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Comparing measurement principles of three gloss meters and using them for measuring gloss on metallic embellishments produced by the printing industry

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Abstract

When measuring gloss, beneath the amount of reflected light that is reflected on a surface, also the light distribution that decides about the image forming capability of a surface has to be considered. In this study, three gloss meters (micro-TRI-gloss from Byk Gardner, IQ-S from Rhopoint, RA-532H Surface Reflectance Analyzer from Canon) that measure different aspects of gloss such as the amount of specular reflected light as well as the light distribution are used. The principles of the different aspects of gloss are explained and it is shown how the instruments measure these. Finally, measurement results taken from four different metallic embellishments from the printing industry are shown and discussed.

Index Terms: gloss measurement, gloss meters, metallic embellishments

1 Introduction

In the printing industry, the measurement of gloss of printed products is of high importance for quality control as well as for the communication about requirements regarding gloss between the customer and the print shop [1].

According to ASTM E284-17 [2], gloss is defined as the “angular selectivity of reflectance, involving surface-reflected light, responsible for the degree to which reflected highlights or images of objects may be seen as superimposed on a surface”.

In former studies, Ji et al. [3] showed that compared to the sensitivity to differences of gloss in the mid-gloss region, the sensitivity on gloss differences is higher for extreme matte and extreme high-gloss samples. According to Obein et al. [4], for the high-gloss samples, the observers bring variations in the distinctness of the reflected image into account, additionally to the perception of the total amount of reflected light.

In the printing industry, when the gloss of a product is of interest, traditional gloss meters are usually used. Yet, these only measure one aspect of gloss, namely the specular gloss. Hence, certain nuances of gloss cannot be measured and the correlation between human visual sensation and instrumental gloss quantification is not necessarily given [5].

In this study, three portable handheld gloss meters are compared and used. The first device is a traditional gloss meter that is commonly used in the printing industry. It measures specular gloss at three different angles. Next, two more sophisticated gloss meters are introduced that measure more aspects of gloss than the traditional gloss meter. Using those instruments, measurements on metallic embellishments from the printing industry are taken and compared.

2 Principles of gloss measurement

Appearance industry professionals have tried to determine a minimum of measurement techniques of gloss to characterize a large set of gloss nuances [6]. This has produced different scales or aspects of gloss appearance such as specular gloss, haze, distinctness of image (DOI) or image clarity (IC). The understanding of these measurement techniques and the different aspects of gloss is the foundation of understanding modern gloss meters. These measure the bidirectional reflectance distribution function (BRDF) and derive the aspects of gloss from it.

2.1 Specular gloss

The principle of the measurement of specular gloss is shown in figure 1 a. A light source on one side flashes a directional beam with an inclination of θ, the specular angle, on a sample surface where it illuminates the measuring spot. The light is reflected and due to texture and micro roughness, the light is both specular reflected, scattered as well as partially absorbed. For most gloss meters, θ is 20°, 60° and 85°. The specular angle of 60° is the "standard geometry", the specular angle of 20° is used for high gloss finishes and the specular angle of 85° is used for very matte surfaces. The so-called specular gloss is measured in a region around the specular angle. This region is set by the aperture size of the receiver. The different aperture sizes for the different angles of measurement are shown in table 1.

Table 1: Angles of the light source aperture and receptor aperture for the measurement of specular gloss at 20°, 60° and 85° after ASTM D523-14 [7]. The angles α and β correspond to figure 1 a.

	In plane of measurement (α)	Perpendicular to plane of measurement (β)
Light source aperture (for all angels)	0.75° ± 0.25°	2.5° ± 0.5°
20° receiver aperture	1.8° ± 0.05°	3.6° ± 0.1°
60° receiver aperture	4.4° ± 0.1°	11.7° ± 0.2°
85° receiver aperture	4.0° ± 0.3°	6.0° ± 0.3°

The distribution of the intensity of the reflected light in the region around the specular angle θ can be depicted as a gloss curve as shown in figure 1 b. As can be seen in this figure, the overall intensity in a specific region of the gloss curve is measured as specular gloss. The specular gloss cannot be used to make a statement about the shape of the gloss curve.

