The Paper Influence on ICC-profiles

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Abstract

An ICC-profile created for a printing press or a printer includes all parameters that influence the colour rendering. These consist of the influence of the press and the materials used as paper, ink, blanket and plate. Many graphic arts companies use different paper qualities as well as different printing presses. There is an evident risk, that the amount of profiles that has to be made and used, easily can become too large to be handled in the workflow in a practical way.

In this study we have done an evaluation of the influence different paper parameters have on the ICC-profiles and on the print result. We have also evaluated the possibility of finding "standard" profiles for a category of papers.

Test charts with colour patches were printed in order to study the influence of the various paper qualities and paper parameters on colour rendering. The colour patches were also used to create ICC-profiles. Test charts and images were printed with ICC-profiles and analysed due to colour rendering. The colour rendering was expressed as ΔE^* and in terms of being alike or different determined by visual judgement. The correlation between these values and

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paper parameters such as surface roughness, whiteness and absorption was studied.

It was observed that paper roughness, paper whiteness and absorption characteristics do influence the colour rendering. The colour rendering also depends on the image type.

An image with skin tones is more sensitive to the use of an inappropriate ICC-profile than an image with many vivid colours. The result indicates that it is possible to use profiles for different categories of paper qualities.

A common ICC-profile can not be used if the paper differs in roughness or if it's whiteness exceeds a specific limit. In this paper, we will report which paper qualities can be grouped together and which ones can not. We will also show the influence of paper roughness, whiteness and absorption.

Background

The ICC-profiles as they are defined by (International Color Consortium, 1997) are carrying the colour information needed for the conversion of the colour values from one colour gamut to another. Working with ICC-profiles give the operator a tool to handle the colour rendering in a correct way (Has, Newman, 1995), (IFRA, 1996, 1997), (Klaman, 1997), (Caretti, Klaman, 1997), and (Schläpfer, Steiger, 1998). In order to simplify the daily work there is often a demand to minimise the number of ICC-profiles to be used in the workflow.
In this paper we present the results from our work in analysing the press profile considering the influence of paper, the possibility to group papers into different categories and the use of a common ICC-profile for each category.

Crucial paper parameters that influence the colour rendering of images were supposed to be:

- the shade
- the structure
- the absorption

The tests were made with different paper qualities. The printing was done in a sheetfed offset press. The influence of the shade, or more correct the whiteness was studied as well as the structure, measured as the surface roughness. Microscope methods were used in order to study the influence of the absorption.

ICC-profiles for the different papers used in this study were created and used cross-wise for each of the paper categories.

Experimental

Six paper qualities were used: two glossy coated, one matte coated with silk finish, one common matte coated, and two uncoated. These will here be referred to as Art 1 and 2, Silk, Matte, Uncoated 1 and 2.

The print tests were made in a Roland sheetfed offset press. The coated papers were printed with a screen ruling of 60 l/cm and the uncoated ones with 54 l/cm.

The ICC-profiles were created with software from LOGO, ProfileMaker Pro, with test form TC2.9. The ICC-profiles were applied to the test images in Photoshop 4.0 with ColorSync Photoshop Plug-In Modules 2.1 (ColorSync-paper from Apple, 1997) and the images were mounted in a test document created in QuarkXPress 4.0.

Prints, without ICC-profiles, but with the ProfileMaker test form were used for evaluating the influence of different paper parameters on colour rendering. The colour patches were measured with a spectrophotometer and analysed in a microscope.

The ICC-profiles were used for two images: one IT8.7 test form and an image with skin tones, light colours and saturated vivid colours.

The ICC-profiles were applied in such a way that each profile was used for the paper for which the profile was created for as well as for the other papers as seen in the *Table 1.* Profiles created for a coated paper were not used for an uncoated paper and *vice versa.*

Profile	*Created for paper*	*Notation for paper with profile*	*The other papers with profiles*
a1	Art 1	Art 1_{a1}	Art 2_{a1}, $Silk_{a1}$, $Matte_{a1}$
a2	Art 2	Art 1_{a2}	Art 1_{a2}, $Silk_{a2}$, $Matte_{a2}$
s	Silk	$Silk_s$	Art 1_s, Art 2_s, $Matte_s$
m	Matte	$Matt_m$	Art 1_m, Art 2_m, $Silk_m$
u1	Uncoated 1	Uncoated 1_{u1}	Uncoated 2_{u1}
u2	Uncoated 2	Uncoated 2_{u2}	Uncoated 1_{u2}

Table 1. Papers and profiles.

Colour measurements

To study the influence of the paper quality

- L^*, a^* and b^* were measured in the ProfileMaker testform for 74 light and dark tones
- L^*, a^* and b^* were measured for 17 tones in a tone scale between 0 and 100% for cyan, magenta and yellow.

Measuring was performed with a Gretag Spectroscan under conditions 45/0 geometry, no polarisation, 2° observer, D50 and 380-720 nm measuring interval.

