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Spectrophotometric Examination of Rough Print Surfaces

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Abstract
The objective was to assess the impact of the surface texture of individual creative paper types (coated or patterned) on the quality of printing and to identify to what extent the various creative paper types require specific types of spectrophotometers. We used stereomicroscopic images to illustrate unprinted and printed surfaces of creative paper types. Surface roughness was measured to obtain data on the unevenness of surfaces. Spectrophotometric tests were used to select the most suitable spectrophotometer from meters with different illumination setup for testing any given print. For the purpose of testing, we used spectrophotometers which are commonly available generally used to test print products for colour accuracy. With the improvement of measuring geometries, illumination setup, colour measurement becomes more and more capable of producing reliable results unaffected by surface textures. Our tests have proved this fact by showing that the GretagMacbeth Spectrolino with annular illumination is less sensitive to surface texture than the X-Rite Spetrodensitometer and the Techkon SpetroDens with directional illumination. Further tests have brought us to the conclusion that there is a difference even between the two devices with directional illumination. While the X-Rite 530 Spectrodensitometer is more suitable for testing coated surfaces, the Techkon SpectroDens can come close to ΔE*ab values produced by the annular illuminated device for textured surfaces.

Key words: design (creative) papers, surface roughness, colour measuring geometries, illumination setup, colour gamut

Introduction

Nowadays customers and printing houses strive to create the most special possible products which appeals to all senses and thus engages the target group. The ever-growing range of creative paper types do not only provide a primary function of any print product but also help customers communicate positive messages such as environmental awareness, a demand for high standards, or even power.
Such paper types differ from conventional paper in surface texture and also pose printing difficulties with an impact on the quality of colour rendering.

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We were curious to learn how the measuring geometry/illumination setup of locally available spectrophotometers affect or distort measuring results on creative print surfaces, and what degree and direction of colour shifting they may cause.

Creative papers

The production of creative paper types is varied according to material quality, colouring and surface texture. The starting material for all types of paper is called the base paper, which is surface-finished, impregnated, coated or treated in some way and provided with qualities to match its intended use.

Creative paper categories are as follows:
- smooth/matte (e.g. Rives Artist),
- textured (e.g. Rives Design),
- metallic (e.g. Galaxy),
- transparent (e.g. Cromatico),
- containing inclusions (e.g. Keaykolour Recycled Natural and Mineral).

Smooth, matte-surfaced creative paper types include pulp-coloured paper, smoothened and coated India paper types. Such India paper has a loose fibre structure, high cotton content and are thicker than paper types of the same grammage. Various additives are used to lend the paper a special appearance (e.g. paper product families with a parchment or marble look).

Special surface textures are provided by means of embossing *(Figure 1)*. Various patterns are textured using an embossing roll and counter-roll. A base paper with a moisture content of 8-12% should be used to allow for elongation.

A metallic appearance can be achieved through application of a special coating that creates a continuous layer, adhering to the carrier surface.

Paper can be coated by various methods. Metallisation comprises the application of an aluminium or bronze film of molecular thickness. Metallic paper is produced using so-called metallic flocks which may be of aluminium or bronze, as well. For this method, the carrier is some sort of adhesive material, normally varnish or a casein solution. *(Antalis, 2010)*

Transparent (aka parchment) paper is used using an impregnating method. Parchmentisation involves the base paper being run through a bath of sulphuric acid and then that of ammonia for neutralisation before being dried.

Paper types with inclusions are normally of recycled paper, which may contain primary or recovered fibre.

Base paper for creative paper types always undergo some kind of surface treatment, whether physical or chemical. Surface treatment is a paper production process change changing surface qualities either temporarily (e.g. corona treatment) or permanently (e.g. coating, laminating or impregnating) *(Annus, 2003)*.

Measuring geometries used at spectrophotometry

The optical characteristics of samples subjected to spectrophotometric testing mainly depend on two factors – the illuminating light source and the geometric arrangement of sample and sensor, that is, the measuring geometry.

Differences between reflective values obtained through testing with various measuring geometries are due to a normally mixed nature of the spatial distribution of radiation reflected from sample surfaces (as mentioned earlier). In summary, a varied extent of specular reflection also occurred in addition to diffuse reflections with most of the samples. To allow reproducibility of testing conditions, CIE standardised four measuring geometries in 1931:

45/0 measuring geometry: the beam illuminating the sample is at 45° from the surface normal with a maximum allowable deviation of 5°. The angular difference between the direction of detection and the surface normal may not exceed 10°.

