PRINTING SCREEN PREPARATION BY LASER EXPOSURE

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Colour constancy is a key objective in enhancing ceramic tile quality. According to a survey conducted at a single-fire tile manufacturing facility, 20% of the cases in which shades (minor colour differences) appeared occurred when screens were changed. It was furthermore found that the photolithos used in screen production exhibited changes in dot shape, size and number on making successive copies of the photolithos.

As a result it was decided to attempt to produce printing screens without having to use photolithos, by using laser exposure in screen preparation, a technique that has been successfully employed in other branches, especially in the textile sector. The technique is based on using digitised image data to reproduce the desired image on a screen covered with a photopolymer coating, on exposing targeted areas to a laser of suitable wavelength.

The aim of the study was to produce printing screens by the laser exposure technique for decorating ceramic tiles. This first required establishing starting working conditions: exposure (intensity and velocity), type of emulsion and catalysis (catalysis time and type of catalyst). This was done by performing a series of tests programmed by factorial experiment design. Test results were assessed by characterising the resulting screens, which revealed the importance of the type of emulsion. This led to the development of an emulsion with improved characteristics.

Suitable working conditions were set with the new emulsion for the exposure equipment, in terms of type of screen fabric and emulsion to be used. Finally, the exposure equipment was calibrated and results verified by means of printing screens that were put into service in the industrial production line, with satisfactory results.

1. INTRODUCTION

Ceramic tiles can be decorated by different methods, however screen printing is currently the most widespread decorating technique employed in ceramic floor and wall tile manufacture, whether by the single- or double-firing process[1].

The technique involves decorating the tile by means of a suspension that is forced through a screen consisting of a fabric covered by a mask (emulsion), which defines a design. The suspension is deposited on the ceramic tile, thus reproducing the design. This decorating method allows obtaining fine detail and good design reproduction, yielding high quality products[2].

One of the problems besetting ceramic tile manufacture and impairing tile quality, also partly due to the screen printing operation, is the appearance of shades (minor colour differences) in tiles[3-5]. As a result of ever higher quality demands, GRES DE NULES, S.A. conducted a study on the variables affecting the appearance of shades in ceramic tiles. The study showed that in about 45% of the cases in which shades were detected, these were caused by modification of the variables corresponding to the screen-printing operation (screen, squeegee, fixative and ink). Of these, the most important variable was screen changing. This produced around 20% of the arising shades. It was also shown to be the single most important factor in producing shades of all the studied variables throughout the whole process (including pressing, glazing and firing).

These variations, arising on using different screens, occur because screen characteristics (thickness, tension, open area, etc.) differ. This led to an attempt to improve the printing screen production process with a view to obtaining more consistent screen characteristics.

Fig. 1 presents a schematic setting out the printing screen production process. This is briefly done as follows[6-7]. In the first place, the fabric is stretched and glued to the screen frame. The fabric is then degreased by washing, after which the screen is dried. Subsequently a photosensitive emulsion is applied and the emulsion coated screen is dried at a suitable temperature. A photolitho (polyester sheet with the positive of the image to be reproduced) is placed on the dried screen, which is exposed to a lamp emitting UV light. The screen is then developed by washing with pressurised water. In this step, the water soluble emulsion is removed in the areas untouched by UV light (blocked out by the image of the photolitho), whereas the emulsion coating which hardened on exposure to the UV light has become insoluble and is left on the screen.

The photolitho preparation step was observed to be largely responsible for

[1]. *Tecnología cerámica. V, Esmaltes cerámicos*. Valencia: Instituto de Química Técnica, 1985.
[2]. GUERRERI, G. *La serigrafía sulle piastrelle in ceramica*. Faenza: Faenza Editrice, 1980.
[3]. NEGRE, F. ; MORENO, A.; SÁNCHEZ, E., et al. *Factores que influyen sobre la variabilidad de la tonalidad de baldosas cerámicas*. Communication presented at XXXIV Congreso Anual de la Sociedad Española de Cerámica y Vidrio. L'Alcora (Castellón), 14-17 September, 1994. (Unpublished)
[4]. NEGRE, F; SANZ, V.; GIMÉNEZ, S., et al. *Estado actual de la técnica de decoración de baldosas cerámicas mediante serigrafía*. Communication presented at XXXIV Congreso Anual de la Sociedad Española de Cerámica y Vidrio. L'Alcora (Castellón), 14-17 September, 1994. (Unpublished)
[5]. PEÑALVER ,J.; MARTÍ, V. ; PORTOLÉS, J., et al. *Study of screen-printing application control variables and their influence on shades in tiles*. In: IV World Congress on Ceramic Tile Quality (QUALICER). Castellón, 1996, p. 309-321.
[6]. KOSLOFF, A. *Screen printing techniques*. 3rd ed. Cincinati: ST Publications, 1993.
[7]. PEYSKENS, A. *Fundamentos técnicos de la realización de pantallas para serigrafía*. Appiano Gentile: Saati, 1991.

producing the differences found among screens bearing the same design. Variation in the shape, size and opacity of the dots that make up the image of a photolitho lead to differences in screen open area, causing different amounts of ink to be deposited on the tile and producing shades.