In order to be able to compare the colour values from the 74 colour patches they were divided to 50 light and 24 dark tones. The light tones were defined as tones where the total amount for one separate colour is maximum 50 %, for a two colour combination maximum 60 %, for a three colour combination 70 % and for a four colour combination maximum 90 %. Similarly the dark tones were defined with the values of minimum 90, 180, 260 and 320 %.

ΔE^*_{ab} according to (ISO 12647, 96) was used to a comparison value for the colour rendering difference of the six paper qualities. The value for the Art 1 paper was used as a reference for all the other papers. In addition to that the value for the uncoated 1 paper was used as a reference for uncoated 2.

In the same way ΔE^*_{ab} was measured for the IT8.7 test chart printed with ICC-profiles for 15 colour patches, also light and dark tones.

Visual judgements of colour rendering
The proofs were divided into groups where the paper with its own profile was the reference with which the other papers with that same profile were compared.

For each proof 10 persons judged the image with the girl. The image was evaluated according to its identity with the reference. Identical in this case was defined as no or a very small visual difference. The evaluation was made separately for skin tones and for bright or vivid colours in the clothes.

Microscopic analysis
Prints were analysed with an ESEM (Environmental Scanning Electron Microscope), electron microscope of type Philips 2020 and light microscopy, technique and methods described of by e.g. (Hornatowska, J. Et al. 1998) and (Cameron, R.E., 1994). Proofs used for these tests were Art 1, Matte and Uncoated 1.

Results of colour rendering measurements of offset prints on different paper qualities

The values for the 74 colour patches described earlier are seen In Table 2. The ΔE^*-values are the mean values for 50 and 24, respectively, tones. The value for unprinted paper is also shown.

Compared papers Reference paper Art 1	ΔE^* **50 patches, light**	ΔE^* **24 patches, dark**	ΔE^* **paper**
Art 2	1,5	1,2	1,0
Silk	1,6	1,8	1,8
Matte	3,1	2,4	1,3
Uncoated 1	3,5	13,7	2,1
Uncoated 2	4,6	16,2	3,8
Reference paper Uncoated 1			
Uncoated 2	3,4	3,5	2,9

Table 2. ΔE^**-values of offset prints on different paper qualities.*

The difference in colour rendering increases in the order glossy coated paper, silk and matte papers. The difference between the glossy coated paper and the uncoated papers is considerable. The difference between the two uncoated papers is larger than the difference between the coated and the matte coated paper for instance. In figure 1 the 74 values are plotted against the ΔE^*-values for each colour patch for the Silk and the Matte paper using the Art 1 paper as reference. In figure 2 the Uncoated 1, paper has been compared to Art 1, in the same way. From the figures, it can be concluded that there is a difference between the glossy coated and the silk and matte coated paper. The largest differences are found between the matte and the glossy coated papers. The difference between the glossy coated and the uncoated paper increases dramatically in the dark tones.

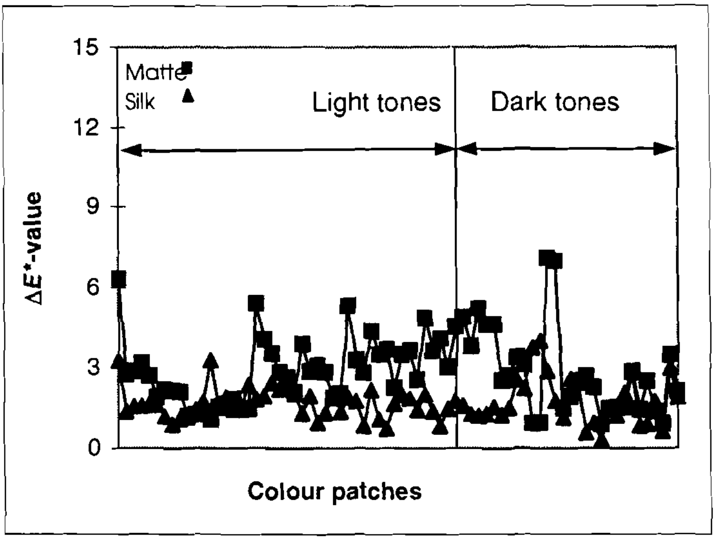


Figure 1. ΔE-values for light and dark tones for colour patches printed in offset.*

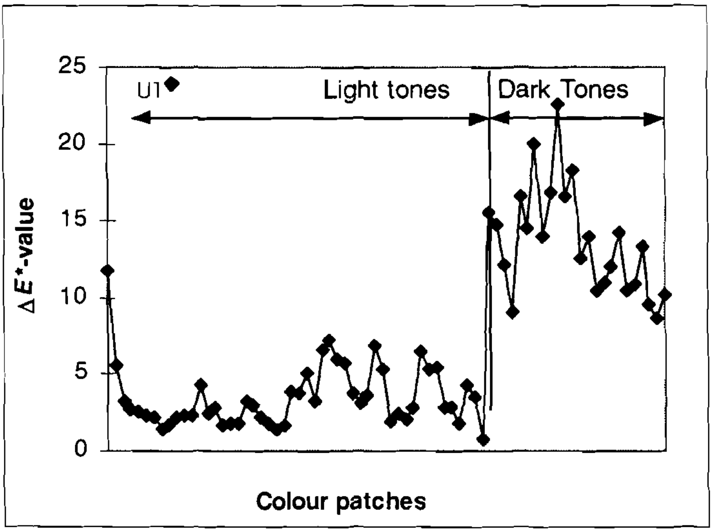


Figure 2. ΔE-values for light and dark tones for colour patches printed in offset.*