0/45 measuring geometry: the beam illuminating the sample is perpendicular to the sample surface with a direction of detection of 45° and no difference over 5° being allowed

The above two measuring geometries are called guided measuring geometries. They are less sensitive to sample luminosity, but such measurements are influenced by the surface texture. Therefore, industrial testers use illumination and detection from multiple sides.

For diffuse reflective measurements, the tester must be fitted with a so-called integrating sphere to transfer diffuse reflected light to the detector.

The inner side of the integrating sphere is coated with a non-absorbent material (i.e. not absorbing light) such as MgO or $BaSO_4$.

d/0 measuring geometry (diffuse/perpendicular): the integrating sphere illuminating the sample in a diffuse manner. The angle between the surface normal and the direction of detection cannot exceed 10°.

0/d measuring geometry (perpendicular/diffuse): the angle between the axis of the beam illuminating the sample and the sample normal is below 10°. Light beams reflected from the sample are gathered by the integrating sphere.

For diffuse measuring geometries, the sample texture does not at all or only slightly influence the measurement.

The following codes are used for diffuse measuring geometries:

di:8°: diffuse illumination, detection below 8°, with reflective component included. The result obtained will be R = reflectance factor.

de:8°: diffuse illumination, detection below 8°, with reflective component excluded. Its symbol is R, as well *(Schulz, 2008)*.

Test printing and measurements

For measurements we designed an appropriate testchart with primery and spot colours *(Figure 1)*. Test charts were printed on the creative paper products using an OKI C9600 colour laser printer at standard working setup *(Szentgyörgyvölgyi, 2010)*.

Because the test objective was to assess to what extent the various surface textures of creative paper types