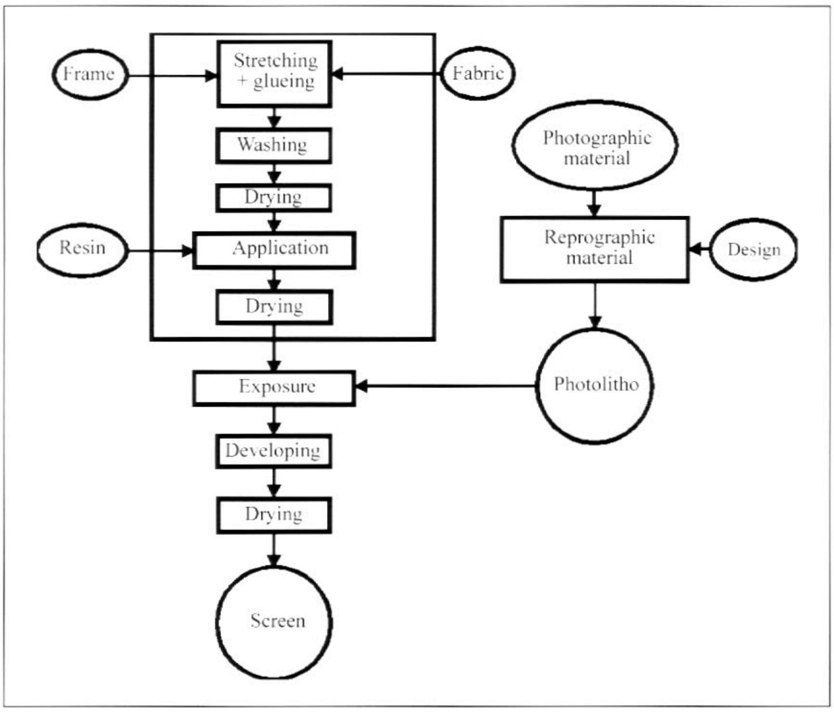

Figure 1. Schematic of the printing screen production process.

The traditional and most widespread photolitho preparation process involves using reprographic techniques[8], which allow different photolithos to be obtained of the design (pattern, stone, etc.) to be printed on the tile. After making the original photolithos, subsequent modifications are made by copying. The copying process is where differences arise between photolithos bearing the same design. This was confirmed experimentally by examining two photolithos with a stereoscopic magnifying glass. Figs. 2 and 3 show photographs of the same area in both photolithos. Differences can be observed in the opaque regions, which will yield differences in ink release.

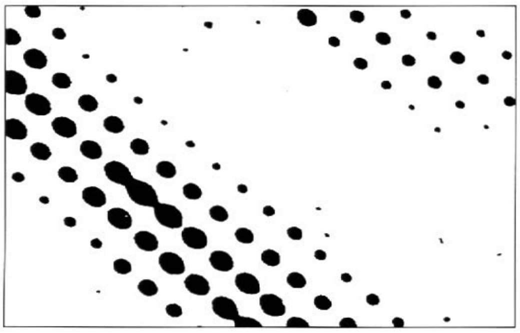

Figure 2. *Photograph of a given area of an original photolitho (magnification 19x)*

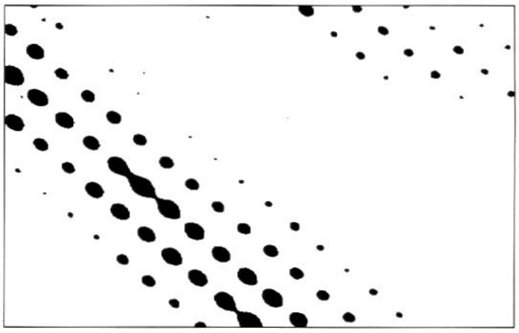

Figure 3. *Photograph of the same are in a copy of the original photolitho (magnification 19x)*

[8]. MARA, T. *Manual de serigrafía*. Barcelona: Blume, 1987.

