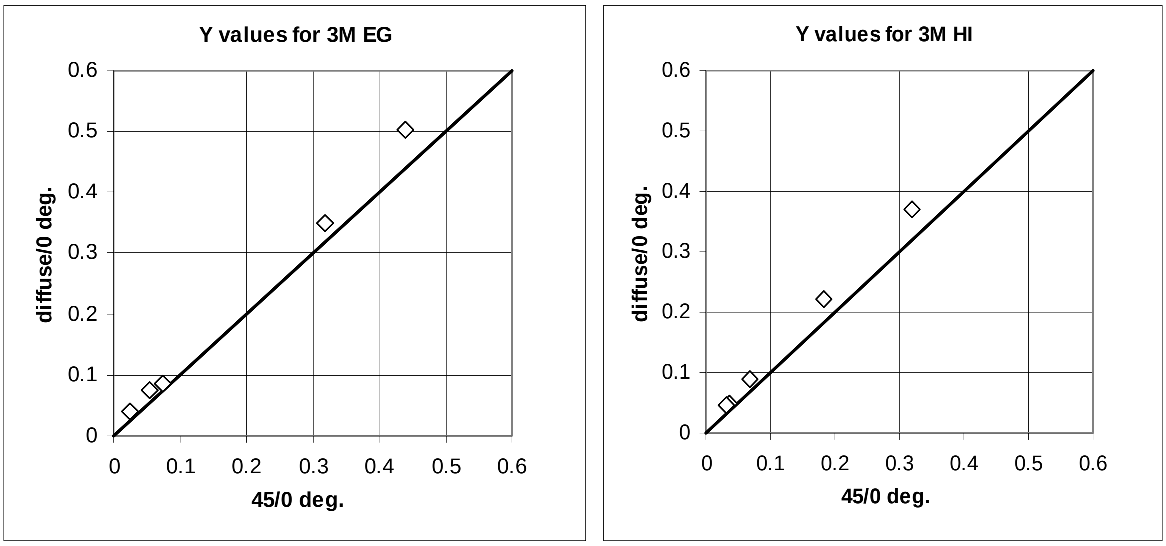


Figure 15: Comparison of the luminance factor values Y for the two measuring geometries, for two glass beaded sheeting materials.

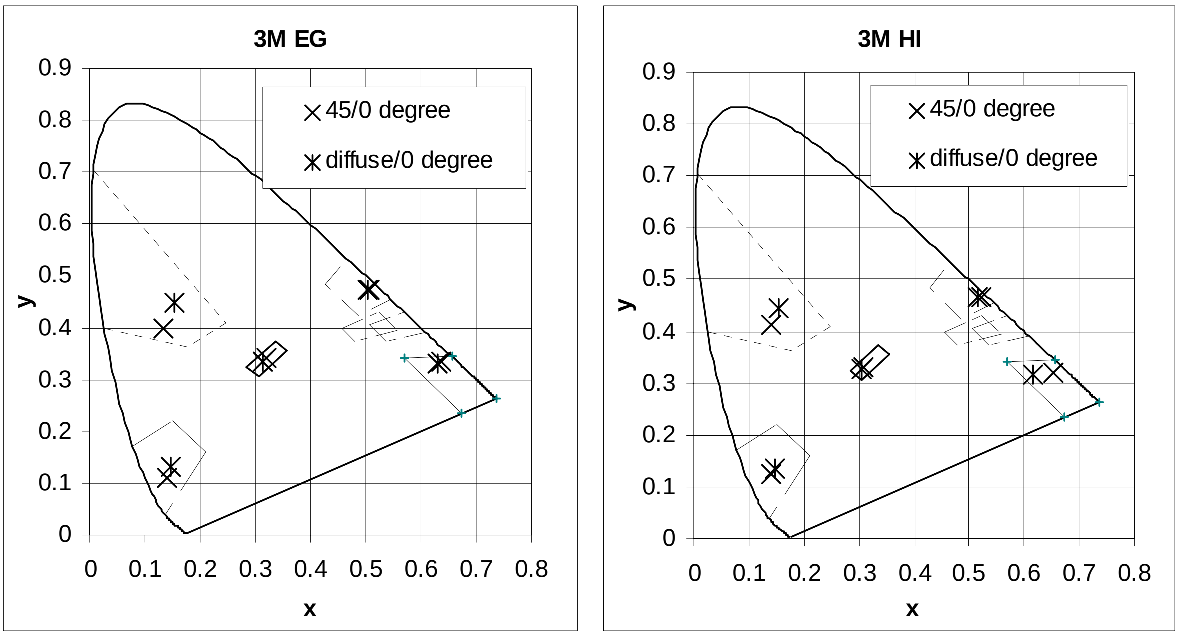


Figure 16: Comparison of the chromaticities for the two measuring geometries, for two glass beaded sheeting materials.

The luminance factor Y for microprismatic sheeting materials measured in the diffuse/0° geometry are provided in table 1.

Table 1: Luminance factor Y for microprismatic sheeting materials measured in the diffuse/0° geometry.