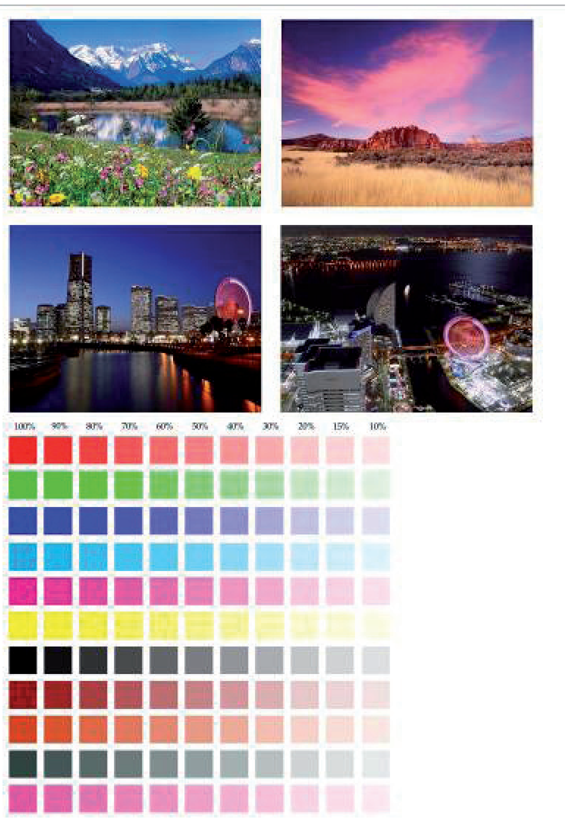

Figure 1: Test chart

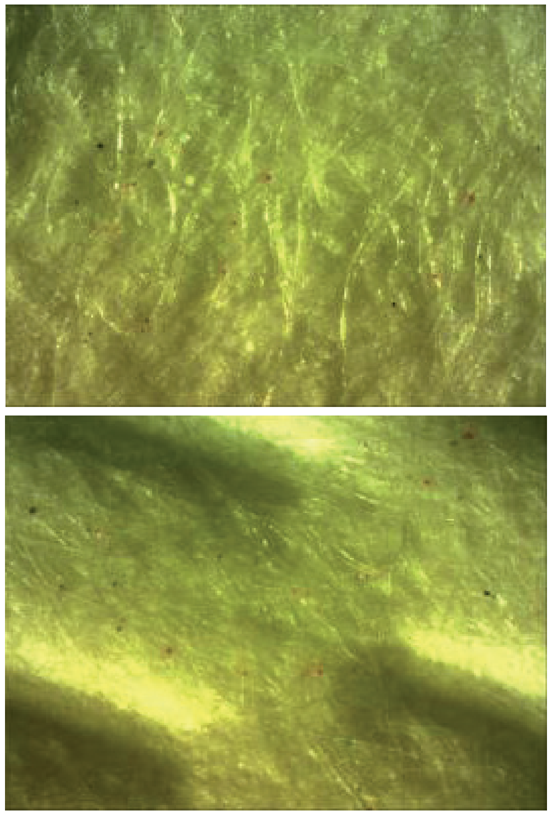

Figure 2: Stereomicroscopic image of Rives Tradition and Rives Design

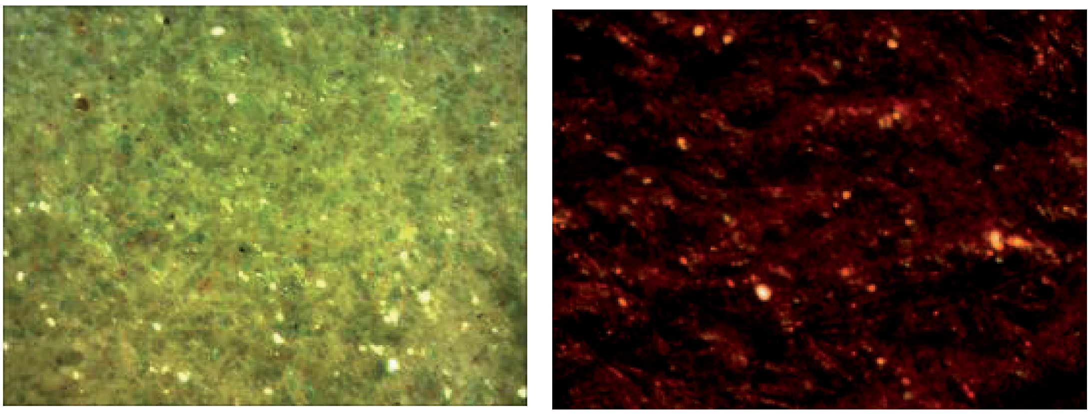

Figure 3:Stereomicroscopic image of Curious metallic pearl és Curious metallic purple

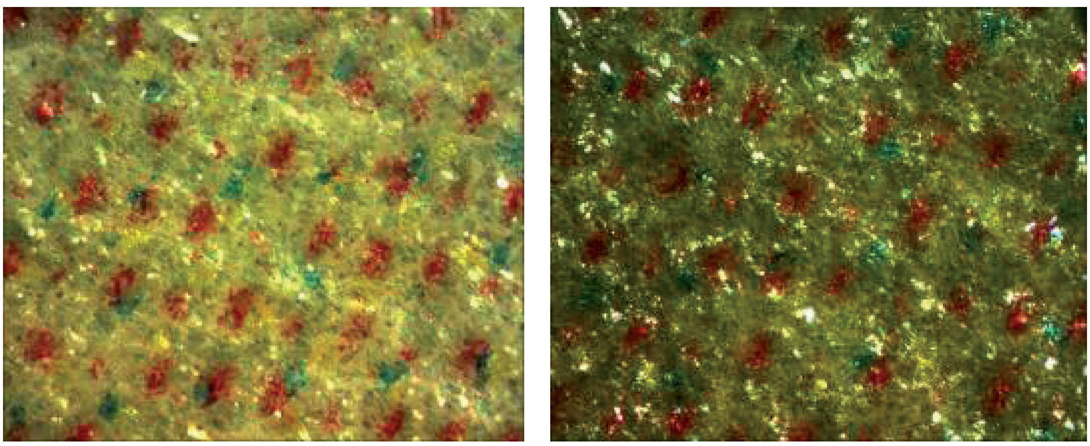

Figure 4: Stereomicroscopic image of printed Curious metallic pearl and Curious metallic silver

(whether coated or patterned) influence the results of spectrophotometric testing. In selecting paper types, attention was paid to ensuring that samples differ in properties. Accordingly, watermarked paper, paper with random and regular surface textures created using embossing rolls, as well as coated and pulp-coloured paper types.

