PRINTING SCREEN CONTROL BY MEANS OF A COLORIMETER

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ABSTRACT

One of the most important problems in the ceramic tile branch is avoiding the appearance of shades (small colour differences) in tiles, which is an important objective in achieving enhanced end product quality.

Shades are often due to changing screens during screen printing in the production line.

The present paper describes the development of a method of controlling printing screens prior to use in production by means of a colorimeter.

This has first required establishing screen limits of acceptability, in accordance with company criteria.

A relation was subsequently sought between the measurements obtained with the colorimeter (chromatic coordinates) and the variable to be controlled (screen percentage open area for ink).

Finally, to evaluate the proposed method, measurements were performed with the colorimeter on different substrates (images on paper, photolitho and printing screens), obtaining satisfactory results in every case.

1. INTRODUCTION

One of the greatest concerns in the ceramic tile manufacturing process, which directly affects tile quality, is the variation of tile end colour in the screen printing operation.

Many factors influence the appearance of shades in screen printing such as the materials making up the inks, ink density and viscosity, application conditions at the printing head, and processing of the printing screen 1.[1]

Some of these factors have been dealt with elsewhere [2-4].

At our company production plant it was observed that shades appeared when screens were changed. It thus became necessary to find a screen control method to determine whether the screens are appropriate or not for use in production.

The parameter chosen for control was the screen percentage open area for ink. To date, to our knowledge, only image analysis is available to measure the percentage open area directly on the screen [5].

This method consists of acquiring an image and subsequently processing it by specific software.

The method has various disadvantages:

- Obtaining satisfactory image analysis largely depends on good image acquisition. This may be difficult depending on the resolution of the video camera and the lighting system.
- Image analysis involves complex software, requiring extensive knowledge by the user.
- The steps to be followed in analysing the image depend on personal user criteria.

For all these reasons, it was considered necessary to seek a different control method, which did not exhibit these disadvantages.

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[1] PEYSKENS, ANDRÉ. *Fundamentos técnicos de la realización de pantallas para serigrafía.* Saati S.p.A. Como, 1991.

[2] SHARMA, K.D. *Génesis de la variación de tonalidades de las baldosas cerámicas y algunos remedios que se recomiendan.* Qualicer 90.

[3] PEÑALVER, J.; MARTÍ, V; PORTOLÉS, J.; NEGRE, P.; BARBA, A.; GIMÉNEZ, S.; MONFORT, E. *Study of screen printing application control variables and their influence on shades tile.* Pag. 323. Qualicer 96.

[4] PERIS-FAJARNÉS, G.; ALCAÑIZ M.; OLIVARES, M.; LENGUA I. *Quantitative analysis of printing variables affecting in screen-printed tiles.* Pag. 265.Qualicer 98.

[5] RUSS, JOHN C.; *Image processing handbook.* 2nd.ed. CRC. Boca Ratón. 1995

2. OBJECTIVE

The purpose of the present study was to develop a method that would allow conducting printing screen control by using a colorimeter, an instrument widely found in the ceramic industry.

The following basic objectives were set to develop this control method:

- Obtaining the percentage difference in open area for ink, which produced a shade in ceramic tiles, according to company criteria. This would allow establishing the acceptability limits of a screen for use in production.
- Search for a relation between the chromatic coordinates and percentage open area to allow using the colorimeter as a measuring instrument.
- Determination of the validity and accuracy of the method, by comparing the theoretical results with the experimental data found with the colorimeter.

3. EXPERIMENTAL DEVELOPMENT

3.1. MATERIALS AND MEASURING METHOD

3.1.1. Obtaining acceptability limits screen use in production

To find the difference in percentage open area for ink, which gave rise to a shade, a series of tiles glazed with a glossy white was screen printed with a NEUTRAL GREY INK.

The ink used consisted of a screen printing base (55%), pigment (2%) and screen printing vehicle (43%). Working density was 1.57 g/cm^3.

The screen printing application was run in an industrial line with an automatic head (DKK 104) using a screen with 90 threads/cm, rejecting the first tiles until the head had stabilised.

The resulting tiles were fired in a 60-m-long industrial kiln at a peak temperature of 1080°C, using a 45-min cycle.

The procedure adopted to determine the percentage open area that gave rise to a shade and hence the acceptability limits for production is set out in point 3.2.1.

3.1.2. Control method

To verify the validity and accuracy of the colorimeter as a control instrument of the screen percentage open area for ink, different substrates were prepared on which the chromatic coordinates were measured:

- Control dot patterns on paper obtained by printing with a HP-2500-CP plotter.
- Control dot patterns on a photolitho, obtained by an AGFA PROSET-9400 filming system.
- Control dot patterns on a printing screen.

The photolitho was screened from 1% to 100% open area at 25 dots/cm and 48° inclination.

The printing screens were prepared using different light exposure times (60, 80, 100, 120 and 140 passes), holding the other process parameters. The fabric was consisted of 90 threads/cm monofilament polyester; screen tension after stabilising was 11 N/cm and emulsion thickness was 7 microns.