An even clearer pattern can perhaps be seen for the differences between the papers when using the same type of diagrams for the tone scales. In figure 3 the difference is shown between the Art 1 and 2 for the tone scale and similarly figure 4 for the matte coated and in figure 5 for the uncoated paper. The difference between the unprinted papers is marked in the diagrams with a thin line. The difference between the two glossy coated papers is small, compared to the much larger difference between the matte and the glossy coated. There is an increase in the darker tones compared to the light and again a dramatically increasing difference between the glossy coated and the uncoated paper.

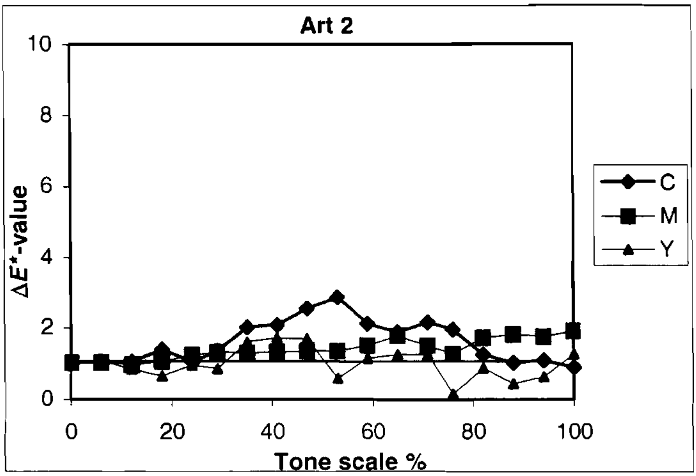


Figure 3. ΔE-values for the tone scale of Art 2 compared with Art 1.*

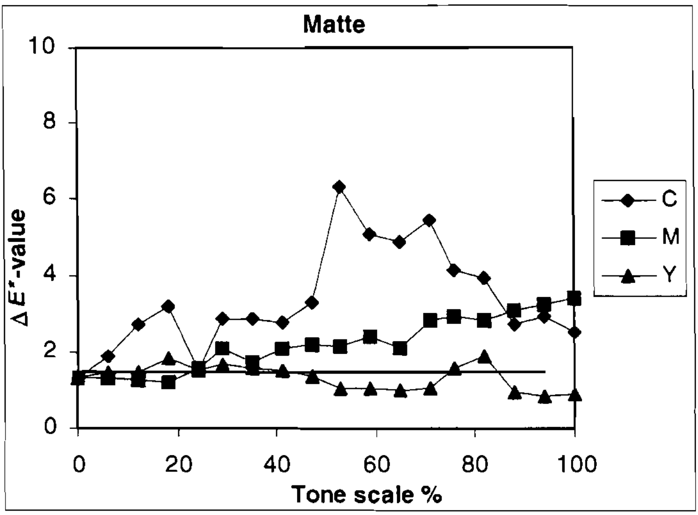


Figure 4. ΔE-values for the tone scale of Matte compared with Art 1.*

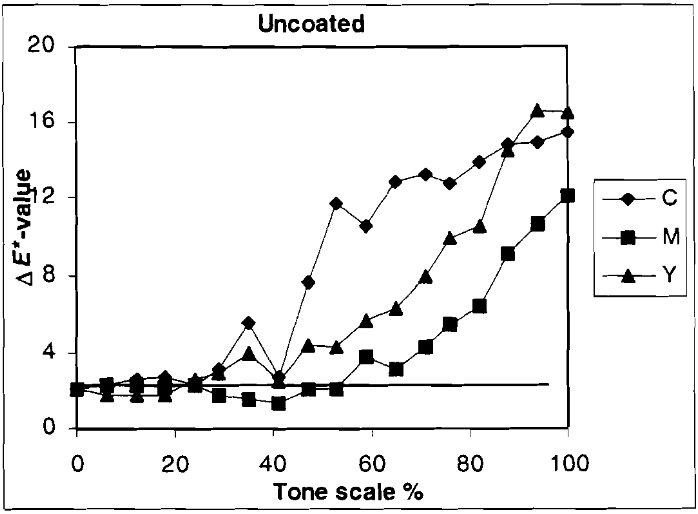


Figure 5. ΔE-values for the tone scale of Uncoated 1 compared with Art 1.*

Paper properties like surface roughness and absorption will probably have more influence, as more ink is put on the paper and will increase the difference in the colour co-ordinates of dark tones. It can be expected that this also indicates that it is possible to use the same ICC-profile for all glossy coated papers but probably not for a glossy coated paper as for a matte coated. The difference between coated and uncoated papers is as expected large and consequently therefore without interest to evaluate whether it is possible to use common profiles for those two categories.

