J. Coat. Technol. Res., **18** (6) 1501–1509, 2021
https://doi.org/10.1007/s11998-021-00515-8

Consistent determination of the contrast ratio of white inks

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Received: 27 May 2020 / Revised: 7 May 2021 / Accepted: 10 May 2021

Abstract Translucency is a critical property of print on flexible packaging. It forms the basis for obtaining full color gamut, hiding the contents of a package and even creating the scanner readable digital codes for point of purchase tracking. The print industry has followed the paint and decorative coatings industry, the paper industry and the plastics industry in attempting to identify measurement methods that will accurately describe translucency or its opposite, opacity. Both of these properties are defined in terms of the contrast ratio, the ratio of the luminous reflectance of a coating placed over a black and a white substrate. In this paper, the theory of diffuse reflectance spectroscopy is used to define the measurements used to determine the contrast ratio. A brief experimental study illustrates the strong points and weak points of traditional contrast ratio measurements. A better model of contrast ratio determination is hypothesized, and an experiment is designed and reported that demonstrates both the validity of the hypothesis and a method for obtaining consistent estimates of the contrast ratio.

Keywords Opacity, Contrast cards, Saunderson correction

Introduction

Translucency is a critical property of the print on flexible packaging. It forms the basis for obtaining full color gamut, hiding the contents of a package and even creating the scanner readable digital codes for point of purchase tracking. Opacity, the complement of translucency, is also an important property of paints,[1] plastics[2] and papers.[3,4] The most fundamental definition of opacity comes from optical physics where it is stated that opacity is the ability of a material to prevent the transmission of light; it is the reciprocal of the transmittance factor.[5] Translucency is defined as the property of a specimen by which it transmits light diffusely without permitting a clear view of objects beyond the specimen and not in contact with it. Both effects describe restricting the transmission of light through the film, with opacity being the stronger or limiting case.

The listed industries have developed some type of index related to the visual perception of opacity. In these indices, the measurement includes the determination of a contrast ratio. Contrast is also a perceptual attribute in graphic reproduction, related to the visibility or detectability of print over the background or against the surround. Thus, there are many reasons to assess the contrast of print. Examples include the readability of information on packages, printed pages and barcodes. The printing ink business has attempted to adopt the measurement techniques developed by the paint and decorative coatings businesses for the measurement of translucency and contrast. This involved laying down a standard film of ink or coating onto a substrate that is partially white and partially black and reading the luminous reflectance (CIE Y tristimulus value) for each of the two areas. The contrast ratio is the ratio of the luminous reflectance of the film over the black area divided by the luminous reflectance of the film over the white area. The ratio is then scaled to 100 to simulate a percentage. From this measurement, the coatings industry will estimate the ability of a single layer of paint to hide the color of the wall or wall covering or to estimate the coverage of a single gallon of paint with the ability to completely hide the appearance of the surface under the paint. The

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thickness of the paint film is typically measured in *mils* or thousands of an inch. The opacity or hiding power is related to the area of coverage times the thickness of the film. In the plastics industry, a similar index is used but now the plastic is a polymer film that may be tens or hundreds of *mils* thick or a chip that is several millimeters thick. But ink film thickness is measured in *microns* and there are about 25 *microns* in a 1 *mil* thick coating or plastic film. Such thin ink films make it particularly difficult, if not impossible to obtain opacity, so an accurate index of translucency is critical to the printing industry. Typical median particle diameters for white pigments are 0.36 μm to 0.53 μm, so a nominal 1–2 μm ink film will have only 3 to 5 pigment particles between the top of the film and the bottom of the film. Fundamental to the accurate determination of the translucency of an ink film is the ability to make consistent measurements of the contrast ratio. This paper documents a study on the assessment of translucency via contrast ratio and is not concerned with how to formulate an ink to achieve a desired contrast

Theory

The use of the contrast ratio to determine opacity is based on the concept that a fully opaque film will not be influenced by the reflectivity of the substrate upon which it is printed. This is a fundamental precept of diffuse reflectance spectroscopy. An optically thick medium will not pass any radiant flux to the back of the layer, but all radiance will be returned to the surface by multiple scattering from the pigment particles uniformly dispersed within the coating. Thus, a polymeric film printed over a white substrate and over a black substrate should have identical luminous reflectance readings and the ratio will be unity or scaled to 100. However, it is highly unlikely that the optically thin ink layer will ever be able to approximate the scattering power of a 50 μm to 100 μm thick paint film or a 1000 μm thick plastic chip. It will thus be important to quantify the luminous reflectance of the ink over the black substrate as well as over the white substrate with great precision.