Our testchart were printed on the following types of creative papers:

- Curious metallic pearl,
- Curious metallic silver,
- Curious metallic purple,
- Rives Tradition white,
- Rives Design white,
- Chamois watermarked,
- DIPA matt coated,
- Canon copy (for etalon).

Surface examination

A stereomicroscope type BTC was used, connected to a Tucsen digital web camera was used to examine printed and blank sample surfaces. Microscope images of samples were displayed on a screen and recorded using TSview software. Samples were illuminated with lamps from underneath and from the sides.

Paper samples types Rives Design and Tradition had surface textures created using embossing rolls. While Rives Design had a regular surface pattern, Rives Tradition had an irregular surface pattern. Such and similar surface textures are typical of Rives-type paper products *(Figure 2)*.

The selection of samples included a surface-treated base paper coated to give it a pearl finish (Curious Metallic Pearl) and a pulp-coloured paper product with a metallised finish (Curious Metallic Purple) *(Figure 3)*.

The bright spots made visible by lateral illumination are reflections from the particles that lend the paper a metallic look. This effect has an influence on the quality of the image printed on the surface. Out of specially coated samples, the ones with a pearly finish were found not to have the same absorbing capacity as non-coated paper. In addition, incident light is more easily reflected from coated surfaces. Owing to such effects, the print colour intensity falls short of that of prints on conventional, non-coated paper *(Figure 4)*. Watermarked paper type Chamois shows a surface image nearly identical with that of the Rives Tradition *(Figure 5)*.

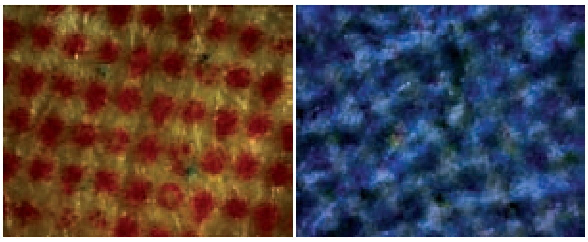

Figure 5: Stereomicroscopic image of printed Rives Tradition és Chamois watermarked

Surface roughness measurements

Roughness of paper comes from various types of surface unevenness (either intentional or occurring through production failures) whose micro-geometric characteristics can be mapped using state-of-the-art electronic topographic measuring devices.

The test objective was to determine the roughness of the paper types selected. A Mitutoyo SJ-201P roughness tester with a contact sensor was used for roughness testing. Measurements were done on each sample both longitudinally and transversely. The characteristics recorded during testing were R_a, R_z,R_q, $R3_z$ with PC75 filter (as per Standard ISO 1997). Measured values were exported into an Excel spreadsheet, containing

Table 1: Paper roughness

Type of paper	Roughness (µm)							
	Transversely				Longitudinally			
	R_a	R_z	R_q	$R3_z$	R_a	R_z	R_q	$R3_z$
Rives Tradition	4,25	29,80	5,33	25,60	4,25	29,80	5,33	25,60
Rives Design	4,07	20,80	4,85	11,30	11,33	46,24	14,42	-
Curious metallic purple	4,96	27,19	6,19	12,81	3,55	19,06	4,35	-
Curious Metallic Pearl	2,77	19,36	3,54	8,68	0,55	5,35	0,70	4,03
Curious Metallic Silver	3,60	19,10	4,42	-	3,64	20,02	4,61	-
Chamois	5,83	36,67	7,03	33,00	5,08	34,53	6,24	29,07
Copy paper	3,74	20,56	4,49	12,22	2,61	14,69	3,16	9,56
Dipa matt coated	2,61	15,55	3,24	9,42	2,22	12,83	2,71	8,81

measured data from the original profile, as well as the Measured Profile based on the measured data and the R profile adjusted by the filter. The distance between the two measured values was 0.5 μm.

From the evaluation point of view, parameters R_a and R_z of the four values are decisive *(Table 1)*. The average surface roughness (R_a) of Rives Tradition is almost the same longitudinally as transversely, the difference amounting to mere thousandths of a millimetre. Of all creative paper types, Curious Metallic Silver shows a similarly minor general roughness variation. Transversely, Curious Metallic Pearl shows a general roughness value much smaller than even that of Dipa matt coated paper. In this case, the coating creates a surface much smoother than that of a non-coated paper type.