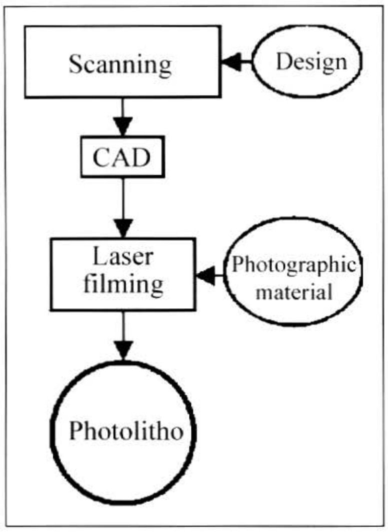

Figure 4. Schematic of photolitho preparation by filming.

A new technique has recently been incorporated in making photolithos (Fig. 4). This involves digitising the image using an electronic scanner; the image can then be modified by computer with suitable software. The photolitho is ultimately produced by laser filming. This procedure allows reproducing photolithos from digitised images so that they can be readily and reliably reproduced provided they are made by filming.

A way of suppressing the variations in screen characteristics from using photolithos would be by eliminating this step. Equipment is currently marketed[9] for the exposure of printing screens used in the textile and paper branches, which no longer requires preparing a photolitho. The technique is based on using digitised image data to reproduce the image on a screen with a photopolymer coating by exposing the targeted areas to a laser beam of suitable wavelength. The printing screen preparation process by this technique is illustrated in Fig. 5.

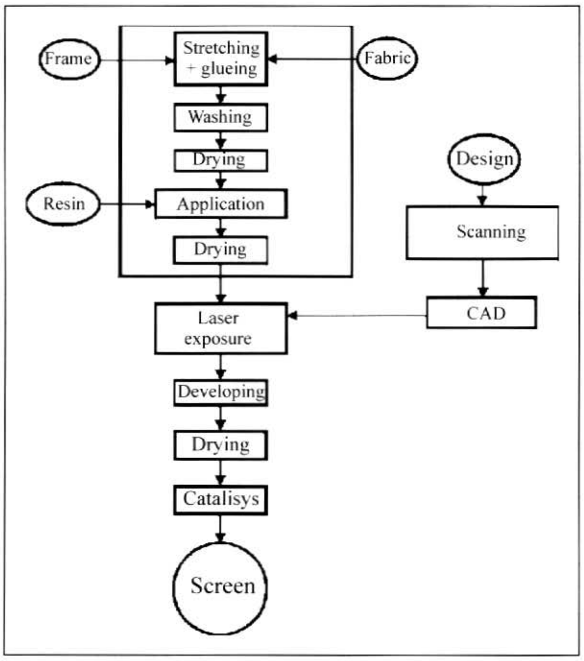

Figure 5. Schematic of the printing screen preparation process by laser exposure.

It can be observed that the process involved in creating the digital image is similar to the one described above (Fig. 4), while screen preparation prior to exposure is in turn similar to the traditional procedure (Fig. 1). The exposure step is conducted by a laser system; the screen is subsequently developed by washing with pressurised water. There is finally a last step, not required in the traditional process, in which the screen is treated with a catalyst to improve its resistance to abrasion and chemical attack.

This technique allows flexible handling of the images to be obtained on the screens owing to CAD techniques, yields savings in photographic materials and suppresses the risk of defects arising relating to the photolitho.

Considering the above it was decided to adopt this last system for obtaining printing screens to be used in ceramic tile manufacture. The work set out below was conducted with a view to establishing the possibility of using the system for this purpose.

Laser exposure equipment (DISE 3) supplied by MOGRAFO (Fig. 6) was used. The equipment could not be directly implemented in the ceramic industry since it required using an emulsion whose characteristics were specifically suited to the instrument. These characteristics differed from those of emulsions used in current screen production in tile

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[9]. GOLD, R. *Insolación de las pantallas por proyección y por formación digital directa de la imagen*. In Serigrafía. no. 25, March-Aprill, 18-23, 1992,

manufacture. Moreover, the working conditions of the equipment depended on emulsion characteristics and thickness of the emulsion-coated screen. As the equipment was developed for other sectors in which type of emulsion and screen fabric were different, it was necessary to establish the relevant working conditions.