All the measurements for determining the chromatic coordinates were performed on a MINOLTA CM-508d manual spectrophotometer. Three measurements were run for each sample, modifying the spectrophotometer position each time, calculating their arithmetic mean.

The CIELab colour measurement scale was used, whose parameters are defined as:

L*: indicates the position on the white axis (L*=100), black (L*=0).
a*: indicates the position on the red axis (a*>0), green (a*<0).
b*: indicates the position on the yellow axis (b*>0), blue (b*<0).

The measuring conditions were as follows:

- Specular component included.
- Illuminant D65.
- Observer 2°.

Photograph of the measurement method.

3.2. EXPERIMENTAL PROCEDURE

3.2.1. Finding the acceptability limits of a screen for use in production

A printing screen will be acceptable for use in production if the difference between the theoretical percentage open area for ink and the experimental (real) one is less than the value of the percentage open area that produces a shade in ceramic tiles.

Therefore, in order to set the screen acceptability limits the first objective was to establish the value of the difference in percentage open area for ink, which would produce a shade.

As the appearance of a shade depends on the judgement of the observer, it was considered necessary to establish a general company criterion. A group of persons was selected representing the various departments directly or indirectly involved in evaluating shades at some stage in the production process.

The group consisted of 30 people, as set out in Table 1.

DEPARTMENT	No. PERSONS
Management	1
R&D	2
Laboratory	4
Production	11
Sales	6
Quality	6

Table 1.

The study was started by dividing the grey scale into three areas: light area (from 15% to 25% open area), medium area (from 45% to 55% open area) and dark area (from 75% to 85% open area). A representative open area value was taken for each of these areas: in the light area (20%), in the medium area (50%) and in the dark area (80%).

A photolitho (Figure 1) was prepared with these areas screened in 1% increments together with the corresponding printing screen. After obtaining the ceramic tiles with this screen using the NEUTRAL GREY INK, the screened areas were cut off and arranged in three groups (from 15% to 25%, from 45% to 55% and from 75% to 85%).

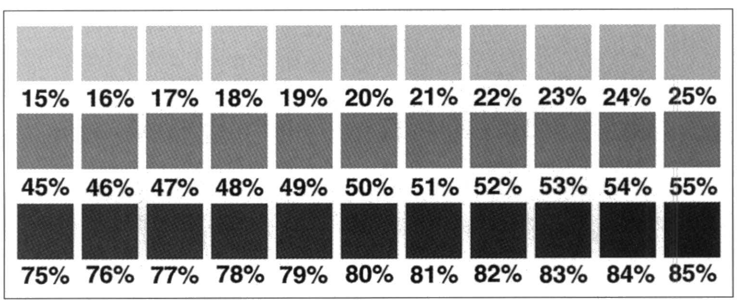


Figure 1.

The group of selected persons then performed the following test:

- Each person was given a standard piece from the three groups (light, medium and dark), corresponding respectively to 20%, 50% and 80% of the open area.
- Pieces were to be separated in each group, in which a change of shade was observed with regard to the standard tone.
- The open area was recorded of the pieces considered to exhibit no difference to the standard tone.

- For each group, the difference between the value of the percentage open area of the standard piece and that of the pieces considered not to exhibit shades determined the percentage open area limit for ink that produced no shades.

The limits were found by averaging the results of all the participants.

For example, in the case of the medium area group with a standard 50% open area, no shade was found in the pieces with 48, 49, 50, 51 and 52% open area. The upper acceptability limit (Ls) would be: 52%-50% = 2% difference in the open area in order to not exhibit a shade, while the lower acceptability limit (Li) would be 48%-50% = -2% difference in the open area.

If the difference between the theoretical and experimental (real) open area in the control dot pattern exceeded the acceptability limits, the screen would not be suitable for production.

3.2.2. *Development of the control method*

After establishing screen acceptability limits according to company criteria, it was necessary to determine whether the colorimeter could serve as a suitable instrument for measuring the percentage open area for ink.

This required finding the relation between the chromatic coordinates (L*, a*, b*) and the percentage open area.

The study was started by measuring the chromatic coordinates on the substrates where the processing stages were as few as possible with the colorimeter, to avoid deviations owing to process variables.

a) Measurements on the plotter

The first measurements were performed on a screened area with a high resolution (600 dpi), obtained by printing with a plotter (Figure 2).

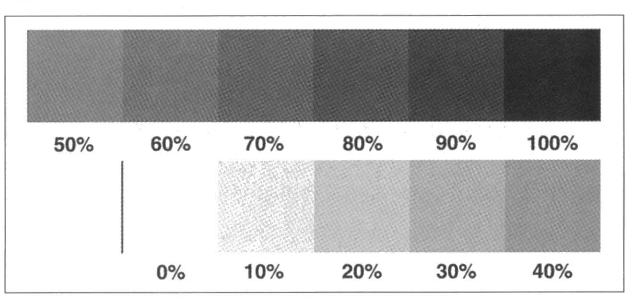


Figure 2.