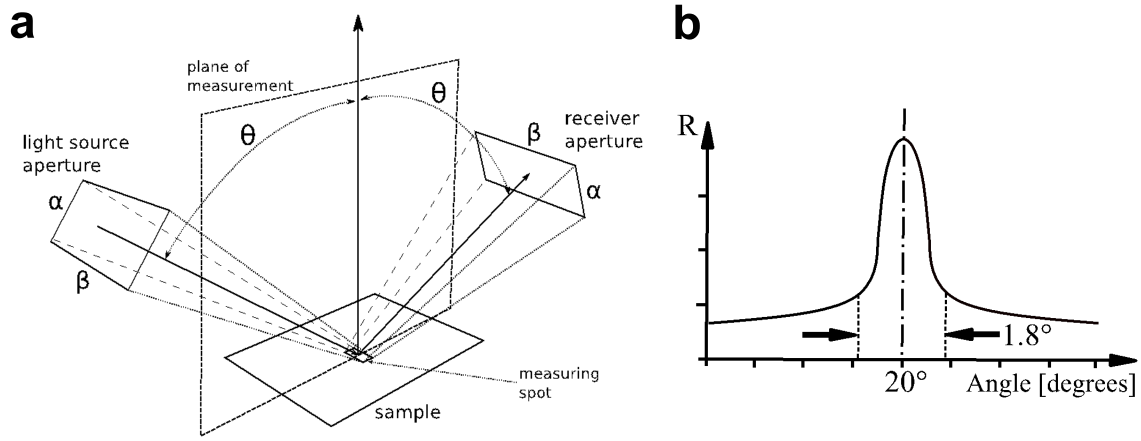

Figure 1: Part a (after [6]) shows the principle of a gloss meter. Light passes through an aperture of a specific size and illuminates a measuring spot under a specific angle. A part of the reflected light passes through a receiver aperture and the intensity of the light is measured to obtain a specular gloss value. Aperture sizes and measuring spot are not to scale. Source and receiver lenses are not shown. Part b (after [8]) shows the part of the reflected light in the gloss curve for a measurement of specular gloss at the specular angle of 20°. R is the intensity of reflected light. The drawing plane equals the plane of measurement.

Ideally, when measuring the specular gloss of a sample, it is compared to a standard with a refractive index of 1.567 for the sodium D line for which a specular gloss value of 100 gloss units (GU) is assigned for every angle θ as stated in ASTM D523–14 [7] and ISO 2813:2014 [9]. The specular gloss value measured at the angle θ is derived as follows:

$$gloss_{\theta}[GU] = 100 \cdot \frac{R(sample)_{\theta,D}}{R(standard)_{\theta,D}}$$

R is the intensity of light, *D* is the region in which it is measured. It is determined by the aperture size of the receiver. The used standards of gloss meters usually do not have a refractive index of precisely 1.567, which has to be made up for by using a correction factor.

For common print products, it cannot be expected to obtain gloss values higher than 100 GU because their reflectance factor usually does not exceed the one of the standard that is usually out of glass with a black background. However, since the reflectance factor of metal is much higher than that of dielectric materials, more light is reflected and less light is absorbed. Hence, for printed metallic embellishments the measured gloss values are often greater than 100 GU. [10]

2.2 Haze

According to ASTM E284-17 [2], haze is the “scattering of light at the glossy surface of a specimen responsible for the apparent reduction of contrast of objects viewed by reflection at the surface”.

Various attempts have been made to use gloss meters for separating specular reflection from the reflection close the specular reflection to obtain the haze [11]. The method that gained the most acceptance and that is described in the following is shown in ASTM E430 - 11 as method B [12] that is very similar to ISO 13803:2014 [13]. For this measurement method, the ratio of the signal on the haze sensors to the specular gloss is taken as follows:

$$haze[HU] = 100 \cdot \frac{R(sample)_{18.1°,D\_haze} + R(sample)_{21.9°,D\_haze}}{gloss_{20}[GU](standard)}$$

D_haze is the size of the haze apertures beneath the aperture for specular gloss as shown in figure 2. The aperture sizes for the haze after ASTM 430 – 11 method B are 1.8° ± 0.05° for α and 5.5° ± 0.25° for β. Haze is reported in haze units (HU).