In a review of current practices in ink production laboratories, it is observed that several different issues might be contributing to the lack of agreement on the determination of the level of the contrast ratio of a printed white ink. The first issue of note is the use of various contrast cards on which the inks are printed. There is a range of card types, uncoated, matte coated and glossy sealed surfaces, each designed to interact in a nearly ideal way with the ink that is being tested. Thus, the same ink printed over an uncoated card, whose black area has only a 20% reflectance, and over a sealed card, whose black area has a 1% reflectance, will produce very different estimates of the contrast ratio. The second issue is that of measurement geometry. In times past, it was assumed that white materials produced a fully diffuse, uniform flux of reflected light and any reasonable instrument geometry would capture and characterize that flux equally well. The CIE[6] has reported that this is not the case and even densitometers, well documented in ISO 5,[7] are not well controlled enough to obtain the best inter-model agreement. While reviewing the measurement systems used to determine contrast ratio, the following geometries, described here in the terminology of ISO 5 and CIE 176, are identified in the various standards documents: 6 inch integrating sphere with diffuse influx of light onto the specimen and the capture of the directional efflux along the normal to the specimen (d:0), directional influx at 15° from the normal to the specimen and an integrated diffuse efflux collection using an integrating cube (15:d) and directional influx at 45 degrees from the normal to the specimen and directional collection of the efflux along the normal to specimen (45c:0). Finally, there is the geometry that involves hemispherical diffuse influx from an integrating sphere and directional efflux at 8 degrees from the normal to specimen (d:8). The first two methods are standardized in the paper industry, the third method is a standard in the graphic arts industry and the last method is used by both the paint and plastics industries.

Figure 1 shows a simplified schematic of the geometry of the measurement of translucency using the 45:0 bidirectional geometry instrument found in ISO 13655[8] which is the primary standard for optical properties of printed inks. This schematic illustrates the interaction of the various light beams with the inks, substrates and backing materials typically used in the assessment of the optical properties of printed flexible films. These films are used in many packaging applications including snack food bags, bread bags, retort pouches and candy bar wrappers. The white inks or coatings are used as a base for the colored inks that are applied to reproduce the product graphic and the brand identity and logo colors that are critical to the success of such products in the consumer market place.

When the light flux impinges on the surface of the ink film, some of the light is reflected from the surface in a specular or mirror-like direction. The amount of light is predicted by the laws of Fresnel.[9] For unpolar-

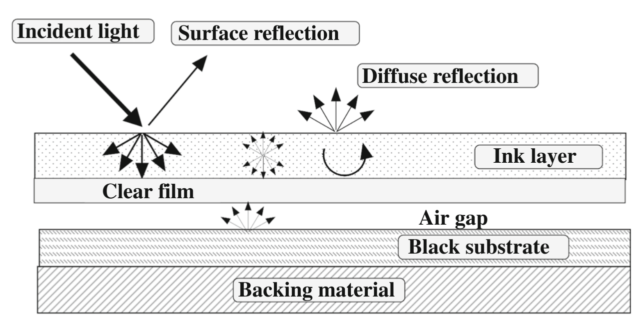

Fig. 1: Schematic of an ink film placed above a contrast card

ized light at the influx angle 45°, the specular efflux angle is – 45° (the other side of the normal to the surface) and the amount of light reflected is a function of only the refractive index of the two the media and the influx angle. In this paper, as is the usual case in optics, the angles shown here are all measured relative to the normal to the surface.

$$R(\theta) = 0.5 \times \left(\left(\frac{n_1 \cos(\theta_i) - n_2 \cos(\theta_t)}{n_1 \cos(\theta_i) + n_2 \cos(\theta_t)} \right) + \left(\frac{n_1 \cos(\theta_t) - n_2 \cos(\theta_i)}{n_1 \cos(\theta_t) + n_2 \cos(\theta_i)} \right) \right) \tag{1}$$

where n_1 is the refractive index of the polymer film (n_1 = 1.47) in air (n_2 = 1.0). The angle θ_{i} (45°) is the angle of *incidence* for a rectilinear beam and θ_{t} (29°) is the angle of *transmission* through the surface into the coating. The angle of transmission is easily obtained through the application of Snell's Law which relates the angles of the passage of light through a dielectric medium to the refractive index values inside and outside of that medium. This law of geometric optics can be found in most high school physics textbooks. The surface reflectance at θ_{i} = 0° is 3.6%, at θ_{i} = 40° it is 4.2%, at θ_{i} = 45° the surface reflectance is 4.6%, at 60° the reflectance is 8.4%, at 75° the reflectance is 24.7% and at 90° the surface reflectance is 100%, such that no light enters the ink film (Fig. 2).

When the light comes from within the ink film and attempts to exit the polymer film and enter the air, the role of the angles will be reversed but not the identification of the materials. The air still has a refractive index of 1.00 and the polymer film a refractive index of 1.47. Now, there is a critical angle beyond which the reflectivity becomes a constant 100% and all light is bent back into the ink film. For the polymer film with a refractive index of 1.47, this critical angle is 42.9°. This is the effect that produces total internal reflection that is so useful in mid-infrared spectroscopy. This shows that it is more difficult for light to reach the detectors in a 45:0 or 0:45 spectrocolorimeter (Fig. 3).