The chromatic coordinates were measured of each open area on this image and the difference in colour (ΔEi*) was calculated of each area with regard to the corresponding value at 0% open area from the following equation:

$$\Delta E_i^* = ((L_i^* - L_0^*)^2 + (a_i^* - a_0^*)^2 + (b_i^* - b_0^*)^2)^{1/2}$$
$$i: 0\%, 10\%, ..., 100\%$$

ΔEi* was plotted against the theoretical percentage open area.

As in the dots corresponding to 0% and 100% open area there is no difference between theoretical and experimental ΔE^*, a straight line was drawn uniting these points. This straight line would correspond to the theoretical straight line $\Delta E_i^* = f(\%A)$, where A = ink open area. All the experimental points should fit this theoretical straight line if there was no deviation owing to process variables.

Knowing experimental ΔEi^*, the theoretical straight line allowed determining the real percentage open area.

The final results were expressed as the deviation between the experimental (real) and theoretical percentage open area. This deviation was compared with the acceptability limits of a printing screen, found as set out in the foregoing section.

$$\text{Deviation} = (\%A_{\text{experimental}}) - (\%A_{\text{theoretical}})$$

b) Measurements on the photolito

Having performed the measurements on the images obtained with the plotter, the next step was performing colorimetric measurements on the photolitho.

These measurements were carried out on a photolitho screened from 1% to 100% open area (Figure 3), following the same method described for the image obtained by the plotter.

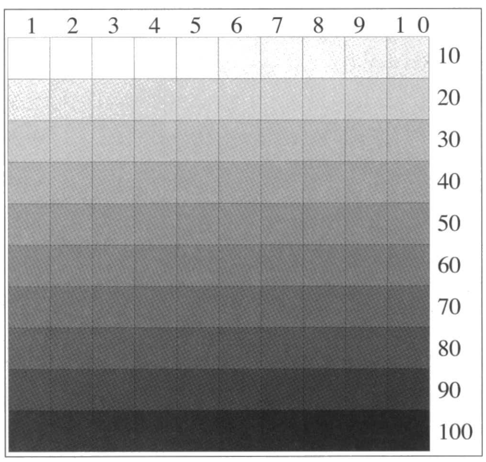


Figure 3.

c) Measurements on the printing screen

Finally, analogously to the foregoing cases, measurements were performed on a control dot pattern (Figure 4) on a printing screen.

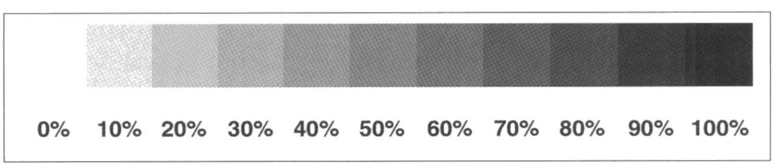


Figure 4.

4. RESULTS AND DISCUSSION

4.1. FINDING THE ACCEPTABILITY LIMITS OF A SCREEN FOR USE IN PRODUCTION.

The acceptability limits of a screen for use in production (L) according to company criteria are presented in Table 2.

	Li	Ls
LIGHT AREA Standard 20% A	-2	3
MEDIUM AREA Standard 50%A	-2	2
DARK AREA Standard 80%A	-3	4

Table 2.

A = A = ink open area.
Li = lower limit expressed as %A.
Ls = upper limit expressed as %A.

The criteria are observed to be stricter in the medium area of greys (standard 50%), where more shades were detected, in which variations of only 2% open area compared to the standard were considered to exhibit the same shade.

In the case of the light and dark areas of greys (standard 20% and standard 80%, respectively), the criteria were broader, accepting as the same shade up to a difference of 4% open area in the case of the dark area. In these two areas, the appearance of shades was detected in the percentage open area values below the standard earlier than in the higher values.

4.2. MEASUREMENTS PERFORMED ON THE IMAGES OBTAINED WITH THE PLOTTER

The colorimetric measurements were performed on three identical images, finding the arithmetic mean of the measurements. Table 3 presents the data, which are plotted in Graph 1.

The experimental data found can be observed to practically lie on the theoretical straight line drawn between 0% and 100% open area.

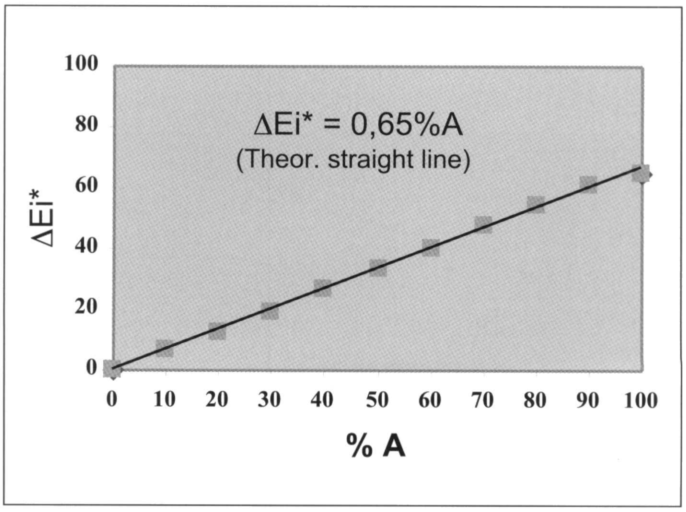
If the relation between these experimental data is sought, it can be observed that the existing correlation between ΔE_i^* with % open area is linear, obeying the equation $\Delta E_i^* = 0.66\%A$, where $R^2 = 0.999$.