In the next chapter, the result of the influence of the use of different ICC-profiles is reported.

Results of tests with ICC-profiles

In this part of the study, the influence of the use of different ICC-profiles was investigated. As mentioned earlier the proofs had been grouped together and the reference of each group was the paper with it's own profile (the correct profile). The result of the visual judgements is shown in table 3. Here it is shown how many persons in the panel that found the proof being alike the reference. The ΔE^*-value for each paper is the mean value of the 15 measurements described earlier. In figure 6 the graphic interpretation of the result of the visual judgement is shown. On the x-axis are the papers with ICC-profile and on the y-axis the percentage of persons in the panel who has judged the image to be alike the reference.

Profile	Paper with profile	ΔE^*, mean value for 15 patches	Visual judgement n=10	
			Skin tones Alike %	Vivid colours Alike %
a1	Art 2_{a1} $Silk_{a1}$ $Matte_{a1}$	1,6 1,6 2,0	70 60 20	80 60 30
a2	Art 1_{a2} $Silk_{a2}$ $Matte_{a2}$	2,0 1,8 2,3	60 70 40	60 70 60
s	Art 1_s Art 2_s $Matte_s$	1,3 1,3 1,8	70 80 70	80 90 80
m	Art 1_m Art 2_m $Silk_m$	2,4 2,8 2,3	20 10 20	40 80 80
u1	Uncoated 2_{u1}	0,9	50	90
u2	Uncoated 1_{u2}	1,2	50	80

Table 3. The result of the visual judgement and ΔE-values for the proofs.*

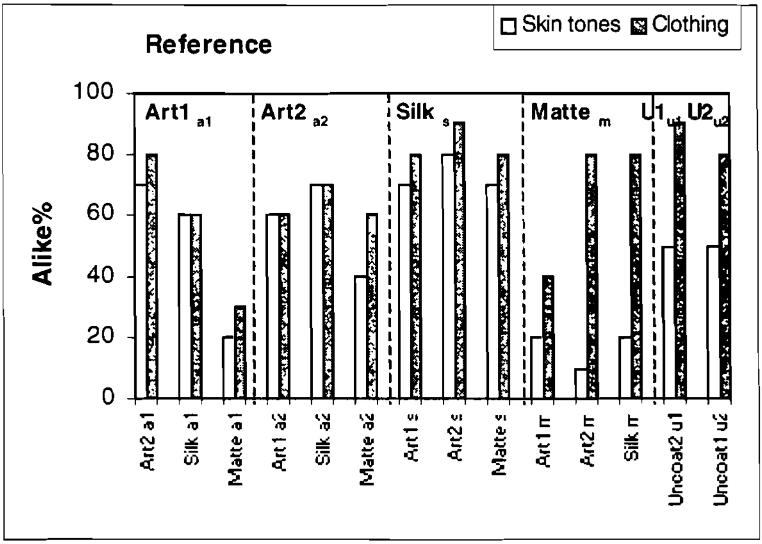


Figure 6. Result of the visual judgements for coated and for uncoated papers.

The result from figure 6 and table 3 can be summarised as follows:

- It is more unsuitable to use an "incorrect" profile for images with skin tones than for images with saturated colours.
- Glossy papers can be grouped together and the same profile used.
- Matte coated papers with silk finish can be included in this group as well.
- A profile created for a glossy coated paper should not be used for a common matte-coated paper since it will probably not give a satisfying image quality. A profile created for a matte-coated paper is not to be recommended to use for a glossy coated paper.
- When $\Delta E^* > 2$ a majority of the persons of the panel seemed to judge the images as different.
- Less than 50 % of the panel judged the images alike when the uncoated papers were evaluated, and since uncoated papers can be very different, the recommendation for uncoated papers must be, at least when high quality is aimed at, to create a specific ICC-profile for each paper.
- If there is a demand for a single ICC-profile, which can be used for glossy coated as well as for matte and silk coated papers a profile created for a silk coated paper is to be recommended. It will be optimal as a compromise profile for these groups of papers.

In figure 7 is plotted the values for the visual judgements as a function of the ΔE^*-values for each paper. A better correlation is found between the values for the skin tones than for the colour tones of the clothes. This is also what can be expected since the eye is supposed to be more sensitive to such colours as skin tones than to such colours as found in the clothing.