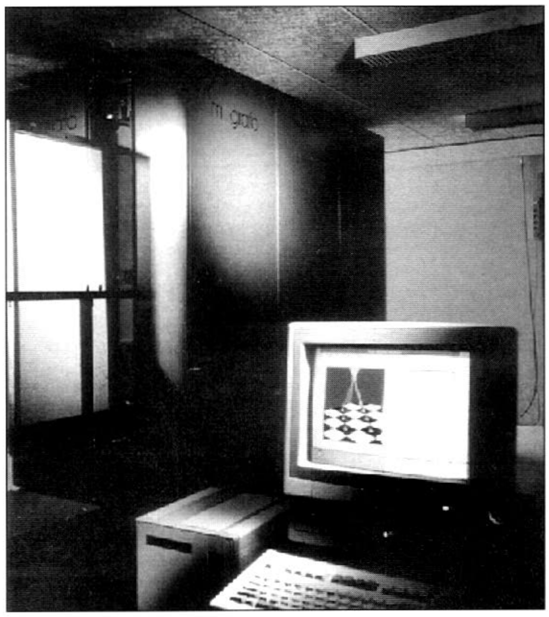

Figure 6. *Photograph of the outside of the DISE 3 equipment*

2. DISE 3 EXPOSURE EQUIPMENT

The system allows hardening (curing) the photosensitive emulsion directly by irradiation with a laser beam, controlled so that it only irradiates (hardens) the targeted areas (established by the design) of the screen surface[10].

An argon laser generates the laser beam which, by means of an optical unit, is reduced to a light point of diameter below 1/50 mm (20μm). The exposure equipment is fitted with an optical system to ensure that the laser light strikes the screen surface at right angles, thus avoiding the problem of dot distortion in the screen. Screen exposure takes place by scanning, moving the light point over the screen with great accuracy.

The system's resolution depends on the diameter of the light point; in this case resolution was 1270 dpi.

Synchronised laser beam modulation (on/off) with light point movement ensures that the screen is only exposed in those regions in which the emulsion is to be hardened. This modulation is produced by digitised data conversion of the design with a Raster Image Processor (RIP) into a bit map that contains the laser beam on/off signals.

Screen production by the DISE 3 system is schematically illustrated in Fig. 7. The digitised design to be printed on the tile, prepared by the design department (in EPS

[10]. Andersen, A.V. *A scanner system for successive irradiation of a working surface, particularly for ultra-violet exposure of a photo emulsion on a serigraphic printing frame*. Swedish Patent. PCT/DK89/00108. WO 89/11116. 1989-11-16.

format), is fed into the computer where production is prepared by appropriate software: DIPP (DISE 3 Production Preparation), which allows placing the image in the frame, turning and inverting it, etc. This software replaces the manual process of photolitho positioning in the frame prior to exposure, according to the traditional procedure. The design data, converted into a bit map, are sent to the exposure unit control station. At this station, the DMS software (Dise Monitoring System) controls exposure unit operations: adjustment of laser velocity and intensity, selection of frame size, inspection of production, door opening, switching off, etc. The bit map corresponding to the design that is being worked on is sent from this station to the exposure unit via optical fibres.

The screen is positioned for curing in the exposure unit. Inside the unit the screen is held by a pneumatic system at a set distance from the scanner. The scanning head contains optical systems for converting the laser beam into a light point and making it strike the screen surface at right angles. This head, which sends out the light point, is located on a system that can move in two directions XY, thus enabling the whole screen to be scanned.

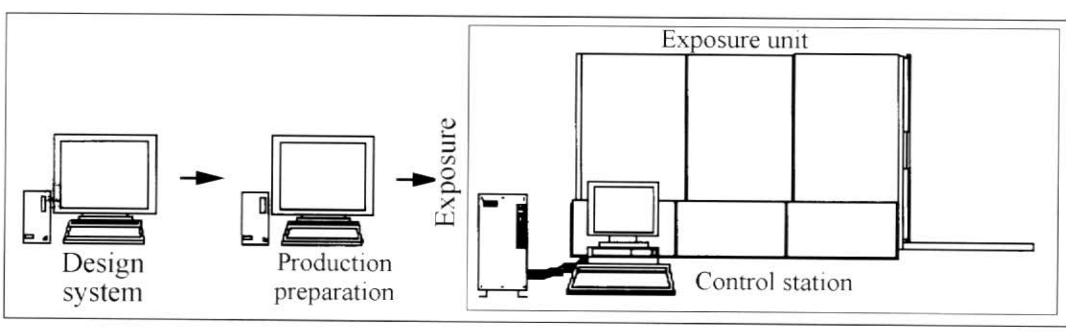

Figure 7. *Screen production by the DISE 3 system*

3. PHOTOSENSITIVE EMULSION CHARACTERISTICS

The emulsion is an integral part of the system so that it needs to meet a series of specific requirements, which are set out below.

The emulsion must react rapidly, since the laser beam runs at high speed across it owing to production requirements. The exposure time for each point ranges from 0.1 to 0.45 μs, 50 times less than the exposure time used in the traditional procedure.

Laser emission is not polychromatic, as is the UV lamp emission used in the traditional method, but is monochromatic. This means that the emulsion for laser exposure needs to exhibit high sensitivity in the spectral region emitted by the laser.