These results appear to validate the use of the colorimeter as a measuring instrument, so that it was decided to conduct measurements on the photolithos to be able to verify this.

For the subsequent measurements performed on other substrates, the linear correlation existing between ΔE_i^* and then % open area for ink was assumed to hold.

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	92.40	1.78	-5.87	0.0	0.0	0	
10	86.25	1.36	-4.00	6.4	9.9	0	-2
20	79.77	1.33	-4.07	12.8	19.6	0	3
30	73.05	1.68	-4.09	19.4	29.9	0	
40	65.94	1.28	-3.57	26.6	40.9	1	
50	59.55	1.13	-3.72	32.9	50.6	1	-2
60	52.06	0.92	-3.87	40.4	62.1	2	2
70	45.32	0.11	-3.69	47.2	72.5	2	
80	38.68	-0.51	-3.27	53.8	82.8	3	-3
90	31.82	0.28	-3.50	60.6	93.3	3	4
100	27.47	3.05	-2.99	65.0	100.0	0	

Table 3.



Graph 1.

4.3. MEASUREMENTS PERFORMED ON THE PHOTOLITHO

In this case the colorimetric measurements were also performed on three identical photolitos, calculating their arithmetic mean. All the boxes were measured from 1% to 100% open area, however in table 4 and Graph 2, only the data are presented relating to each group of ten.

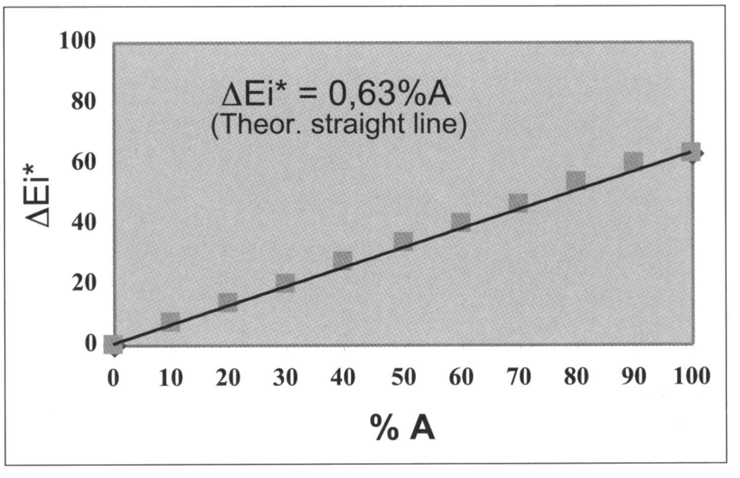
Graph 2 shows that the experimental points also follow a linear correlation between ΔE_i^* and l % ink open area, obeying the equation $\Delta E_i^* = 0.66\%A$ with R2 = 0.997.

Table 4 shows that the deviation in the percentage open area is also by excess. This can be due to the filming system being calibrated with excess intensity, so that the dot that appears in the photolithos is as black-opaque as possible.

In a filming system, with time, there is a loss of intensity owing to dirt caused by dust in the prism. This would lead to non-opaque dots allowing light to pass through during screen exposure, producing errors in the percentage open area.

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	91.46	1.91	-5.67	0.0	0.0	**0**	
10	84.32	1.67	-5.23	7.2	11.3	**1**	**-2**
20	77.46	1.53	-4.62	14.0	22.3	**2**	**3**
30	71.31	1.34	-4.21	20.2	32.0	**2**	
40	64.30	1.24	-3.45	27.3	43.2	**3**	
50	57.64	1.07	-2.78	34.0	53.8	**4**	**-2**
60	51.32	0.94	-2.10	40.3	63.9	**4**	**2**
70	45.13	0.83	-1.28	46.6	73.8	**4**	
80	38.12	0.80	-0.07	53.6	85.0	**5**	**-3**
90	31.92	0.75	1.40	60.0	95.1	**5**	**4**
100	28.92	0.88	2.57	63.1	100.0	**0**	

Table 4.



Graph 2.

To compare the measurements run on the colorimeter, measurements were performed on the photolitho with a densitometer. Table 5 gives the results.

Theor. %A	10	20	30	40	50	60	70	80	90	100
%A colorimeter	11	22	32	43	54	64	74	85	95	100
%A densitometer	11	22	32	43	53	63	72	82	92	100

Table 5.