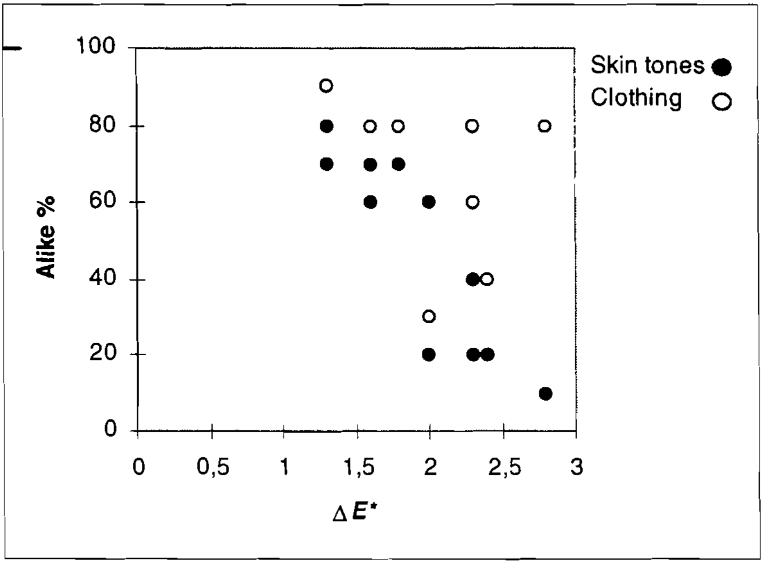


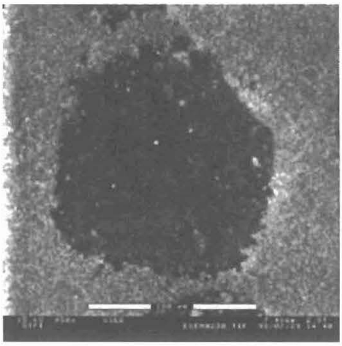
Figure 7. The visual judgements as a function of the ΔE-values.*

Results of microscope analysis

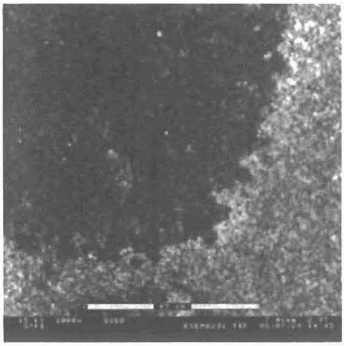
Studies with ESEM

Screen dots were enlarged into two different sizes. The images of figure 8 show that:

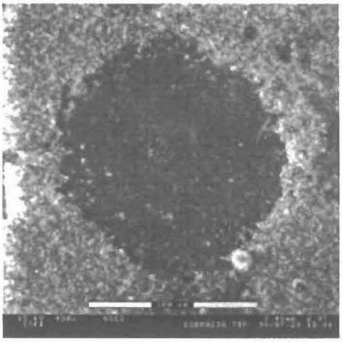
- The glossy coated paper, Art 1, has a smooth surface with a relatively even dot edge. The dots are round with an even surface.
- The matte coated paper, Matte, has a somewhat less smooth surface. The dots are still round but have a little unevenness at the edges compared with the glossy coated paper.
- The uncoated paper has a very rough surface with fibres very clearly exposed. It is difficult to identify where the dots are located. The edges are uneven and the ink does not cover the unevenesses. Deep cavities can be seen in the paper surface.



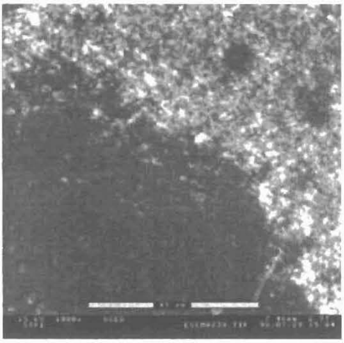
Art 1, 450x



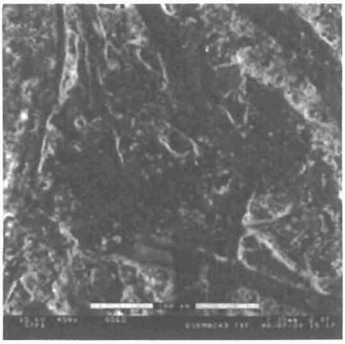
Art 1, 1000x



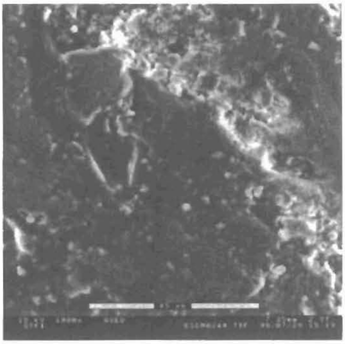
Matte, 450x



Matte, 1000x



Uncoated 1, 450x



Uncoated 1, 1000x

Figure 8. Enlarged dots on three different paper qualities. An ESEM was used with two magnifications.

Studies with light microscopy

Cross-sections in the Z-direction of the printed papers were studied. The cross-sections show the ink layer on the top, then the coating and then the base paper. The proofs consisted of one print with a thick ink layer and one with a thin ink layer. The cross-section images are shown in figure 9 and the figures show how the ink is distributed both on and in the paper.