For Rives Design, the greatest difference in surface roughness is shown in the direction of production, one possible reason being the regular surface texture. The figure below shows the graph based on the original surface and the adjusted R profile *(Andó, 2010)*.

The largest roughness height (Rz) was found longitudinally on Rives Design. On the other end of the spectrum, Curious Metallic Pearl show the smallest distance between the extreme peak and trough values. Our tests show that coated paper types have the lowest Rz values, the reason being the coating film smoothing out any surface unevenness. Copy paper and Dipa also qualify for the smooth surface category. Paper types with a surface texture arguably show the largest distance between the highest and lowest points.

Rives Design was found to have the largest roughness height (R_z) in longitudinal terms. Transversely, however, the watermarked paper product showed the largest peak-to-trough difference, with similar results obtained upon longitudinal testing, as well.

The tests showed that coated paper samples (Curious Metallic Pearl and Curious Metallic Silver) had a surface less rough than standard copy paper. A coating does not only lend favourable surface properties to the base paper, but also ensures increased smoothness.

Spectrophotometric measurements

Spectrophotometric tests were used to compare three different devices, which had been calibrated for absolute white to obtain test results in relation to such reference.

The purpose of the tests was to determine to what extent the surface texture and colouring of various paper types influenced the results of spectrophotometric and spectrodensitometric testing. Spectrophotometric testing was carried out with 3 different spectrophotometers including a X-Rite 530 Spectrodensitometer, a GretagMacbeth SpectroScan and a Techkon SpectroDens *(Table 2)*.

First we would like to know how influence the surface of paper the reproducibility our measurement results *(CGATS, 2007) (Nussbaum, 2010)*. We measured the choosen fields of papers 10 times and calculated their standard deviation. We established that in this case reproducibility depends on the surface properties strongly, mainly at X-Rite device *(Table 3)*.

After checking of the reproducibility of measurement the evaluation of printed test chart's measurement followed. It was based on L*, a* and b* values from copy paper and our test chart thereon as reference standard values. The tests allowed a comparison to be drawn between colour measuring instruments with annular illumination and one-side illumination in terms of dependence on surface texture quality *(Table 4)*.

Table 2: Main technical data of spectrophotometers (Source: Operator manuals)

Technical data	Type of device		
	GretagMacbeth SpectroScan	Techkon SpectroDens	X-Rite Spectrodensitometer
Measurement geometry/ illumination setup	45a/0	45i/0	45i/0
Type of illumination	D50	D50	D50
Observer	2°	2°	2°
Repeatability (short term)	0.03 CIE dEab	0.03 CIE dEab	0.1 CIE dEab
Inter-instrument agreement	0.3 CIE dEab	0.3 CIE dEab	0.4 CIE dEab

Table 3: Reproducibility of devices at design papers and Canon Copy

Reproducibility	Type of device		
	GretagMacbeth SpectroScan	Techkon SpectroDens	X-Rite Spectrodensitometer
Curious metallic silver	0.58 CIE dEab	0.75 CIE dEab	1.01 CIE dEab
Rives Tradition	0.61 CIE dEab	0.81 CIE dEab	0.92 CIE dEab
Rives Design	0.61 CIE dEab	0.74 CIE dEab	1.15 CIE dEab
Chamois watermarked	0.48 CIE dEab	0.60 CIE dEab	0.96 CIE dEab
Canon Copy	0.43 CIE dEab	0.59 CIE dEab	0.78 CIE dEab

Table 4: ΔE^*_{ab} values calculated from measured values from the three devices for yellow fields of the two paper samples selected (etalon – Canon copy)

Tone value	ΔE^*_{ab}					
	Spectrolino S.		Techkon S.		X-Rite S.	
	Types of paper					
	Rives Design	Rives Tradition	Rives Design	Rives Tradition	Rives Design	Rives Tradition
100%	3,34	4,53	3,46	4,12	3,32	4,88
90%	3,19	4,74	3,45	4,33	3,50	5,09
80%	3,02	6,65	3,05	5,66	3,08	7,06
70%	2,71	7,64	2,64	5,53	2,91	7,80
60%	3,34	7,58	3,14	5,74	3,21	6,81
50%	2,72	7,51	2,70	6,11	2,87	6,91
40%	2,78	5,90	2,90	5,11	2,64	5,94
30%	3,46	4,56	3,99	4,49	3,42	5,15
20%	3,26	3,29	2,95	3,14	3,07	3,51
15%	3,27	3,55	3,07	3,36	3,12	4,36
10%	3,19	4,13	2,96	3,81	3,03	4,64
0%	3,02	4,80	3,66	5,19	2,98	5,64