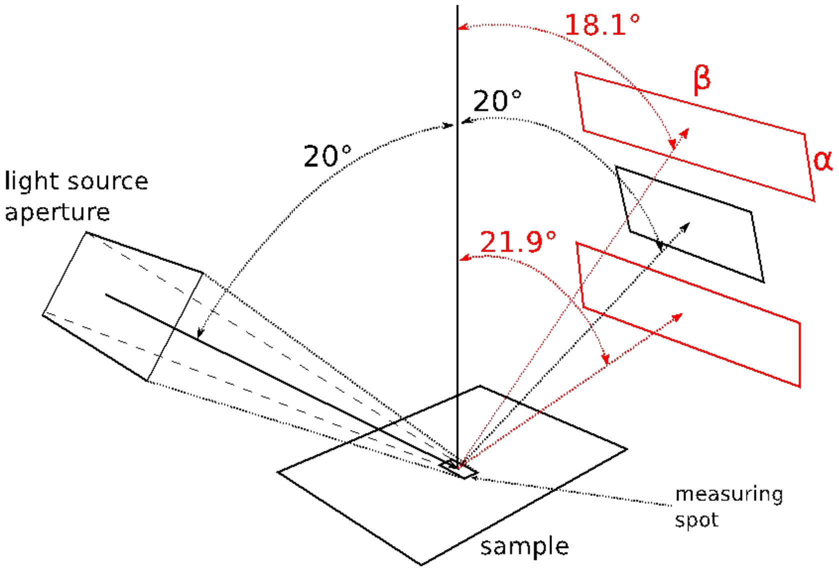

Figure 2: Principle of a haze meter as described in ASTM E430-11 method B and ISO 13803:2014. The haze component is collected with apertures off the specular shown in red color. The specular gloss is used for the denominator in the haze calculation. The width α in the plane of measurement of the haze component is 1.8° ± 0.05°, the length β perpendicular to the plane of measurement of the haze component is 5.5° ± 0.25°. Aperture sizes, measuring spot and angles are not to scale. Source and receiver lenses are not shown.

2.3 Distinctness of image and image clarity

ASTM E284-17 [2] describes DOI and IC as the “aspect of gloss characterized by sharpness of images of objects produced by reflection at a surface”.

ASTM D5767 – 95 - 2012 [14] describes three methods of DOI/IC measurement. Other concepts not mentioned in the norms of measuring the DOI/IC are summarized in [15].

ASTM D5767 – 95 - 2012 method A describes the measurement of the DOI. ASTM D5767 – 95 - 2012 method B describes one measurement method of IC that is very similar to a method described in JIS-K 7374:2007 [16]. These two methods are shown in the following.

According to the DOI measurement method, reflectance factor measurements are made at the sample at the specular angle as well as 0.2 to 0.4° off the specular viewing angle of 20° or 30° (usually the DOI is measured at 20°). These values are used to obtain the DOI value.

DOI values close to 100 indicate a very high sharpness and values close to 0 indicate a very high induced waviness in the reflected image. The DOI is reported in percent (%). The calculation is as follows; the dash (-) indicates that the light between the angles is recorded:

$$DOI[\%] = 100 \cdot \left(1 - \frac{R_{19.6°-19.8°}(sample) + R_{20.2°-20.4°}(sample)}{R_{19.95°-20.05°}(sample)}\right)$$

For the IC measurement, light passes from the light source through a slit and is radiated on a surface. Rectangular to the optical axis an optical comb is placed that moves rectangular to the axis of the reflected light. The amount of light measured when a transparent part is on the axis is M. When an opaque part is on the axis the amount of light is measured as m. The ratio between (M-m) and (M+m) results in what is called image clarity (IC). The angle of illumination and measurement is 60°. [17]

The calculation is as follows:

$$IC[-] = \frac{M - m}{M + m}$$

The principle if IC measurement is shown in figure 3 a. The optical comb shown in figure 3 b has four different grades of width. Using four different grades lead to four IC values which are reported together with the regarding grade.

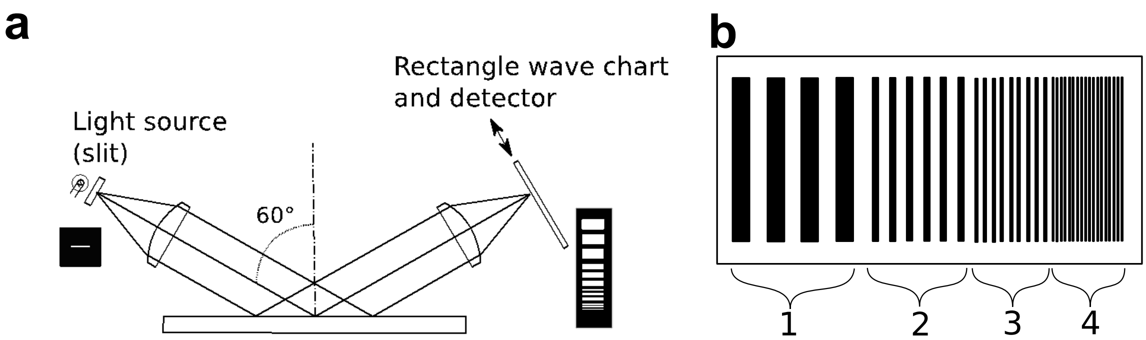

Figure 3: In part a the measurement setup for IC is shown after [17]. Light passes through a slit is reflected at a sample and passes through an optical comb. The light that passes through the optical comb is recorded and from those measurements the IC is calculated. Part b shows an optical comb having four different widths of opaque and translucent regions after [18]. IC is reported together with the width of the opaque regions on the optical comb.