	3M DG	3M UG	NC CG	Avery T-7500
white	39%	39%	50%	52%
yellow	23%	24%	30%	27%
red	5,9%	6,0%	9,2%	5,3%
blue	2,6%	2,6%	6,1%	6,2%
green	6,3%	7,0%	10%	8,8%

The Y values of table 1 seem reasonable. Y values were in fact also measured for the 45°/0° geometry using the Gardner 45°/0° Color-guide, but as these values represent only one possible result with this geometry, a comparison is not attempted. It is only mentioned that the average values for the white materials for the different rotations of figures 6, 7, 8 and 9 are higher than for the corresponding values of table 1 (from 4% to 23% higher). The reason is probably that the sparkle contributes much more in the 45°/0° geometry than in the diffuse/0° geometry.

The chromaticities for microprismatic sheeting materials measured in the diffuse/0° geometry are provided in figure 17.

There is a case, where the chromaticity point is outside of the colour box, refer to the colour green for 3M DG. Apart from this the chromaticities shown in figure 17 seem reasonable. Chromaticities were in fact also measured for the 45°/0° geometry using the Gardner 45°/0° Color-guide, but as these represent only one possible result with this geometry, a comparison is not attempted. It is only mentioned that there are more cases, where the chromaticity point is outside of the colour box.

It is probably easy to establish horrific results for the 45°/0° geometry using other instruments than the Gardner 45°/0° Color-guide.

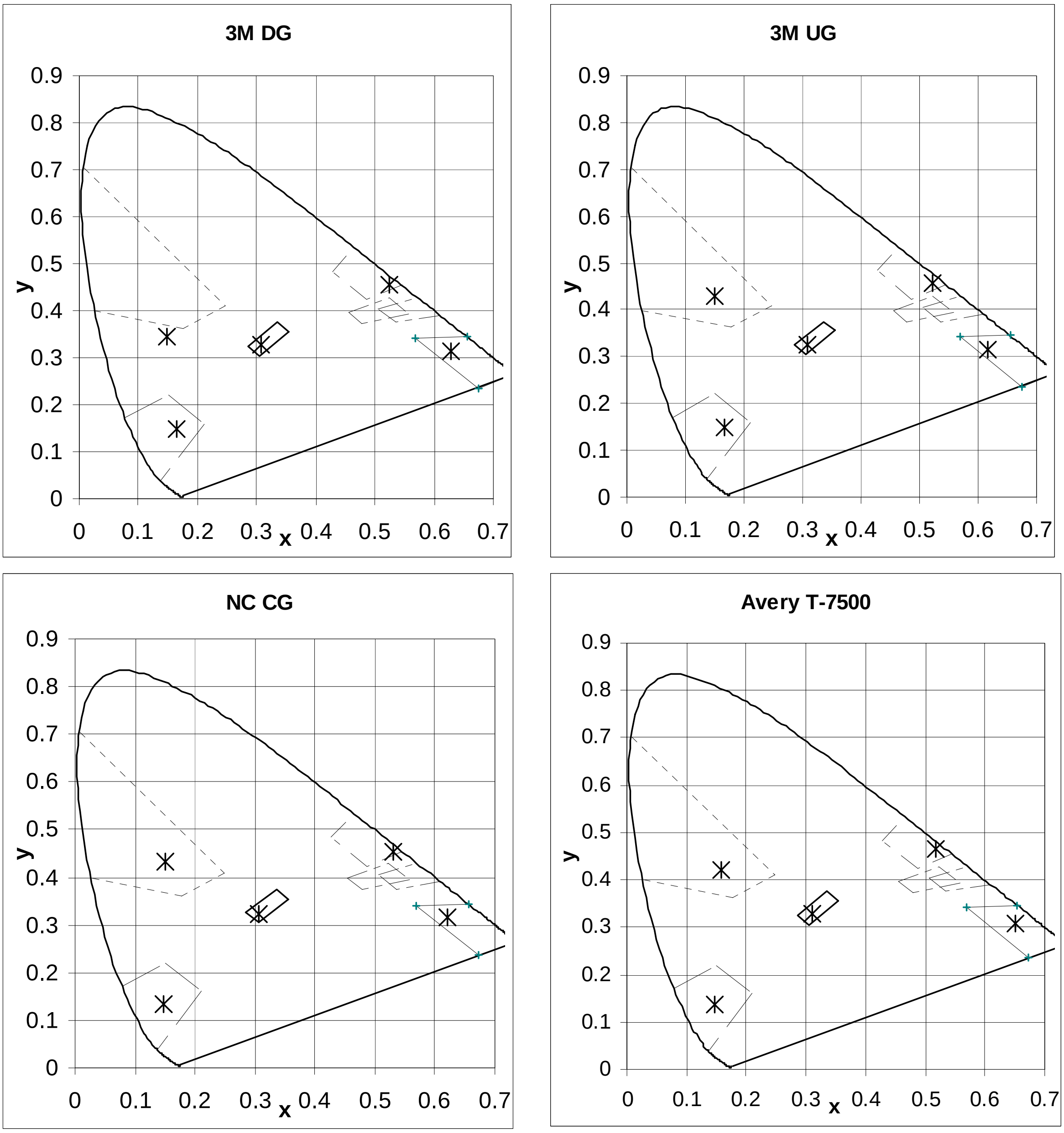


Figure 17: Chromaticities for microprismatic sheeting materials measured in the diffuse/0° geometry.