Another of the variables to be taken into account is the thickness of the emulsion applied o the screen fabric, which can lie in the 6 to 20 μm range. The high specific energy presented by laser radiation allows the emulsion surface to be very easily hardened, but makes penetration into the deeper layers much more difficult. In developing the image in water this leads to characteristic peeling of the cured emulsion surface layer from the fabric.

Besides all the foregoing characteristics, the emulsion shall also exhibit good chemical resistance and mechanical strength, since in tile production the screens are subject to high abrasion, owing to the type of screen-printing inks used, tile characteristics and chemical attack by the screen-printing vehicles contained in ink compositions.

The laser radiation-cured emulsion is very sensitive to water and moisture in general. Thus after developing in water, a chemical catalyst needs to be used to harden the emulsion, improving chemical resistance and hence suppressing the tendency to peel from the fabric during use in the production line. This catalysis step is not required in screen production for the paper and textile branches, as the inks used and the process itself are less aggressive.

4. ESTABLISHING STARTING WORKING CONDITIONS

In the DISE 3 equipment it was necessary to set the velocity and intensity of the laser beam to be used in irradiating the screens. On the other hand, different commercial photosensitive emulsions are available which could be used for producing this type of screen, so it was necessary to assess whether these products were suitable. It was furthermore also necessary to evaluate the type of catalyst and catalysis time to be used for obtaining adequate emulsion hardening.

To establish suitable working values for the various parameters, a rigorous study was conducted on how all these parameters affected printing screen characteristics.

4.1. EXPERIMENTAL PROCEDURE

To programme the experiments to be run on an industrial scale, given the many parameters to be studied, it was decided to choose an experiment design that would provide maximum information with the least number of experiments. The selected model was the Taguchi L_{18} model[11], which allows studying factors at two or three levels, as was desirable in our case. The levels of the studied variables are set out in Table 1. Emulsions 13-3748 and 13-4710 had been developed by SAATI, taking into account the characteristics to be exhibited for use in the laser exposure equipment involved. The EA emulsion was an emulsion that is marketed for use in instruments of this type. Similarly, of the catalysts used, one commercial product was found (CA), while the other was supplied by SAATI (Fixing agent-C3).

Parameter	Levels		
	1	2	3
Type of emulsion	13-3748	13-4710	EA
Laser velocity (pps)	117	140	163
Laser power (mW)	350	400	--
Type of catalyst	CA	Fixing agent -C3	--
Catalysis time (min)	10	20	--

Table 1. *Variation levels of the five studied parameters.*

[11]. Box, G.E.P.; Hunter, W.G.; Hunter, J.S. *Estadística para investigadores*. Barcelona: Reverté, 1989.

Table 2 indicates the levels of the five parameters in each of the 18 tests that were performed, determined by the selected experiment design.

Test no.	Parameter levels				
	Laser power	Type of emulsion	Laser velocity	Type of catalyst	Catalysis time
E1	1	1	1	1	1
E2	1	1	2	2	2
E3	1	1	3	2	2
E4	1	2	1	1	2
E5	1	2	2	2	2
E6	1	2	3	2	1
E7	1	3	1	2	1
E8	1	3	2	2	2
E9	1	3	3	1	2
E10	2	1	1	2	2
E11	2	1	2	1	1
E12	2	1	3	2	2
E13	2	2	1	2	2
E14	2	2	2	2	1
E15	2	2	3	1	2
E16	2	3	1	2	2
E17	2	3	2	1	2
E18	2	3	3	2	1

Table 2. *Parameter levels in the different tests.*

The 18 screens were prepared in the usual fashion using polyester fabric with a mesh count of 77 threads/cm stretched over the frames, tensed at 14 N/cm. The emulsion coating was applied with an automatic applicator. Applied coating thickness was 10 μm. The screen coated with the emulsion to be tested was put into the DISE 3 equipment and a control pattern print was run, consisting of various regions with different theoretical open areas (0, 10, 20, 30, 40, 50, 60, 70, 80 and 90%).

The abrasion resistance of the resulting screens was determined by a standard TABER abrasion tester[12], which allowed assessing emulsion loss in terms of the number of abrasion cycles that the screens were subjected to. This test was carried out on a screen area without any design and on the screen side that presented most emulsion (the screen face in contact with the tile in the production process). The screens underwent 1000 abrasion cycles, which were run in 100 cycle stages; weight and thickness loss in the tested screen part were determined after each stage.

The percentage real open area was determined ((emulsion-free area/total area)) ¥ 100) of the different parts of the control pattern (10, 30, 60 and 90% theoretical open area). The test was carried out by an experimental assembly that allowed examining the screen surface through a stereoscopic magnifying glass. The conveniently illuminated image was captured by a CCD camera that permitted image digitisation and subsequent computer processing[13].