Table 5: ΔE^*_{ab} values calculated from measured values from the two devices and differential ΔE^*_{ab} values obtained for green fields of the three samples selected 1.: Canon Copy; 2.: Rives Design; 3.: Rives Tradition

Tone value	ΔE^*_{ab}								
	Techkon SpectroDens			X-Rite Spectrodensitometer			ΔE*ab(X)-ΔE*ab(T)		
	1.	2.	3.	1.	2.	3.	1.	2.	3.
100%	1,20	1,72	1,89	0,45	0,81	1,20	-0,75	-0,91	-0,69
90%	1,15	1,30	2,07	0,37	1,64	1,30	-0,79	0,34	-0,78
80%	1,00	1,17	1,88	0,96	0,71	0,34	-0,04	-0,47	-1,54
70%	0,83	1,77	2,22	1,44	0,83	1,42	0,61	-0,93	-0,81
60%	0,74	2,42	1,85	1,53	1,30	1,19	0,79	-1,11	-0,67
50%	0,56	0,88	1,28	0,69	1,92	2,07	0,13	1,04	0,78
40%	0,51	0,57	1,00	1,56	1,89	2,81	1,04	1,31	1,81
30%	0,71	0,70	0,56	3,18	3,86	3,72	2,47	3,16	3,16
20%	1,29	1,04	0,80	3,25	4,19	4,52	1,96	3,15	3,71
15%	1,12	1,13	0,71	3,96	4,66	4,84	2,84	3,52	4,13
10%	1,43	1,12	1,04	4,51	4,63	5,32	3,08	3,51	4,28
0%	2,25	2,20	2,51	5,08	5,82	6,07	2,82	3,63	3,56

Table 6: ΔE^*_{ab} values calculated from measured values from the two devices and differential ΔE^*_{ab} values obtained for green fields of the three samples selected:
1.: Chamois watermarked; 2.: Curious metallic silver; 3.: Curious metallic pearl

Tone value	ΔE^*_{ab}								
	Techkon SpectroDens			X-Rite Spectrodensitometer			$\Delta E^*_{ab}(X)-\Delta E^*_{ab}(T)$		
	1.	2.	3.	1.	2.	3.	1.	2.	3.
100%	1,67	1,32	2,01	1,05	0,73	0,71	-0,62	-0,58	-1,30
90%	2,23	2,19	2,82	0,77	1,34	1,55	-1,46	-0,85	-1,27
80%	1,49	2,16	2,14	0,97	0,29	1,30	-0,52	-1,87	-0,84
70%	1,68	2,52	2,43	0,89	0,57	0,82	-0,79	-1,95	-1,61
60%	1,89	2,00	2,63	0,87	0,63	1,04	-1,02	-1,38	-1,58
50%	1,43	1,86	2,46	1,41	0,94	1,33	-0,02	-0,91	-1,14
40%	1,38	2,09	2,09	1,53	0,50	2,07	0,14	-1,59	-0,03
30%	0,76	2,01	2,05	1,41	0,59	2,01	0,65	-1,42	-0,04
20%	0,64	2,38	1,88	1,80	0,59	2,56	1,17	-1,79	0,68
15%	0,59	2,08	1,81	1,98	0,43	2,73	1,40	-1,64	0,92
10%	0,67	2,00	1,59	1,82	0,38	2,79	1,14	-1,63	1,20
0%	2,96	1,87	1,01	2,41	0,40	2,90	-0,55	-1,47	1,89

Table 7: Changes in reference values and the calculated ΔE^*_{ab} values

No. of measurement	Spetrolino SpetroScan				X-Rite densitometer				Techkon SpetroDens			
	L*	a*	b*	ΔE^*_{ab}	L*	a*	b*	ΔE^*_{ab}	L*	a*	b*	ΔE^*_{ab}
1.	95,72	-0,47	1,75	4,65	95,26	-0,88	0,31	4,83	95,30	-0,28	2,52	5,34
2.	95,71	-0,47	1,75	4,66	95,43	-0,88	0,33	4,67	95,31	-0,27	2,54	5,34
3.	95,66	-0,46	1,78	4,71	95,54	-0,87	0,31	4,55	95,20	-0,82	2,28	5,38
Average	95,70	-0,47	1,76	4,69	95,41	-0,88	0,32	4,68	95,27	-0,46	2,45	5,35

Our tests showed that the sample texture did not have any influence on test results where annular illumination was used – unlike with directional illumination.