- The glossy coated paper, Art 1, has a very smooth surface and the ink is distributed evenly on the surface and is not penetrating into the structure.
- The matte coated paper, Matte, which does not have as smooth a surface as the glossy coated paper. The surface is somewhat wavy and the ink has penetrated the structure to and fro. In some parts the ink is missing.
- The uncoated paper has a very rough structure where the ink penetrates into pores and cavities.

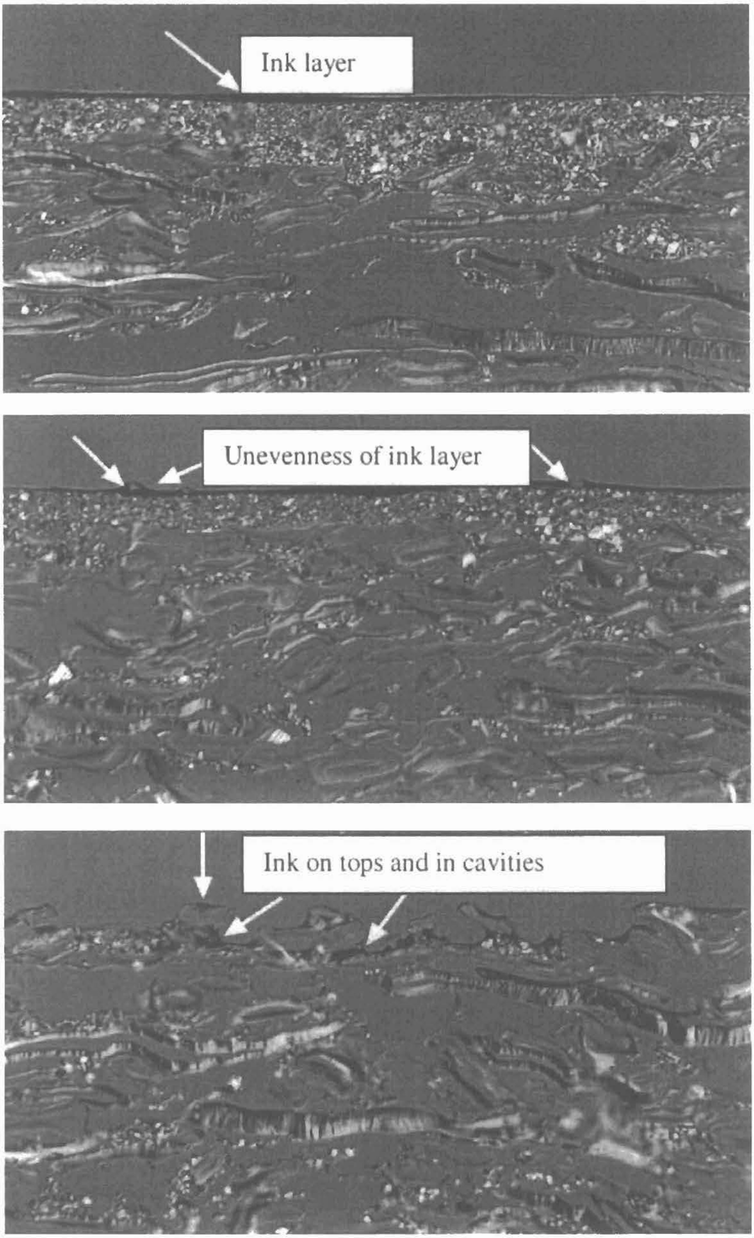


Figure 9. Cross-sections of Art 1, Matte and Uncoated 1.The arrows are showing the unevenness of the ink layer caused of the paper surface structure.

Relationship between colour rendering and paper parameters

Experimental

Papers were characterised with respect to optical properties and surface roughness. CIE-Whiteness and fluorescence was determined with spectrophotometer Elrepho 2000 for D65 and observer 10°. The whiteness values can be seen in table 4.

Paper, g/m^2	CIE-whiteness, W	Fluorescence whiteness
Art 1, 170	115,1	35,7
Art 2, 130	114,1	33,3
Silk, 150	116,8	33,9
Matte, 130	110,2	27,7
Uncoated 1, 170	145,9	64,0
Uncoated 2, 150	144,3	68,7

Table 4. CIE-Whiteness and fluorescence of the different paper qualities.

Paper surface roughness was measured with Parker Print Surf. The measured values are seen in table 5.

Paper, g/m^2	Surface roughness, μm
Art 1, 170	1,09
Art 2, 130	1,16
Silk, 150	1,75
Matte, 130	3,53
Uncoated 1, 170	6,98
Uncoated 2, 150	6,39

Table 5. Surface roughness for the papers measured with Parker Print Surf.

Correlation surface roughness — colour rendering

In order to analyse the surface roughness and it's influence on colour rendering the ΔE^*-value for unprinted paper and for dark and light tones of the colour patches was used as a measure for the colour rendering. In figure 10 the ΔE^*-values are plotted as a function of the paper surface roughness. The diagram shows that the roughness will influence the colour rendering with the largest influence in the dark tones i.e. when more ink is printed on the paper. If there is a large difference in roughness values between two papers the possibility to use the same ICC-profile will diminish. In the figure, the papers with the two highest roughness values are the two uncoated papers.