Once the light enters the ink film, the pigment, normally some grade of titanium dioxide, scatters the light multiple times. Most of the scattering is in the forward direction, but some of the light is scattered away from the forward direction. If this happens enough times, then the light is redirected back up to the surface where it entered the ink (shown in Fig. 1 by the looping arrow). Thus, full opacity requires that the light flux interacts with multiple pigment particles. This is the case in optically thick paint films or plastic chips but is not the case in optically thin ink films.

The light that is not scattered away from the forward direction and the light that is unscattered or scattered so many times that it is propagating downward, once again, reaches the back of the ink film. There, some of it exits the film and enters the backing. The white backing reflects most of the light that enters it and that light again enters the ink film. The black backing reflects only a very small amount of the light that reaches it and much of that small amount may be specularly reflected back into the black backing from the bottom surface of the ink film. But some of the light that interacted with the black backing is propagated back up through the ink film and emerges into the air above the ink film. Both the white backing and the black backing exhibit diffuse reflection and so the light that passes between the upper ink film and the backing is subject to Fresnel reflection, which has already been described.

If the ink film is applied directly to the white and black substrate, as in the case where the substrate is a contrast card with the ink applied by a printability tester or hand-proofer, then the ink film is said to be in optical contact with the contrast card. The surface of

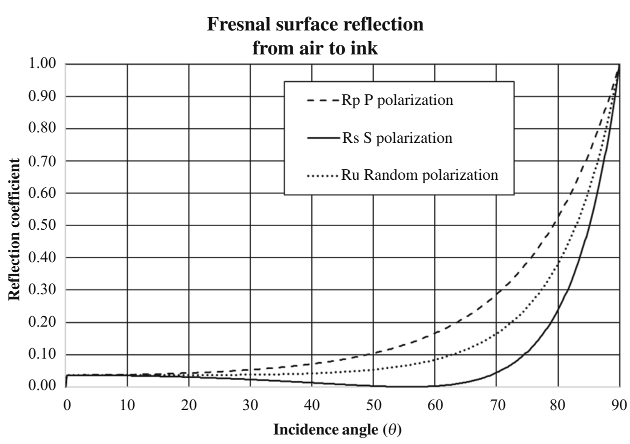

Fig. 2: Surface reflection—Light is incident on the ink film from the air. Traditionally, the subscript P indicates that the electric field vector is parallel to the plane of incidence (German *parallel*) and the subscript S indicates that the electric field vector is perpendicular to the plane of incidence (German *senkrecht*). U is then random polarization in which the electric field vector is a blend of P and S fields and is typical of incoherent light sources

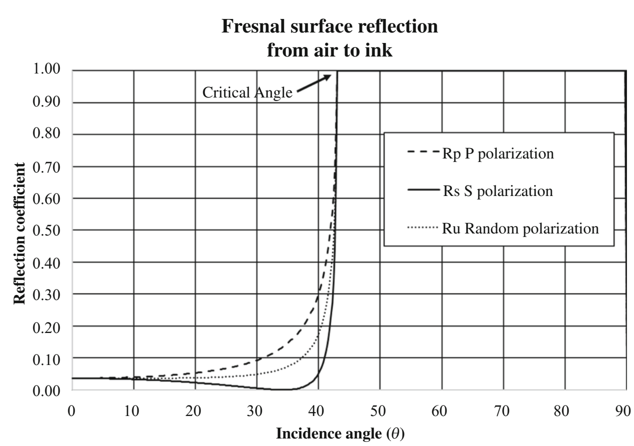

Fig. 3: Surface reflection—Light is incident on the air from inside the ink film

the contrast card is normally coated or sealed and the polymer in that coating has a similar, though rarely identical, refractive index to the ink. In the case where the refractive index of the incident medium, n_i, is identical or very similar to the refractive index, n_t, of the transmitting medium, there is little to no surface reflection between the layers. In the case where the ink layer is printed on a clear film and that film is simply laid over the contrast card, there is an air gap between the two films and that produces a large difference in refractive index and a large amount of specular surface reflection. Figure 4 shows images of two ink films printed on a clear, polyester film. One ink film is a white ink and one is a black ink. The white ink is printed directly onto the polyester film and onto the black ink which has also been printed onto the polyester film, just as might be done with a contrast card. For reference, the middle image shows the black ink on the clear film, next to the black area of a typical contrast card. The luminous reflectance (Y) of the two black areas is virtually identical. The background is a white, uncoated card stock (a), and the contrast ratio is 65 which is typical of a white ink printed on film. Printing ink films are typically only about 1 micron thick, which is about 25 times thinner than an industrial coating. The white ink appears grayish over the black ink on the polymer film, but it appears much brighter over the black of the contrast card. In (b), the black band of a contrast card is slipped behind the black area and shows that the two black areas are visually identical. In (c), the black band is repositioned behind the white ink print. The area on the right appears brighter, indicating a higher luminous reflectance. The measured translucency of the ink film over the black card is visibly and measurably higher than the same ink film printed over the black ink that matches the blackness of the contrast card. This is the aspect of translucency related to the polymeric film not being in contact with the backing. Since the contrast ratio is the ratio of the luminous reflectance of the over black to the over white measurement, the contrast ratio of the print is higher (88) when placed over the black backing than when printed directly onto the black backing.