The date in the table show that while values ΔE^*_{ab} obtained by the Spectrolino remained constant with the change in tone value, results from the Techkon and the X-Rite reached the maximum of the differential colour stimulus at 0% tone value. As both the reference standard and the sample base colours are white, it is safe to conclude that a high ΔE^*_{ab} value results from sample surfaces.

In view of the results obtained, the following calculations were made using data from the Spectrolino, with annular illumination, as the reference standard and comparing results from the other two devices to such reference data.

Tests on copy paper showed that the differential colour stimulus from the Techkon SpectroDens is normally lower than that measured by the X-Rite. For green and black fields with a tone value of 100 to 80%, however, ΔE^*_{ab} values from the X-Rite were found lower. Results from those spots were similar for the rest of the samples.

For the Techkon SpectroDens, calculations gave ΔE^*_{ab} lower than those from the X-Rite 530 Spectrodensitometer for more textured samples with a white base colour as Rives Design, Rives Tradition and copy paper *(Table 5)*.

For the rest of the samples with a non-white base colour, however, different results were shown *(Table 6)*.

The X-Rite 530 Spectrodensitometer only showed a lower ΔE^*_{ab} value for fields with a tone value over 50% on the watermarked paper sample. The same was seen at a tone value of 30% with Curious Metallic Pearl. For Curious Metallic Silver, ΔE^*_{ab} values obtained from the blank surface are better that values from the Techkon SpectroDens.

Finally, a comparison is made between absolute white reference values from the GretagMacbeth SpetroScan, the Techkon SpectroDens and the X-Rite Spectrodensitometer. For the calculation of ΔE^*_{ab} values, the L a and b values (L=100; a=0; b=0) of ideal white was taken as the basis *(Table 7)*.

The differential colour stimulus shows the largest deviation from ideal white with the Techkon SpetroDens. Reference values for the Techkon SpectroDens mostly shift towards yellow. The most significant shift towards green is shown by the values from the X-Rite densitometer.

Conclusion

Based our results we concluded that it is strongly advisable to test our spectrophotometers at printing of design paper and paper with special surface. It has been established that a spectrophotometer with annular illumination (Spetrolino SpectroDens) produced the most realistic results. Out of the two spectrophotometers with directional illumination, the Techkon SpectroDens is more suitable for testing the textured Rives Tradition and Rives Design, while the X-Rite spetrodensitometer is better suited to spectrometering coloured metallic Curious Metallic Silver and Curious Metallic Pearl. Tests also show that a metallic effect has a minor impact on measuring results.

Surface roughness is one of most important properties of creative paper types and greatly affects their printability. Our surface roughness tests have proved that prints on coated paper show lower roughness parameters than those on non-coated samples. The reason is that such paper is finished with a coating applied as liquid that smoothes out, by gravity filling, any base paper unevenness, while creating a relatively uniform film on the surface. The more times the coating process is repeated, the smoother the surface will be. Another method of making paper special is to texture it using embossing rolls in the course of sheeting. This clearly results in an increased surface roughness.

With the improvement of measuring geometries, illumination setups, spectrometering becomes more and more capable of producing reliable results unaffected by surface textures. Our tests have proved this fact by showing that the GretagMacbeth Spectrolino with annular illumination is less sensitive to surface texture than the X-Rite Spetrodensitometer and the Techkon

SpetroDens with directional illumination. Further tests have brought us to the conclusion that there is a difference even between the two devices with directional illumination. While the X-Rite 530 Spectrodensitometer is more suitable for testing coated surfaces, the Techkon SpectroDens can come close to ΔE^*_{ab} values produced by the annular illuminated device for textured surfaces. In the future, we shall continue performing our tests using spectrophotometers with diffuse illumination, as it is worthwhile to be aware of how the choice of spectrophotometer will affect the results of metering colours printed on creative paper, the acceptance of printed colours or any colour adjustment requirements.

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