2.4 Bidirectional reflectance distribution function

The measure that fully characterizes the distribution of light coming from a reflection is the BRDF. Figure 4 shows the directions in which a BRDF can be measured. If the light distribution is only measured in the direction of α, it is a 1D BRDF or planar BRDF and results in a representation as a gloss curve as also shown in figure 1 b and figure 2 b. A 2D BRDF is a function of the two angles α and β. α is the deviation of light in the plane of the incident and reflected light, β is the deviation perpendicular to that plane. [19]

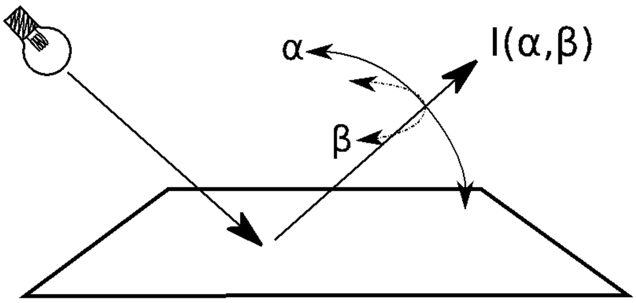

Figure 4: Principle of BRDF after [19]. I is the intensity per steradian.

Traditionally, it takes a lot of effort and very expensive goniophotometers to measure the BRDF. Now, there are handheld and affordable instruments on the market that make the measurement of a partial 1D or 2D BRDF around the specular angle possible.

3 Introduction into the relevant measured variables of the used gloss meters

The three gloss meters that are compared in this study are shown in figure 5 a. On the left, the micro-TRI-gloss model 4446 from Byk-Gardner can be seen. In the middle, the IQ-S from Rhopoint is shown. On the right, the RA-532H Surface Reflectance Analyzer (SRA) from Canon can be seen. In figure 5 b, the calibration standards of these devices are shown. All three devices are calibrated on a black glass standard. The IQ-S is additionally calibrated on a high gloss mirror. For high gloss over 130 GU at the specular angle of 60° the IQ-S measurements have to be related to the high gloss tile. Otherwise, the measurements do not prove as reliable.

All three instruments can measure specular gloss as described above at the specular angles of 20°, 60° and 85°. The micro-TRI-gloss is equipped at every angle with a photodiode for the measurement of specular gloss. At the specular angle of 20°, the IQ-S is equipped with a linear diode array and at the specular angles of 60° and 85° with photodiodes. The SRA is equipped with an area sensor at the specular angles of 20° and 60° and with a photodiode at 85°. That means that the measurement of the IQ-S at the specular angle of 20° results in a 1D BRDF and measurements of the SRA at the specular angles of 20° and at 60° result in 2D BRDFs. From the data that form the BRDF of all reported aspects of gloss such as specular gloss and haze can be derived.