This prompted a question, ‘‘What is the correct contrast ratio for this white ink?’’ Clearly, not only is the translucency dependent on the contrast ratio but also on the how the specimens are prepared for measurement. The contrast ratio is composed of the reflectance of an ink film over the white backing and the reflectance of the same ink film over a black backing. An experiment to understand the relationship between reflectivity and translucency was needed.

Experiment

An experiment was undertaken to systematically study the two sets of effects, reflectance of the ink and reflectance of the backing and determine how they might be related to each other and if possible, a correction or correlation function would be derived. This would allow laboratories using two different methods to inter-relate their measurements and specifications in a meaningful way.

The experiment was designed to assess the sensitivity of the commonly used methods to determine the contrast ratio. Four substrates were selected, a standard, sealed contrast card with a black area in the center, supplied by BYK-Gardner,[10] an uncoated white paper often used as a backing sheet for color measurements, also supplied by BYK-Gardner, a plastic synthetic paper with a semi-matte appearance and very high luminous reflectance, supplied by Yupo USA,[11] and finally a clear polyester film normally used in the packaging ink lab for testing solvent inks. The inks used were Sun Chemical[12] opaque white solvent ink and Sun Chemical process black solvent ink. For the uncoated white paper and the Yupo synthetic paper, a black area was printed across the center of the paper so that the appearance was similar to that of the standard contrast card.

The experiment involved 27 prints of a white solvent-based ink on the various paper and film substrates. The test prints were produced with either an RK Coater[13] with a #6 bar to lay down a thick layer of black ink or a handheld anilox proofer to lay down a thinner layer of white ink. For a substrate without a black area, one was added to the paper or film substrate using the RK Coater. Finally, a print of the white ink was made over the black and unprinted (white) areas of the substrate. Readings of the contrast ratio were taken using different types of backing materials, both white and black. The contrast ratio was measured using a standard, handheld spectrocolorimeter, the X-Rite eXact.[16] Table 1 shows the results of these readings. Given that the ink and method of

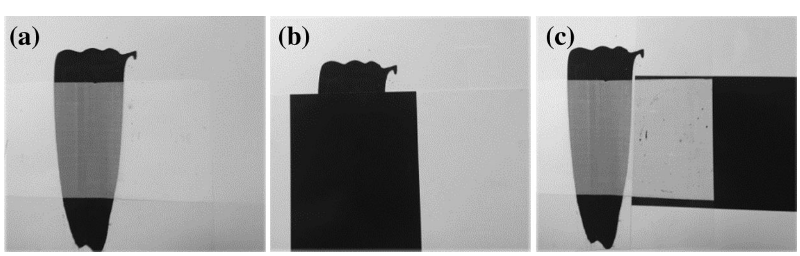

Fig. 4: Print of a white ink on a clear film

Table 1: Luminous reflectance (*Y*) and contrast ratios of the same white ink printed on different substrates and backed with different white and black backings

Print #	White backing	Black backing	Ink over the white	Ink over the black	Contrast ratio
1	83.9	6.7	86.2	21.8	25.3
2	84.6	7.1	86.4	22.7	26.3
3	84.3	7.0	87.1	26.2	30.0
4	82.1	10.7	85.5	27.2	31.9
5	96.4	2.0	96.9	31.9	33.0
6	79.1	0.9	88.1	30.8	34.9
7	95.9	1.0	96.4	34.7	36.0
8	82.3	0.9	86.9	31.7	36.5
9	96.2	1.8	96.7	40.0	41.4
10	82.3	1.7	86.4	38.0	43.9
11	79.4	1.3	88.6	40.6	45.8
12	82.5	1.4	86.7	40.7	47.0
13	78.9	1.7	87.9	36.6	41.7
14	84.1	17.1	86.0	36.0	41.8
15	82.1	5.2	86.7	34.9	40.3
16	81.8	0.7	86.0	36.5	42.5
17	95.7	5.6	95.9	34.6	36.0
18	82.7	7.9	85.5	22.0	25.7
19	95.9	4.4	96.7	42.8	44.2
20	79.4	1.9	88.3	30.1	34.0
21	82.5	2.1	86.9	30.3	34.8
22	96.4	19.1	96.9	36.6	37.8
23	79.6	26.3	87.6	43.7	49.8
24	82.3	16.0	86.9	35.7	41.1
25	75.2	0.8	86.4	59.9	69.3
26	81.2	1.6	90.0	59.7	66.4
27	100.3	0.3	96.2	57.6	59.9