According to these data, the measured photolitho was not within company acceptability limits, owing to the excess area with which it was filmed. However, Table 5 shows that the data obtained with the colorimeter practically coincided with those found on the densitometer, confirming that the colorimeter is a suitable measuring method.

4.4. MEASUREMENTS PERFORMED ON THE PRINTING SCREEN.

After the good results found in the foregoing sections, the following measurements were run on a control dot pattern strip on different printing screens.

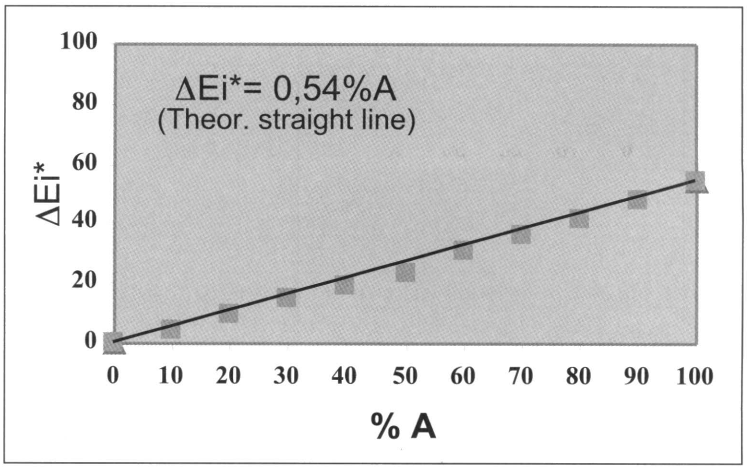
As mentioned in point 3.1 screens were processed at different light exposure times, keeping the other process variables steady.

Three screens were prepared for each exposure time, finding the arithmetic mean of the colorimetric measurements performed on the screens. The results are shown below in the corresponding tables and graphs.

On screens at an exposure time of 60 passes

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	46.36	23.19	-19.81	0	0.0	**0**	
10	47.93	20.82	-17.07	3.95	7.3	**-3**	**-2**
20	51.55	17.88	-14.16	9.33	17.3	**-3**	**3**
30	55.19	15.04	-11.12	14.83	27.6	**-2**	
40	58.71	12.93	-9.02	19.34	35.9	**-4**	
50	62.71	11.29	-7.57	23.64	43.9	**-6**	**-2**
60	68.75	8.30	-4.91	30.74	57.1	**-3**	**2**
70	73.71	6.26	-3.56	36.04	67.0	**-3**	
80	79.32	4.61	-2.65	41.55	77.2	**-3**	**-3**
90	85.09	2.35	-0.91	47.87	89.0	**-1**	**4**
100	91.50	0.96	-0.74	53.81	100.0	**0**	

Table 6.

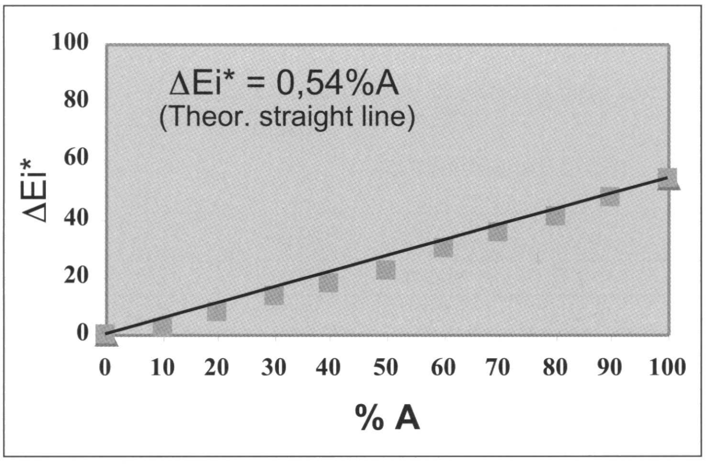


Graph 3.

On screens at an exposure time of 80 passes

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	46.52	23.39	-19.96	0	0.0	**0**	
10	46.75	21.82	-18.15	2.41	4.5	**-5**	**-2**
20	49.92	18.77	-14.62	7.84	14.6	**-5**	**3**
30	53.26	15.97	-11.05	13.41	25.0	**-5**	
40	56.23	13.72	-8.59	17.81	33.2	**-7**	
50	59.84	11.36	-6.47	22.45	41.8	**-8**	**-2**
60	66.85	8.31	-4.16	29.84	55.6	**-4**	**2**
70	72.09	6.44	-3.35	34.89	65.0	**-5**	
80	77.84	4.44	-1.96	40.79	76.0	**-4**	**-3**
90	84.18	2.54	-1.03	47.02	87.6	**-3**	**4**
100	91.12	0.48	-0.83	53.67	100.0	**0**	

Table 7.