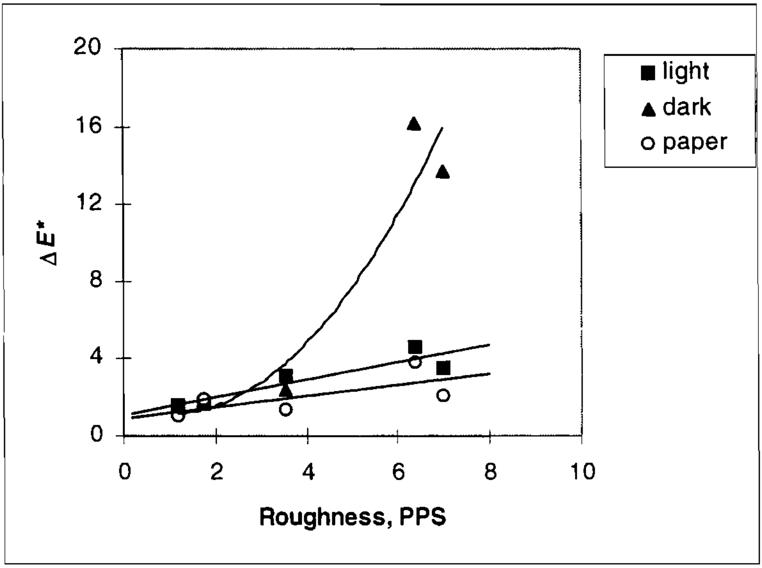


Figure 10. ΔE for papers and colour patches as a function of roughness, PPS. Reference paper was Art1.*

Correlation whiteness — colour rendering

The paper whiteness and it's influence on colour rendering has been studied in the same way as for roughness by plotting ΔE^* for unprinted paper and for the colour patches as a function of CIE-whiteness. The reference paper was Art1. The whiteness has been calculated as ΔWhiteness, which is the difference in whiteness for the different papers compared with the reference paper. As can be seen in figure 11 the values for coated and uncoated papers are far away from each other. To be able to analyse the influence of the whiteness in a better way the whiteness values for only the coated papers were plotted in figure 12. The ΔE^*-value will increase with an increasing difference between values of the proof and the reference.

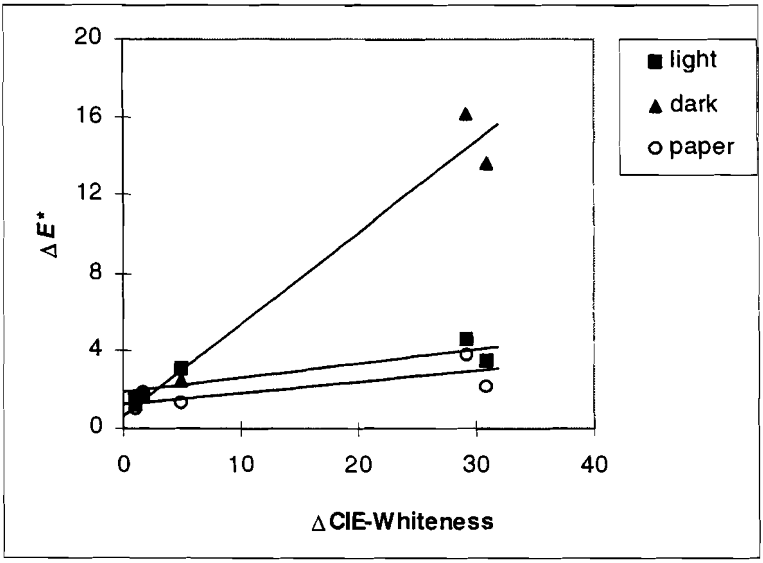


Figure 11. ΔE for papers and colour patches as a function of ΔWhiteness Reference paper was Art1.*

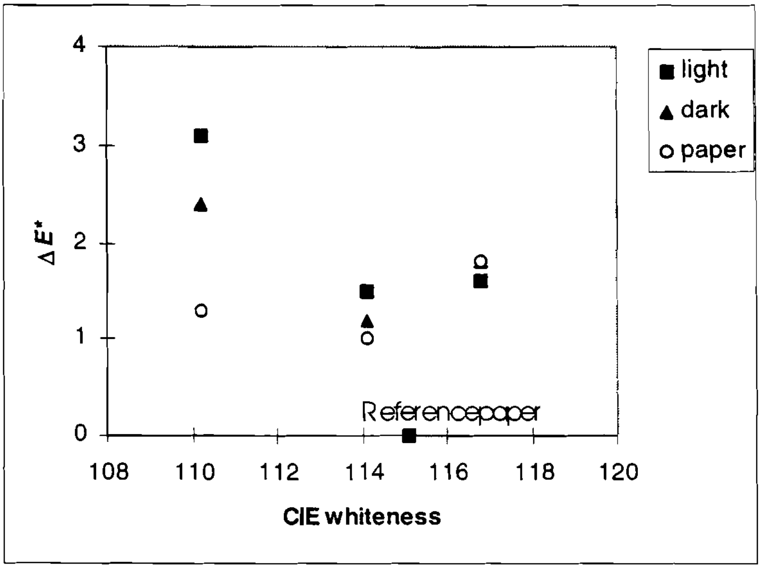


Figure 12. ΔE only for the coated papers as a function of CIE-Whiteness. Reference paper was Art1*