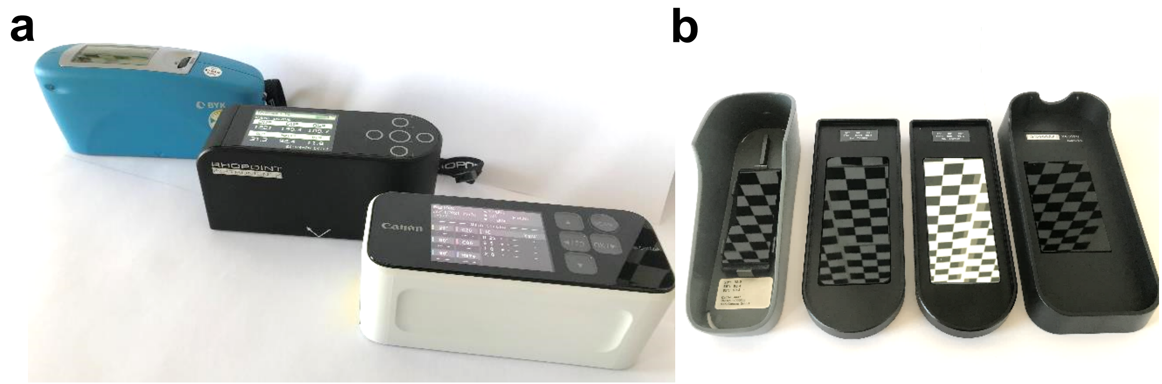

Figure 5: Gloss meters and their calibration tiles. In part a from the left to the right: micro-TRI-gloss, IQ-S, SRA. In part b the tile on the left is used for calibrating the micro-TRI-gloss, the two tiles in the middle are used for calibrating the IQ-S, the one on the right is used for calibrating the SRA.

Using the IQ-S, at the specular angle of 20° from the 1D BRDF the specular gloss value is derived. Besides that, the linear haze described above and three more aspects of haze can be reported. Furthermore, the DOI is reported. Additional values that are special for the instruments of the IQ-series of Rhopoint are the RIQ value that is described as an updated and more precise version of the DOI [20]. The company does not reveal how the RIQ is calculated. The RSPEC value that is also reported, is the highest value of the readings that form the measured 1D BRDF.

Using the SRA, the specular gloss values at the specular angles of 20° and 60° are derived from the measured BRDF. Additionally, the haze is reported, as well as four IC values for four different grades of the optical comb. The moving optical comb is not actually built in the SRA but the values can be derived from the data of the sensor at the specular angle of 60°.

Furthermore, a C20 and a C60 value is reported which are unique Canon indexes. They describe the scattering of light on the surface. The higher the values, the greater the scattering. Their measurement principle is not published. According to [21] these indexes only quantify the image sharpness of the reflection on the surface layer. The inverse of C20 behaves similar as the RIQ value and comparable to the DOI. The inverse of C60 is very similar to the IC. Special about the C20 and C60 values is, that they can be used for both differentiating high-gloss and very matte surfaces, while the DIO, RIQ and IC would result in a reading of zero for matte surfaces. The C20 and C60 values only take the shape of the BRDF into account and not the intensity of reflected light [21].

4 Measurements on metallic embellishments

In the following, measurement results using the three instruments are shown. All measurement values are the arithmetic mean of 10 measurements. Five taken into machine and five against machine direction. In each direction, four measurements were taken near the edges of the sample and one in the center. The four samples are made using different metallizing techniques from the printing industry on paper substrate such as foil fusing, gravure printing, flexo printing and offset printing. The samples can be seen in figure 6. The pictures are taken in front of a chessboard pattern attached to the wall.

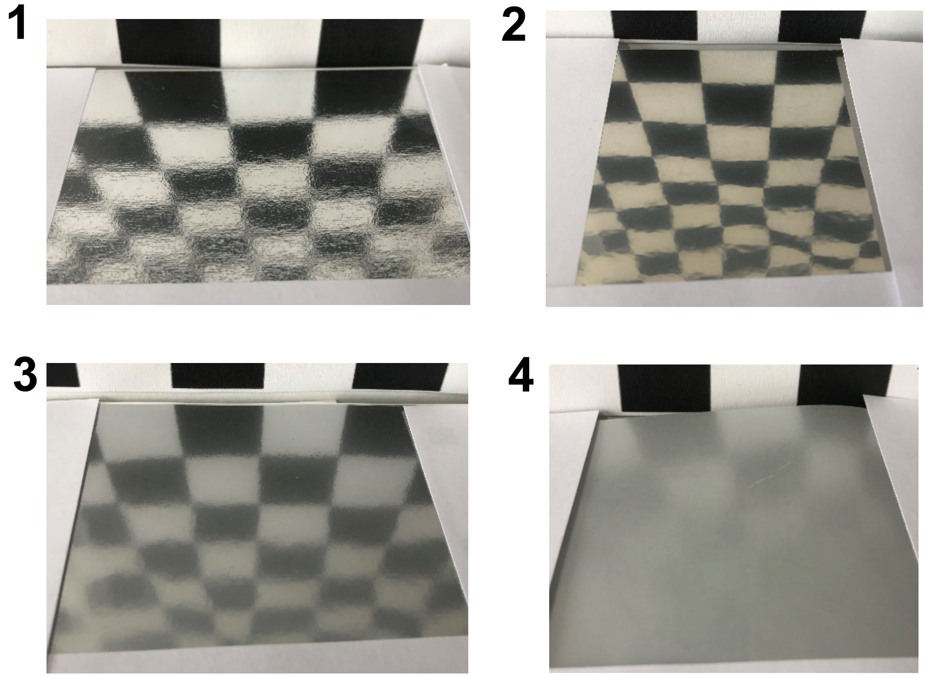

Figure 6: Used metallic samples. Sample 1 is made by foil fusing, sample 2 by gravure printing, sample 3 by flexo printing and sample 4 by offset printing. The substrate of all samples is paper. The pictures were taken in front of a chessboard pattern.