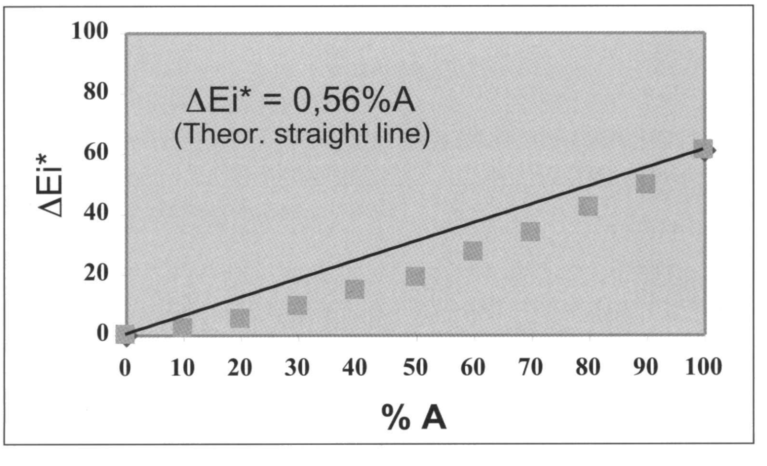


Graph 4.

<u>On screens at an exposure time of 100 passes</u>

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	45.85	25.61	-23.37	0	0.0	**0**	
10	47.05	24.85	-19.95	3.70	6.6	**-3**	**-2**
20	48.97	21.14	-17.70	7.87	14.1	**-6**	**3**
30	51.57	18.78	-15.16	12.11	21.7	**-8**	
40	54.70	16.13	-12.15	17.15	30.7	**-9**	
50	58.94	13.55	-10.16	22.27	39.9	**-10**	**-2**
60	65.28	10.50	-7.74	29.16	52.2	**-8**	**2**
70	70.97	7.65	-5.16	35.85	64.1	**-6**	
80	77.30	6.31	-5.75	40.89	73.2	**-7**	**-3**
90	84.01	4.32	-4.76	47.50	85.0	**-5**	**4**
100	91.59	1.14	-2.58	55.89	100.0	**0**	

Table 8.



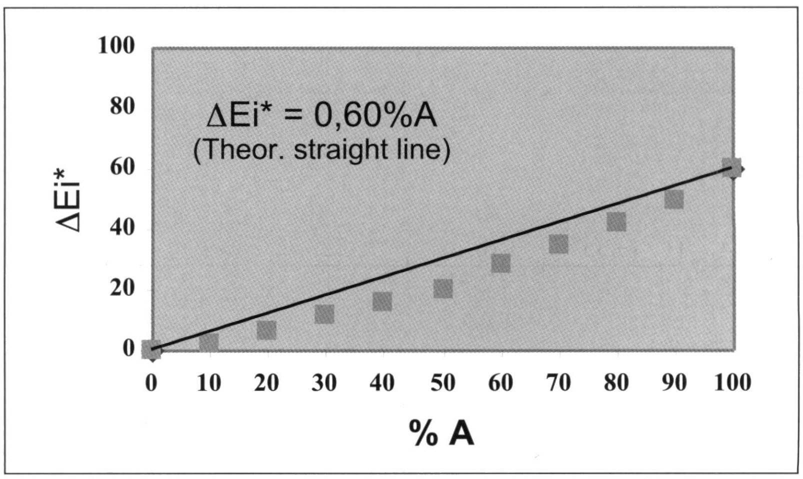
Graph 5.

It can be observed in all these plots that as exposure time rose, the correlation between the experimental points stopped being linear, corresponding to a second-degree equation, as the points deviated owing to screen processing.

On screens at an exposure time of 120 passes

Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	40.98	27.82	-21.75	0.00	0.0	**0**	
10	40.97	26.65	-20.22	1.93	3.2	**-7**	**-2**
20	44.62	24.56	18.47	5.89	9.8	**-10**	**3**
30	48.14	21.59	-16.04	11.08	18.5	**-11**	
40	51.30	19.33	-14.00	15.45	25.8	**-14**	
50	55.48	17.03	-12.26	20.41	34.1	**-16**	**-2**
60	62.18	13.88	-10.15	27.90	46.6	**-13**	**2**
70	68.40	10.88	-7.94	35.06	58.5	**-11**	
80	74.63	8.52	-6.13	41.82	69.8	**-10**	**-3**
90	81.79	5.96	-4.07	49.56	82.7	**-7**	**4**
100	91.11	2.19	-1.28	59.91	100.0	**0**	

Table 9.

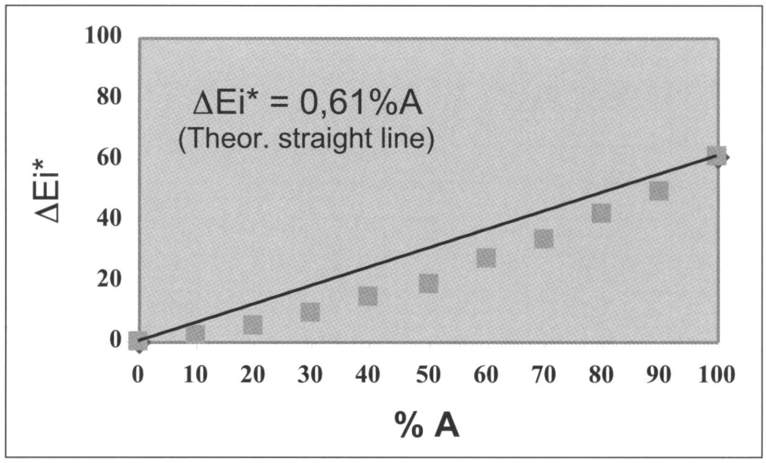


Graph 6.