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[12]. ISO 5470-1980 *Rubber or plastics coated fabrics*. Determination of abrasion resistance.
[13]. Nengre, F.; Moreno, A.; Giménez, S., et al. Control de pantallas serigráficas utilizadas en la decoración de baldosas cerámicas. In: XXXVI Congreso Nacional de Cerámica y Vidrio: libro de resúmenes. Arganda del Rey, Madrid: Sociedad Española de Cerámica y Vidrio, 1996, p. 132 .

4.2. RESULTS

On determining the open area in the different parts of the control pattern in the 18 screens (Table 3), it was found that the experimentally determined open area percentages did not match the theoretical values, nor were they the same for all the screens, that is, the different studied parameters affected this characteristic. However, it was not studied what each parameter's particular effect was, as the open area could be quite simply changed on calibrating the laser exposure equipment. Such calibration involved modifying the design so that the real open area matched the targeted theoretical value. This operation is set out in detail in Section 5.

Test no.	Theoretical open area (%)			
	10	30	60	90
E1	3.5	18.8	53.3	84.5
E2	5.4	33.5	58.8	93.4
E3	1.4	18.6	54.6	89.0
E4	2.4	21.5	50.7	90.9
E5	2.9	31.0	62.5	96.4
E6	2.2	23.1	54.1	95.0
E7	4.5	22.7	59.6	90.1
E8	8.6	33.6	63.5	92.7
E9	3.3	23.2	54.2	89.2
E10	4.0	22.7	50.7	87.6
E11	8.3	30.1	59.1	88.0
E12	1.3	11.9	51.3	86.9
E13	4.4	13.2	57.2	88.0
E14	6.4	28.2	68.3	94.0
E15	1.4	18.2	50.5	88.4
E16	6.1	24.6	59.8	88.9
E17	5.3	26.5	66.3	91.9
E18	2.5	19.4	52.4	86.5

Table 3. *Results of the open area determination in the tested screens.*

In conducting some trials prior to running the experiment design, the method's sensitivity to the operation involved in developing the cured emulsion became clear. The sensitivity became even more evident on observing the screen regions in which small emulsion dots were to be reproduced (high ink release areas). In some cases the absence was detected in these areas of a number of such dots. Fig. 8 shows a photograph of a region, corresponding to a 90% theoretical open area without emulsion loss. The photograph in Fig. 9 shows the same area with emulsion loss produced in developing.

In some of the 18 screens that were produced, emulsion loss was found in regions of the control pattern with high open areas, so that it was considered of interest to establish how each parameter affected emulsion loss in developing, since such loss can give rise to great problems when it comes to reproducing a screen.

Dot loss was assessed in the region corresponding to 90% theoretical open area on computing by image analysis the proportional increase in screen open area owing to emulsion point loss. This calculation was performed by determining the open area (% real area) of the 90% open area, and subsequently estimating the area assuming there had been no emulsion loss (% area without loss). Finally the increase in open area or emulsion loss was calculated by the expression: ((% area without loss -% real area)/(% area without loss)) x 100.

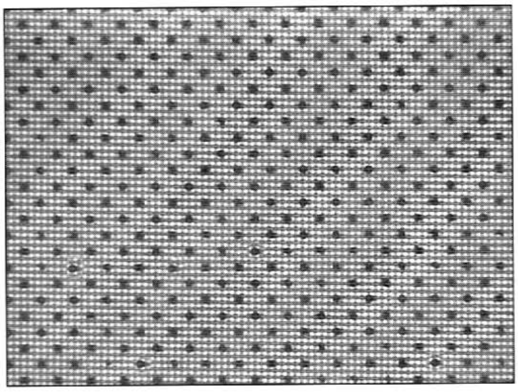

Figure 8. Photograph of a region with a 90% theoretical open area.

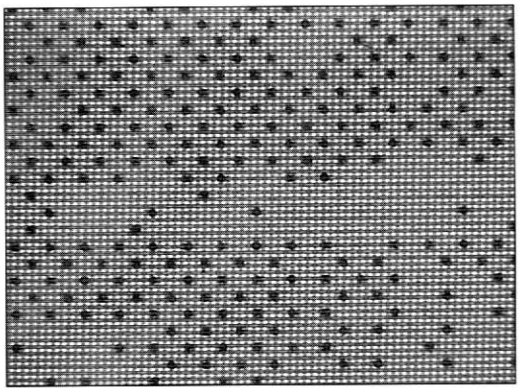

Figure 9. Photograph of a region with a 90% theoretical open area exhibiting emulsion loss..