While it is obvious that sample 4 is much less glossy than the other samples, it could be a difficult task for an observer to judge whether sample 1 or 2 is glossier. It is also difficult to judge on how much sample 2 is glossier than sample 3 and to find the right words to express the visual impression. Yet, it is obvious that both the impression of the surface quality and the quality and brightness of the reflected chessboard pattern come into play when judging the gloss. The measurement results of the different gloss meters help explaining the gloss impression. Table 1 shows the measurement results using the micro-TRI-gloss. When taking the gloss measurement at the specular angle of 20°, which is for judging high gloss and the standard 60° angle into account, it can be seen, that the specular gloss of sample 1 is measured to be higher than that of sample 2. However, the specular gloss values do not help judging the sharpness of the reflected image. Sample 4 is measured to be the most matte sample.

Table 1: Measured specular gloss of the four samples at the angles of 20°, 60° and 85° using the mictro-TRI-gloss from Byk Gardner. The specular gloss values are derived by taken the arithmetic mean of 10 measurements at different point in machine and across machine direction.

Sample number	1	2	3	4
$gloss_{20}$ [GU]	570	466	185	12
$gloss_{60}$ [GU]	515	506	258	53
$gloss_{85}$ [GU]	93	130	92	67

The measurement results obtained from the IQ-S give a deeper insight into the different aspects of the perceived gloss. While the measured specular gloss values at 20 and 60° of sample 1 are still the highest, the DOI and RIQ of sample 2 are much higher than those of the other samples. This shows that sample 2 is not only perceived as the sample with the sharpest reflection, but also measured as that. Sample 1 and 3 are measured to have the same DOI but from the reflected chessboard pattern it can be seen that sample 1 has fine wavy structures. The high haze measured of sample 1 is an indication of those fine structures.

The specular gloss values between the different gloss meters differ due to inter-instrumental disagreement, which is common for gloss meters from different manufacturers [19, 22–24].

Table 2: Different aspects of gloss of the four samples at the angles of 20°, 60° and 85° using the IQ-S from Rhopoint. The values are derived by taken the arithmetic mean of 10 measurements at different point in machine and across machine direction. Haze, DOI, RIQ and RSPEC are derived from the data of the LDA at 20°.

Sample number	1	2	3	4
$gloss_{20}$ [GU]	687	627	233	17
$gloss_{60}$ [GU]	563	535	261	53
$gloss_{85}$ [GU]	83	122	77	57
haze [HU]	522	162	159	22
DOI [%]	21	51	21	1.4
RIQ [%]	3.7	29.2	4.0	1.3
RSPEC [-]	109	176	37	2.6

The gloss curves that are obtained with the IQ-S on the specular angle of 20° are shown in figure 7. Their shape is the cause for the values shown in table 2. As the reflection of sample 2 causes a narrow and high gloss peak at the specular angle, it also has the clearest reflection. The gloss curve of sample 1 is flatter than the one of sample 2 but the overall surface under the curve which is measured as specular gloss is greater. The haze of sample 2 and 3 is nearly the same, because between ±2 - ±4° they have almost the same height and shape. The more diffuse the reflection of a sample, the flatter and wider the gloss curve. This is clearly shown by the flat shape of sample 4, which has the most diffuse reflection of the four samples.