On screens at an exposure time of 140 passes

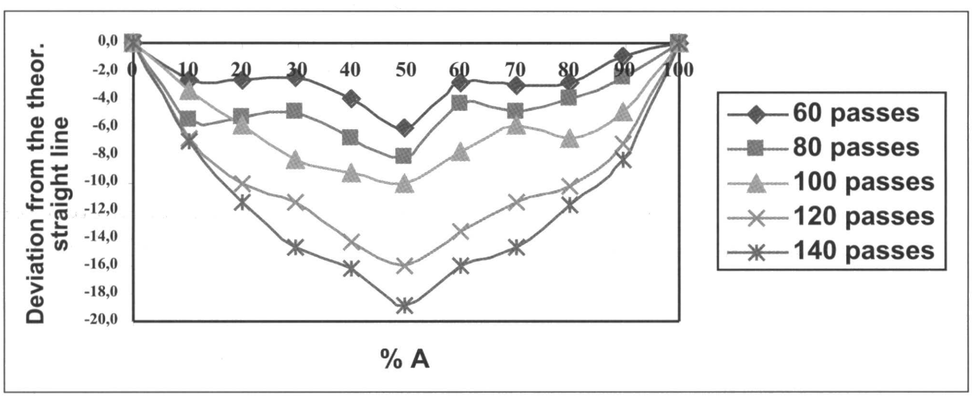
Theor. %A	L*	a*	b*	ΔEi*	Exp. %A	Deviation (%A)	L (%A)
0	41.08	28.65	-22.99	0	0.0	**0**	
10	40.95	27.70	-21.49	1.78	2.9	**-7**	**-2**
20	43.36	25.58	-19.45	5.21	8.5	**-11**	**3**
30	46.68	23.42	-17.7	9.31	15.2	**-15**	
40	50.02	20.40	-14.98	14.57	23.8	**-16**	
50	53.53	18.23	-13.17	18.97	31.1	**-19**	**-2**
60	60.83	14.81	-11.1	26.89	44.0	**-16**	**2**
70	66.80	11.85	-8.84	33.82	55.4	**-15**	
80	74.02	8.82	-6.71	41.75	68.3	**-12**	**-3**
90	81.48	6.04	-4.39	49.89	81.7	**-8**	**4**
100	91.36	1.83	-0.98	61.09	100.0	**0**	

Table 10.



Graph 7.

To compare the results, the data for all the light exposure times were plotted together in Graph 8.



Graph 8.

It can be observed that for each curve the deviation of the experimental data from the theoretical data is greater in the medium area (about 50% open area) than in the light area (about 20% open area) and than the dark area (about 80% open area).

This could be because in the medium area of the photolitho, the perimeter of the dots in contact with the translucent area of light passage is greater than in the rest of the areas. On raising the contact perimeter, the deviation between the theoretical an experimental data became larger as the light reflection at the dot edges increased.

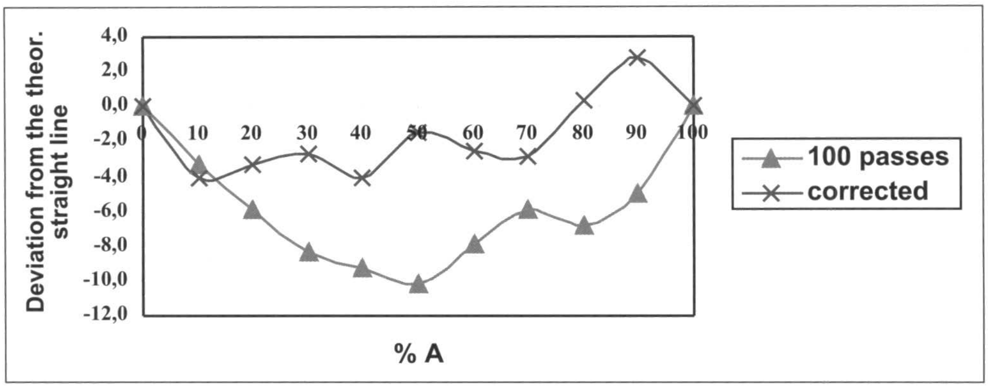
Comparing all the curves shows that the deviation between the theoretical and experimental data increased over the whole scale of greys as screen exposure time rose.

Raising screen light-exposure time increases the hardening of the photosensitive emulsion as well as the area of the hardened emulsion, owing to light reflection at the photolitho dot edges.