Print #27 was measured with a sintered PTFE white plaque and an instrument light trap.

application were consistent, it can be seen that the method of sample presentation is a significant contribution to the variability in the determination of the contrast ratio. An unpublished study by the Flexographic Quality Consortium has reported that contrast ratio determinations of opaque plastic films has a gage R&R repeatability of 0.32 contrast units for white polymer films with a measured contrast ratio of 82 units.

Further measurements were made using two commonly used instruments, a Technidyne BNL-3 Opacimeter,[14] (Fig. 5) an X-Rite Ci7800[15] (Fig. 6) and an X-Rite eXact[16] (Fig. 7) handheld spectrocolorimeter. The BNL-3 is designed for testing the opacity of a single sheet of paper and conforms to the TAPPI T-425 and ASTM D589 test methods for opacity of paper using the 89% backing method. These methods are duplicates and require the use of a ceramic tile with a luminous reflectance of 89.0 and a black backing with a luminous reflectance of 0.5 or less. It has an approximately 15° influx angle and diffuse viewing using a white coated cube. In this method, the specimen holder has a white ceramic tile in one side of the handle that has a diffuse reflectance factor of 89% while the other side of the handle has a cylindrical cavity lined with black felt. The instrument is used by placing the paper onto the specimen port and adjusting the white tile in the handle to hold the paper in place. The instrument is then set to read 100 units for the paper over the white backing. The handle is then reversed without removing the paper and the black light trap is placed over the paper. The instrument

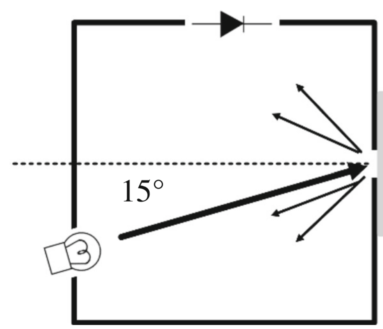

Fig. 5: Schematic of the BNL3 Opacimeter. Light is incident at 15° from the specimen normal and the reflected light is collected into a photodiode from a white-coated integrating cube

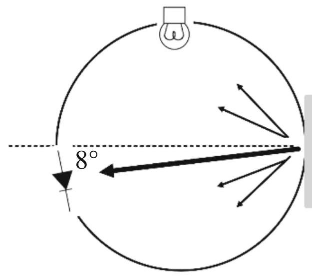

Fig. 6: Schematic of the X-Rite Ci7800 spectroreflectometer. The light is incident onto the diffusely and the reflected light is collected by a diode array spectrograph at 8° from the specimen normal

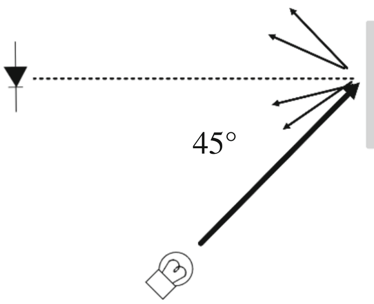

Fig. 7: Schematic of the eXact spectrocolorimeter. Light is incident at 45° from the specimen normal and the reflected light is collected at 0°, along the normal to the specimen

display shows the fraction of the 100% setting, and the readout is thus, a direct display of the contrast ratio as a percentage. The detector is filtered to approximate the *Y* for CIE illuminant A and the 1931 CIE standard colorimetric observer.

The X-Rite Color i7800 is a general-purpose laboratory spectroreflectometer with a 150 mm diameter, Teflon® coated integrating sphere that provides diffuse influx and an efflux angle of 8 degrees. The efflux is captured by a diode array spectrometer and the digitized reflectance factor data are converted into CIE tristimulus values by numerical integration. For comparison, the same CIE illuminant and observer were utilized as were present in the BNL-3.

The X-Rite eXact is a portable, handheld spectrocolorimeter that conforms to the requirements of ISO 13655, having a circumferential influx geometry at 45° and an efflux angle along the normal to the specimen.

Results

The readings of the 27 ink prints were compared to each other for the two instruments used in the experiment. Table 2 shows the contrast ratio for the 27 prints using readings from the eXact as an example of the range of the measurements. In each print, the white ink is identical, only the substrates and method of backing the print have been changed.

Table 2: Contrast ratio readings from three instruments

Ink level	Ci 7800	BNL-3	eXact
25%	28.8	32.3	27.5
50%	46.9	50.5	45.7
75%	49.1	50.4	47.7
100%	49.7	52.1	49.3
200%	58.4	59.3	56.8

The same ink printed in the same way on these different substrates and backing materials, produced contrast ratios between 25 and 69. The repeatability from such determinations has a standard deviation of 0.3 as indicated previously.