Table 4 indicates the characterisation results of the 18 screens corresponding to experiment design. For brevity only the percentage increase in open area (emulsion loss) produced in developing is given in the table, together with weight loss and decreased thickness found in the different screens on undergoing 1000 abrasion cycles.

On subjecting the resulting data for emulsion loss in developing and weight loss to variance analysis, it was found that the parameters that had a significant effect (level of importance <0.05) were the type of emulsion and laser velocity in the former case, and type of emulsion in the latter case. Table 5 reports the level of importance established for each parameter.

Test no.	Emulsion loss in developing %	Abrasion resistance (1000 cycles)	
		Weight loss (mg)	Thickness decrease (μm)
E1	0		4
E2	2.8	18.4	5
E3	0.4	45.4	19
E4	0.0	7.3	3
E5	6.2	4.4	5
E6	8.6	48.9	16
E7	0.0	13.5	4
E8	2.5	12.7	4
E9	1.3	36.7	12
E10	0.0	14.6	4
E11	0.3	10.4	8
E12	0.9	46.7	15
E13	0.0	0	0
E14	4.9	3.5	3
E15	1.6	28.8	13
E16	0	11.2	3
E17	1.6	22.6	8
E18	1.3	49.1	15

Table 4. Results of the determination of emulsion loss in developing and abrasion resistance of the tested screens.

Variance analysis also yielded mean values for the studied properties at every tested level for each parameter. Tables 6 and 7 respectively indicate the mean values corresponding to the parameters that had a significant effect, namely type of emulsion and laser velocity.

Parameter	Level of importance	
	Emulsion loss in developing (%)	Weight loss (mg)
Type of emulsion	0.0453	0.0000
Laser velocity	0.0396	0.0582
Laser power	0.5577	0.7358
Type of catalyst	0.2866	0.3606
Catalysis time	0.7196	0.5444

Table 5. *Variance analysis results*

Emulsion	Mean values	
	Emulsion loss in developing (%)	Weight loss (mg)
13-3748	0.0	8.4
13-4710	4.0	11.2
EA	2.2	41.8

Table 6. *Mean values found for the three types of emulsion.*

Laser velocity (pps)	Emulsion loss in developing (%)
117	0.6
140	4.2
163	1.0

Table 7. *Mean values found for the three laser velocities.*

The above results showed that the most important parameter was the type of emulsion. It was furthermore shown that emulsion reference 13-3748 exhibited the best characteristics as it virtually lost no emulsion in developing and exhibited very low weight loss in abrasion. Laser velocity affected emulsion loss to a greater extent than laser power, however, as already mentioned, these parameters depended on emulsion type, fabric thickness, etc.

In order to compare these findings with a traditional emulsion, weight loss was determined of a screen obtained by the traditional method, on undergoing abrasion. At 100 abrasion cycles, the screen lost a mass of 40 mg, which indicated that emulsions 13-3748 and 13-4710 could be considered acceptable with regard to this property. In the traditional process there was no emulsion loss in developing.

Consequently, emulsion 13-3748 was used to start with, but subsequent trials showed that slight variations in some production process parameters such as drying of the screen prior to placing inside the laser exposure equipment, or the intensity of the developing process, gave rise to emulsion loss. This led to developing a new emulsion with characteristics resembling those of emulsion 13-3748, which however exhibited less sensitivity to the developing process.

SAATI similarly enhanced catalyst characteristics, making it more resistant to chemical attack than the screen-printing vehicles used in ceramic tile manufacture.

Several screens were produced using the new emulsion (SAATIKER 5113 LE) and the new catalyst (FIXING AGENT C5), and bore control patterns printed on them. No emulsion loss was found in developing, and good reproducibility was obtained between the open areas in the control patterns of all the screens. Table 8 indicates the results of the open area determination in some of the screens made. Reproducibility could be considered satisfactory, since it had been established experimentally beforehand that a difference in open area ≤3% produced no difference in final tile colour (shades), whereas at a difference ≥5% shades were found to arise in the tiles.

Theoretical open area (%)	Screen					
	1	2	3	4	5	6
20	8.3	8.0	8.2	7.9	8.1	7.1
30	14.9	15.2	15.4	14.2	15.2	14.9
40	22.4	23.1	22.4	21.5	21.9	21.3
60	45.7	44.8	43.9	46.5	40.0	43.3
70	57.0	57.0	58.0	58.3	56.7	55.4
80	69.7	69.2	70.7	67.0	65.7	67.2

Table 8. *Open area reproducibility in screens produced by laser exposure.*

It can be observed that the theoretical open area did not coincide with the actual open area. This was because the tests were run without calibrating the laser equipment, which was done as set out in the following section.