Relationship roughness/whiteness — visual judgement

The roughness values and whiteness values have also been compared with the visual evaluation values by plotting these as a function of each other in figure 13 and 14 respectively. The values were expressed as ΔRoughness and ΔWhiteness. From the diagrams can be concluded that the more the roughness or the whiteness differs from the reference the more the persons of the panel will judge the images as different.

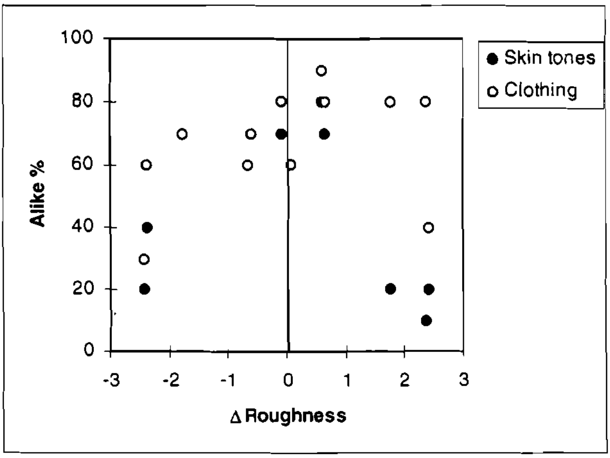


Figure 13. Relationship between ΔRoughness and visual judgement

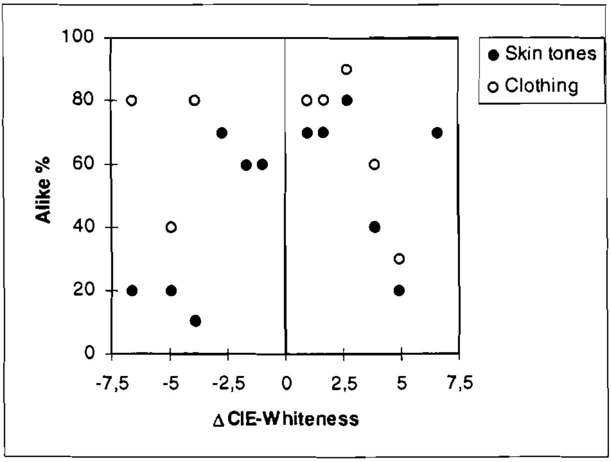


Figure 14. Relationship between ΔWhitenesss and visual judgement

Conclusions

The difference in ΔE^* for colour patches on glossy coated papers compared on matte-coated papers, silk finished was small. It was somewhat larger for glossy coated compared with common matte coated. It was large for a glossy coated paper compared with an uncoated one especially regarding the dark tones.

From the tests of using different ICC-profiles could be concluded:
It is more inadvisable to use a "wrong" ICC-profile, which in this case means a profile created for another paper, for images consisting of skin tones. An image with saturated colours is not as sensitive as the image with skin tones.
Glossy coated papers can be grouped together and the same profile can be used. Matte-coated papers with silk finish can be referred to the same group.
To use a profile created for glossy and matte-coated papers with silk finish on common matte-coated ones does probably not result in sufficiently high quality. Even less recommendable is to use profiles created for matte-coated papers for glossy and matte-coated ones with silk finish.
An ICC-profile created for a matte-coated paper with silk finish can be used as a compromise profile for the categories glossy, silk and matte-coated papers. This will be optimal to use for all categories and will give a good quality.
From the visual judgements can be concluded that at $\Delta E^* > 2$ a majority of the judgers perceive the images as different.
For the uncoated papers > 50 % of the panel judges the images as different and since uncoated papers can be very dissimilar to each other, it is recommended, at least when a high image quality is required to create specific profiles for each uncoated paper.

The relationship between colour rendering and different paper parameters can be concluded as follows:
The roughness of the paper surface will have an increased influence as more ink is printed on the paper surface and separate ICC-profiles are recommended. It must be stressed that the absorption of ink probably also has an important influence when considering the roughness parameter.
The whiteness of the paper has an influence the colour and the larger the difference is in whiteness between two papers the larger the difference in ΔE^*-values will be.
The conclusions could also be verified by ESEM (Environmental Scanning Electron Microscope) and light microscope analyses. The enlarged images reveal how paper categories, due to their different surface roughness and absorption characteristics differ in ink distribution on and in the paper and therefore also differ in colour appearance.

There is, as expected, a correlation between the visual judgements and the colour differences expressed as ΔE^* which is more apparent for skin tones than for saturated colours.

Acknowledgements

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