On developing the screen, the resulting percentage open area was less than the theoretical value, as the surface area of hardened emulsion was greater.

These graphs have allowed establishing the deviation that existed between the photolitho and the final result found on the screen for each light exposure time. The deviation could be resolved by processing the photolitho for each light exposure time in a corrected way.

As a first correction, the detected deviation for each percentage open area was subtracted in the photolitho. This modification was performed with the screen processed at an exposure time of 100 passes. The results are presented in Graph 9.



Graph 9.

The deviations are observed to be much smaller. However, the corrected screen does wholly not meet the acceptability limits. The improvement of this correction will be dealt with in subsequent studies.

Finally, on comparing the deviation found for each curve with regard to screen acceptability limits, the deviation was found to increase as screen exposure time rose.

In view of these results, the appropriate screen exposure time for the lowest possible deviations will be very low. However, low exposure times yield screens with low durability, which are not appropriate for use in production lines.

High exposure times are required to obtain screens with acceptable durability for use in production.

For these reasons, it would be more useful to compare the experimental data to data obtained with a standard screen having acceptable durability and not to a theoretical straight line.

To control the screens processed after the standard screen, the control method will be applied to the standard screen and to the new screen to be used in production. Finally, the deviation will not be calculated with regard to the theoretical straight line, but to the standard screen, in accordance with the following formula:

$$\text{Deviation} = (\%A_{\text{A new screen}}) - (\%_{\text{A standard screen}})$$

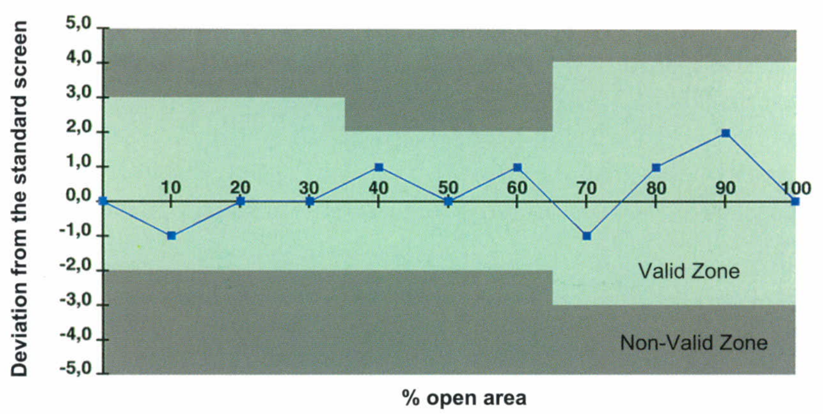
where A = open area

This deviation shall be less than the acceptability limits for the new screen to be used in production. This ensures the absence of shades owing to variations in percentage screen open area.

The application of the control method is shown (Table 11, Graph 10) to a NEW SCREEN exposed at 100 passes, calculating the deviation with regard to a STANDARD SCREEN processed at the same exposure time and verifying whether it met acceptability limits.

%A standard screen	%A new screen	Deviation (%A)	L (%A)
0.0	0.0	0	-2 3
6.6	5.8	-1	
14.1	13.7	0	
21.7	22.1	0	
30.7	31.9	1	-2 2
39.9	39.6	0	
52.2	53.0	1	
64.1	63.4	-1	-3 4
73.2	74.5	1	
85.0	86.7	2	
100.0	100.0	0	

Table 11.



Graph 10.

Graph 10 shows that the NEW SCREEN lies within acceptability limits for use in production.

For screen control it will be necessary to accompany the design photolitho with a control dot pattern on which the colorimetric measurements will be made before putting the screen into production. Figure 5 shows this control strip.

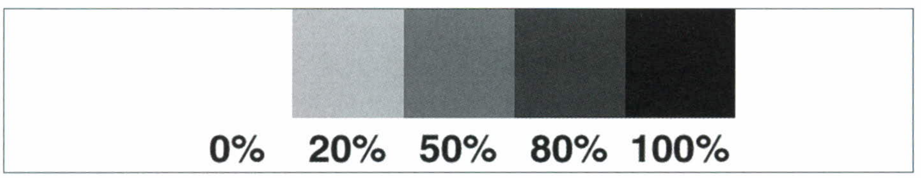


Figure 5.

5. CONCLUSIONS

The present study allowed drawing the following conclusions:

- The acceptability limits were determined of a printing screen based on company criteria for use in the production lines.

- A new method was fine-tuned to perform printing screen control by determining the percentage open area for ink by using a colorimeter.

- In developing the method it was found that as screen exposure time was raised, the deviation of the screen percentage open area increased with regard to the theoretical data.

- The control method will not be performed in relation to a theoretical straight line but to a standard screen with acceptable durability for use in production.

- It was found that using a colorimeter for determining screen percentage open area was a good screen control method, which afforded the following benefits:

    - Objectivity; the measurement finding is independent of the operator
    - Speed and simplicity; highly qualified operators and complex instruments are not required
    - Accuracy and repeatability