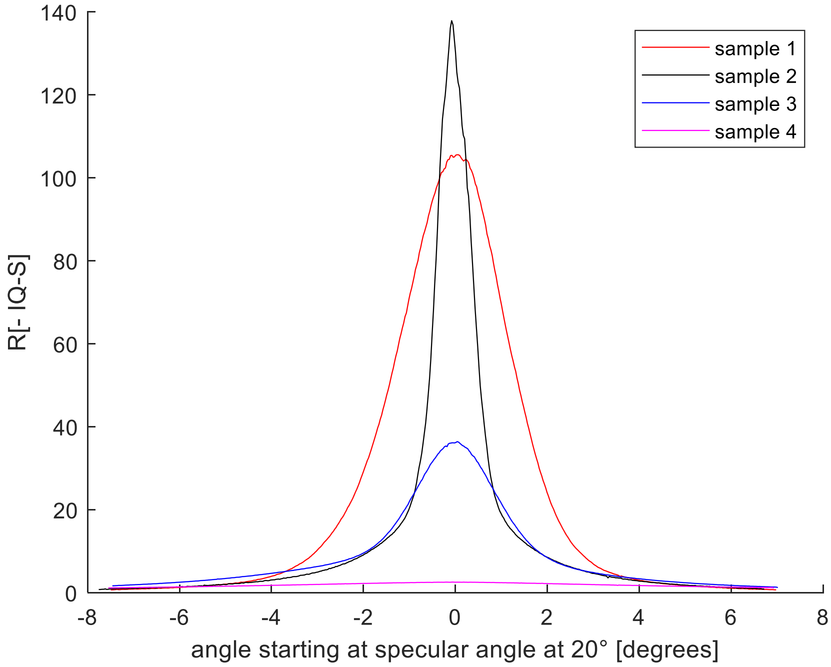

Figure 7: Gloss curves at the specular angle of 20° obtained with the IQ-S from Rhopoint. The more light is reflected on the surface in the specular direction, the higher the curve, the more diffuse the direction the lower the peak and the wider the curve. The name of the measurement device is included in the brackets of the y-axis to clarify the used instrument.

The measurement results obtained with the SRA give further data about the light distribution caused by the reflection. The different measured aspects of gloss can be seen in Table 3. The differences of the gloss values as well as the haze between the samples is similar to the measurement results of the IQ-S. It has to be noted though that the haze value of sample 1 is 300 HU, which is the maximum haze value measureable with the SRA. The scattering values C20 and C60 indicate that the reflection on sample 2 is the least diffuse and on sample 4 the most diffuse. They also indicate that the 2D BRDF of sample 1 and sample 3 almost have the same shape.

From looking at the measurement of sample 4 also the strength of the Canon unique values C20 and C60 become clear. For this sample almost all of the IC values are zero and if the sample would be slightly more matte, all of the IC values would result in zero. Hence, this aspect of gloss would not be comparable anymore to other samples. The C60 value however, that behaves invers to the IC values has a maximum of 1000 and makes a comparison of matte samples regarding the shape of the BRDF possible.

Table 3: Different aspects of gloss of the four samples at the angles of 20°, 60° and 85° using SRA from Canon. The values are derived by taken the arithmetic mean of 10 measurements at different point in machine and across machine direction. Haze and C20 are derived from the data of the area sensor at 20°. C60 and the IC values are derived from the area sensor at 60°. The haze of sample 1 should be higher but the maximum haze value of the SRA is at 300 HU.

Sample number	**1**	**2**	**3**	**4**
$gloss_{20}$ [GU]	640	545	199	12
$gloss_{60}$ [GU]	542	497	271	58
$gloss_{85}$ [GU]	97	133	90	61
haze [HU]	300	206	178	30
C20	69	19	65	260
C60	80	14	52	173
IC 0.25	0.00	3.14	0.00	0.00
IC 0.5	0.00	4.65	0.00	0.00
IC 1.0	0.70	23.81	3.46	0.00
IC 2.0	16.89	58.52	28.40	1.73

The 2D BRDF measurements at the specular angles of 20° and 60° using the SRA of the four samples can be seen in figure 8. It can be seen, that the shapes of the BRDFs measured at the specular angles of 20° and 60° only slightly differ. The shape of the 2D BRDFs measured at the specular angle of 20° of sample 1 and sample 2 look very similar, which also corresponds with the similarity of the C20 and C60 values of both samples. It is important to note that the maximum value of the BRDF is not necessarily in the center and that the BRDF is not symmetrical around the specular direction. This is the case for the BRDFs of sample 2 and sample 4. One reason for this could be the random texture of the surface.