Clearly, the reflectivity of the substrate and or the backing have a significant influence on the measurements. Relatively good agreement was obtained between predictions for inks which were in optical contact with the substrate compared to those which had no optical contact with the substrate. For example, specimens 20 and 21 versus specimens 15 and 18.

The theoretical prediction for internal surface reflection for a medium that is fully opaque is that roughly 60% of the light that is incident on the boundary between the ink film and the air will be reflected back into the medium. Practical experience with thick plastic films has shown that for a light flux that is not fully diffused, the expected reflectance is closer to 40% or maybe a little less.[17]

In the printed white ink example in Fig. 4, some of the light incident on the white ink film is diffused and directed back out of the film into the hemisphere above the film where it is observed as a light gray over the black ink underneath the white ink. Light that does not scatter back up into the upper hemisphere is trapped and absorbed by the black pigment. In image (c), the light that is not scattered upward reaches the back boundary of the polymer film and 40% is diffusely reflected into the ink film. That reflected light reaches the upper surface and about 40% of that light flux is again reflected into the ink film. So then over the air gap, Fresnel optical theory would indicate that the apparent reflectance of the white ink over the black card should be 60% × 40% or about 24% higher than in the case where the white ink is printed directly onto the black ink. This is quite close to the observed 22% difference in the measured luminous reflectances.

In fact, one need only to reduce the diffuse Fresnel reflectance from 40% to about 38% to achieve exactly the results observed. This effect was first reported by Saunderson and is documented in most textbooks on computer color-matching and turbid medium theory. For a perfectly diffuse medium, the diffuse correction is normally given as 60% but Saunderson reported using 40% for plastics and Garcia-Valenzuela also reported that 60% was too high even for a simple white paint film, where the contrast ratio is about 90%. So, it is not exceptional that the Sauderson correction for a translucent ink film may be just less than the 40% seen in plastic chips.

Table 2 shows the agreement between the three instruments for the estimate of the contrast ratio. The white inks were printed on clear film at the normal film weight and concentration. This is identified in the table as 100%. Then a second print, known as a double bump, was applied. Finally, the full-strength inks were cut with clear varnish so that the concentration was 75%, 50% and 25% of the standard load. Since the opacity is derived directly from the contrast ratio, this is a good indicator of how large the disagreement of the readings is to be expected. Note that the BNL-3 always shows a higher contrast ratio than the other two instruments.

The agreement between the instruments is not particularly good. This has also been reported in the field where testing performed on a BNL-3 and on portable spectrocolorimeters has led to significant disagreements.[18] This result has recently been confirmed in an unpublished, internal study by the Flexo Quality Consortium (FQC) committee of the Flexographic Technical Association.[19]

The three different commercial instruments, with well-known but vastly different geometries, were used to collect data on the same set of specimens. Statistical analysis of the predictions of the different instruments showed that a simple linear correction for the light lost in the interface would provide a very high correlation between measurements from instruments with different geometries. But this would make the translucency prediction much more mathematically complex, perhaps requiring estimates of the surface reflection for differing diffuse conditions.

Figure 8 shows a plot of the ratio of the over white reading from the white backing versus the reflectance of the white substrate. The scatter of the data shows two distinct trends.

The ink films were laid down using the flexo handproofer as consistently as possible within the constraints of the proofer. Replotting Fig. 8 with the 7 highest reflectance substrates removed is shown in Fig. 9. Here the linear relationship is much stronger. This indicates that when the reflectance of the ink over the white is lower than the reflectance of the white backing, the reflectance is dominated by the reflectance of the backing. When the white ink reflectance approaches that of the backing, then the over white reflectance varies as a function of the ink film. Under these conditions then, minor variations in the micron thick ink film becomes a major source of uncertainty in the determination of the contrast ratio.

In addition to the stronger linear relationship between the luminous reflectance of the ink and that of the white area, the variability of the data is proportional to how much influence the coating film weight has on the measured reflectance.

This is to be expected since the scattering power of the ink film is proportional to SX, where S is the ensemble scattering coefficient of the pigment dispersion, including effects of particle size and concentration of scattering centers, and where X is the actual optical thickness of the ink film. Variations in ink film thickness will have a direct effect on the reflectance of the ink film on the same order of magnitude as the load of the pigment.

Figure 10 shows the corresponding data for the 27 specimens but this time comparing the luminous reflectance of the ink film over the black area versus the luminous reflectance of the black area. The data plotted in Fig. 10 shows some unexplained variations. For example, the small cluster of points between 5% and 10% luminous reflectance exhibit an over-black reflectance of from 20% to 27%, while specimens printed over black area with approximately a 5% luminous reflectance exhibit a luminous reflectance of 35% to 43%. This magnitude of difference cannot be attributed to variations in film thickness.

If the data are separated into the type of substrate, some additional information is made clear but much of the mystery remains. The data shown in Fig. 11 identify that there is a strong relationship between the measured luminous reflectance of the ink printed over the black area on the uncoated paper substrate but not so

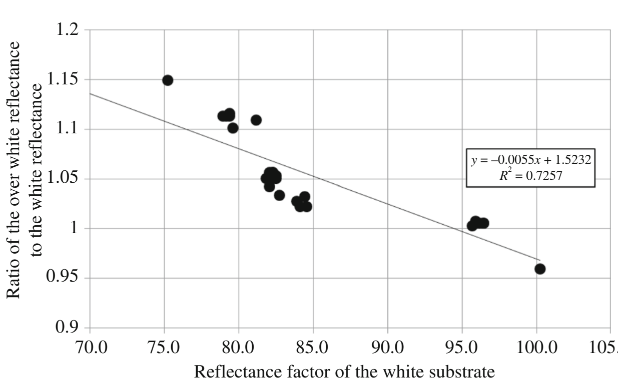

Fig. 8: Ratio of the luminous reflectance (*Y*) of the ink over the white area to the luminous reflectance of the white area as a function of the luminous reflectance of the white area

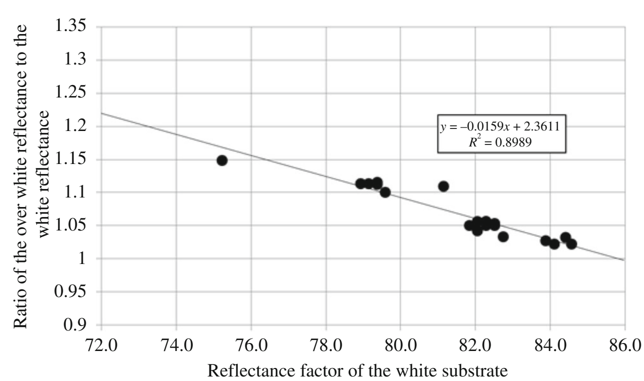

Fig. 9: The same variables as in Fig. 8 but with the 7 highest reflectance substrates removed from the plot

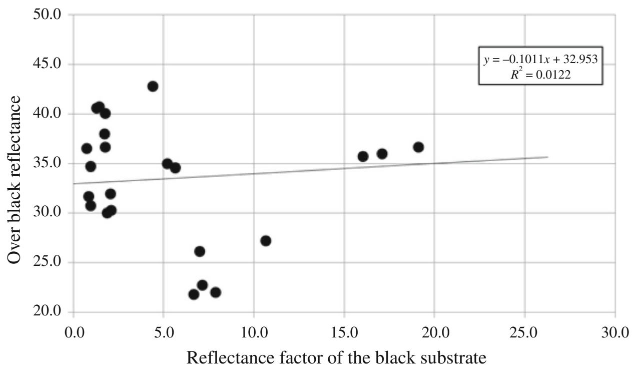

Fig. 10: The luminous reflectance of the white ink over the black area versus the luminous reflectance of the black area

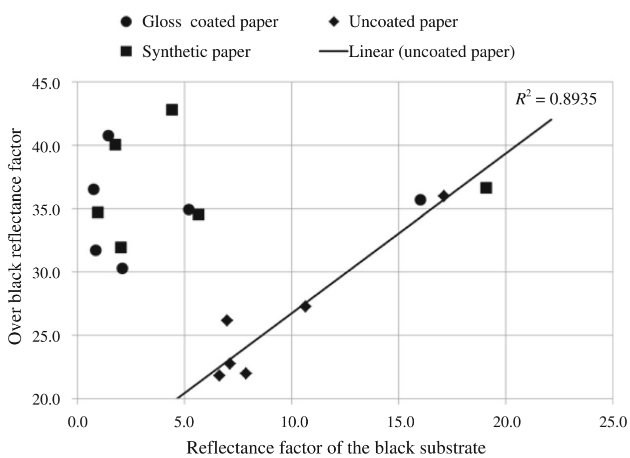

Fig. 11: The same data as shown in Fig. 10 but with the type of substrate identified by the shape of the plotted point

for the other substrates with significant ink holdout. It is important here to note, that in as much as was humanly possible, the white ink film printed over the different black areas has the same optical properties and film characteristics. Truly, ''This is a puzzlement!''

Since the surface of the substrate is consistent within each group of materials, and in particular with the YUPO synthetic paper, the variations in the measurements of the luminous reflectance of the flexo printed white ink over the black area must arise from either specimen preparation errors or significant variations in the adhesion of the white ink onto the previously printed black ink.

Thus, it is possible to observe random variation in the primary modulating property of the assessment of opacity on the order of ±5% due to inconsistency in the application of the hand proofer, just as it was for the prints over the white area.