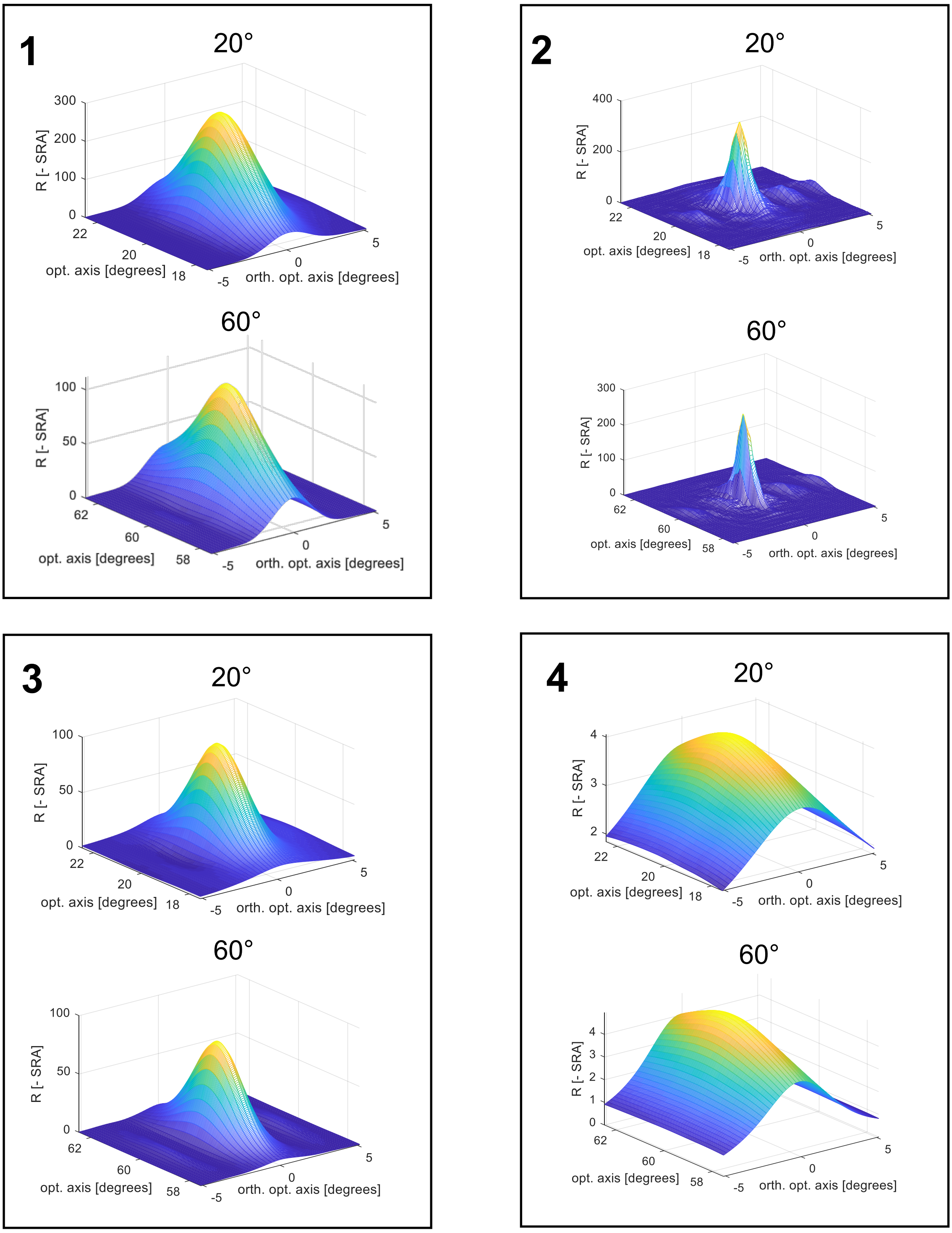

Figure 8: BRDFs measured at the specular angles of 20° and 60° using the SRA. The numbers from 1 to 4 at the sub-figures correspond with the numbers of the samples. It can be seen that the more diffuse the reflection the wider the peak. The maximum of the z-axis varies between the sub-figures. The name of the measurement device is included in the brackets of the z-axis to clarify the used instrument.

5 Conclusion

In this study, three instruments for the study of metallic gloss were compared. It was shown, what kind of aspects of gloss each instrument measures and measurements on metallic embellishments are presented. For different metallic samples with a high range of gloss it was shown that only measuring specular gloss as commonly done in the printing industry is not enough to characterize the gloss appearance because also the sensation of the sharpness of the reflected image comes into play for high gloss samples. However, it is not known yet which measured aspects or what kind of combination of the aspects fit the best to describe the different visual sensations of metallic gloss.

In further studies, visual investigation on metallic embellishments will be performed and it will be investigated further how the measurement results match with human perception for these kind of samples. These tests will be performed with samples produced with various printing techniques and it will be examined how the sensation of metallic gloss differs between samples from those different techniques.

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