One may then conclude that to control the measurement errors due to film thickness variations and obtain improved reproducibility, two things are required. First, to maintain the linearity of the over-white measurement, the white backing should be constant

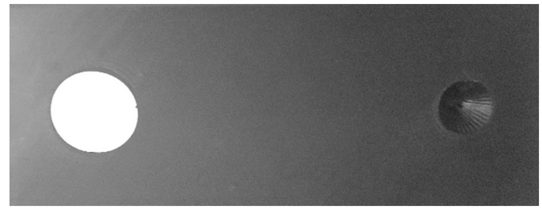

Fig. 12: Image of an opacity test plate. To the left is the AluWhite98 reference white backing tile and to the right (difficult to see) is a cone shaped black cavity to trap light

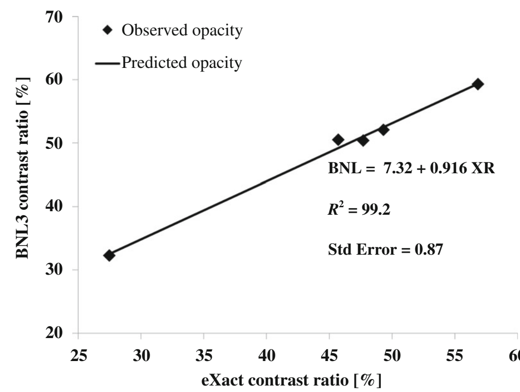

Fig. 13: Regression of the BNL3 (15:d) readings on the eXact (45:0) readings. In the predicted equation, the symbol XR indicates the X-Rite eXact reading and the symbol BNL indicates the BNL3 reading. The standard error is well below a reasonable commercial tolerance on the determination of the contrast ratio of a printed ink film

and whiter than any pigmented inks. Second, to avoid surface inter-reflections and to minimize the diffuse reflectance from the black backing, the black area should have no surface at all. This is similar to the design concept behind the BNL-3, except that an 89% reflecting white plate is specified for the white backing. At the time that this documentary standard for paper opacity was developed, 89% was considered to be a very high reflectance, compared to commonly available papers and ceramic tiles.

Therefore, a special specimen holder was prepared using 3D additive manufacture that contained an optical trap and a special white ceramic backing plate, AluWhite98 from Avian Technologies.[20] This hard ceramic is very white and has a matte surface, reducing the surface inter-reflections between the white and the back of a clear film or paper. It is made from some form of sintered aluminum oxide power. The luminous reflectivity of the white ceramic was very near to 100% (0.9932) and the optical trap reflectance was very near to 0% (0.0003). Figure 12 shows an image of the opacity plate.

If one regresses the BNL-3 predictions onto the eXact predictions, the fit is amazingly good. The resulting regression equation for contrast ratio is obtained from the data in Fig. 13.

$$\text{BNL3\_ContrastRatio} = 7.32 + 0.916 \times \text{eXact\_ContrastRatio} \quad (2)$$

The square of the correlation coefficient is 99.4% and the mean absolute error of the estimate is 0.15% absolute contrast units, about half the size of the standard deviation for reproducibility reported by the FTA study. The eXact can be used to approximate the BNL-3 if a white ceramic plate is used for the backing and a light trap for the black backing. The X-Rite Ci7800 can be modeled this way as well and for this dataset, the standard error is very slightly larger but the linear correlation is the same. Since the X-Rite eXact is the more common instrument used in flexible packaging it is of primary concern for this model.

Conclusions

An experiment on the assessment of contrast ratio was carried out to better understand the differences between determinations of contrast ratio of white inks with spectrodensitometers and the determinations using an opacity meter. The results show that the differences in the reported contrast ratio are due to the specimen preparation and the presentation of the specimen to the instrument and not to differences between the instruments. It is concluded that a more consistent or absolute determination of contrast ratio of translucent, non-opaque materials (contrast ratios below 90%) requires that the backing white must have a luminous reflectance equal to or greater than the intrinsic reflectivity of the white material. Further, the backing black area must have a luminous reflectance of less than 2% absolute reflectance factor (L^*<16). Absolute readings may be achieved by correcting the measured reflectance of the ink or translucent material over the white area and over the black area with the appropriate Saunderson surface corrections. Modern optical reflectometers are inherently repeatable and linear. But differences in geometry or in the imposed scale of reflectance factor result in small to moderate differences in readings of the same material. A simple linear equation was derived using linear regression that can relate the readings of one type of instrument to another for the same types of specimens. This is especially possible in the case of assessing white and near white coatings. In this study, the modern X-Rite eXact was modeled to read like the, now out of production, Technidyne BNL-3, thus extending the scale of contrast generated by that instrument. The standard error of the estimate of the model is less than 1% of the contrast ratio.

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