Abrasion resistance of the new emulsion was determined with the resulting screens. The results are reported in Table 9, where they are compared to data obtained with the emulsion used in the traditional procedure.

Emulsion	Abrasion resistance (1000 cycles)	
	Weight loss (mg)	Decrease in thickness (µm)
Traditional	40	17
SAATIKER 5113 LE	18	3

Table 9. *Abrasion resistance of the emulsion for laser and traditional exposure.*

It can be observed that the new emulsion exhibited greater weight loss than the one obtained with emulsion 13-3748, however this was less than the weight loss found with the traditional one.

5. CALIBRATION OF THE DISE 3 EQUIPMENT

As observed above, laser exposure yielded screens whose open area in the different control patterns did not match expected values in terms of the starting design pattern. It was therefore necessary to establish a transfer function that allowed obtaining the expected (theoretical) open area. This transfer function depended on the type of emulsion and fabric used. Thus, having established the type of emulsion to be employed, the transfer function for each fabric used in normal production was to be determined.

It was thus necessary in principle to establish suitable laser power and velocity for each fabric and each emulsion with regard to the targeted product, subsequently determining the transfer function to be used.

Suitable laser intensity and velocity were determined by producing screens bearing one or more control patterns as a design. Different laser powers (350, 375 and 400 mW) and velocities (105, 117, 140 and 173) were then tested on these screens. If the emulsion had not adequately hardened at a given power and velocity, total emulsion loss was found in regions with a high theoretical open area (80, 90 and 95%) in developing. However, when excessive emulsion hardening had occurred, it was found after developing that regions containing low theoretical open areas (5, 10 %) contained no openings to let through the ink. Appropriate laser strength and velocity were considered to have been achieved when good reproduction of the highest and lowest open area percentages was found.

Having established these two parameters, the transfer function was determined. This was done by producing a screen with a control pattern containing the following theoretical open area percentages: 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 95%. The real open area was then determined on the resulting screen as set out in Section 4.1. The outcomes were then used by the design department to modify the design pattern. The resulting transfer function was subsequently checked by producing screens with a control pattern and verifying whether the different regions actually possessed open areas resembling the theoretical ones.

Table 10 details the findings of the open area determination on two screens produced with the SAATIKER 5113 LE emulsion and the fabric with a mesh count of 77 threads/cm, at a strength of 375 mW, a velocity of 140 pps, and a suitable transfer function. It can be observed that a real open area was found that resembled the theoretical value.

Theoretical open area (%)	Screen	
	1	2
5	4.1	5.0
10	11.0	11.9
20	22.3	21.7
30	31.5	32.2
40	42.5	39.7
50	51.7	49.9
60	57.1	58.6
70	70.0	68.3
80	78.2	76.7
90	89.0	89.0
95	92.9	94.4

Table 10. *Open areas determined after application of the transfer function.*

The same tests were run with the same emulsion and two other different fabrics, one with 68 threads/cm and the other with 61 threads/cm. Table 11 presents the most suitable laser power and velocity for obtaining screens in each case.

Fabric (threads/cm)	Power (mW)	Velocity (pps)
61	400	105
68	400	117
77	375	140

Table 11. *Laser power and velocity required in terms of type of fabric used.*

6. RESULTS ON USING THE PRINTING SCREENS IN THE PRODUCTION LINE.

On obtaining the transfer function for the 77 threads/cm fabric, 10 screens were produced using a design used at GRES DE NULES, S.L. These screens were put into production for the manufacture of a small number of tiles (20). The aim of this trial was to manufacture ceramic tiles with all the screens in a short time, to keep variations in the production process from giving rise to shades in the resulting glazed tiles. All the trials were carried out by the same operator on the same screen-printing machine, using the same ink under the same working conditions.

The resulting ceramic tiles were sorted by the method usually employed in the ceramic industry. All the tiles exhibited the same colour.

7. CONCLUSIONS

The work carried out allowed preparing a new production method for printing screens used in decorating ceramic tiles. The method involved using digitised image data to reproduce the desired image on a screen coated with a photosensitive emulsion by exposure of the targeted areas to a laser beam, using the DISE 3 equipment made by MOGRAFO.

In preparing the method a new emulsion (SAATIKER 5113 LE) needed to be developed by SAATI, exhibiting appropriate characteristics for laser curing and for withstanding arising physical as well as chemical attack in service in the production line.

The use of the laser exposure system with a suitable emulsion allowed obtaining printing screens with good design reproducibility, while suppressing the colour differences (shades) among screens usually found in screen production by the traditional method.

This screen preparation method presents a series of advantages compared to the traditional method, most of which stem from not having to use photolithos:

- Savings in photographic material.
- Simplification of the design storing system since instead of keeping photolithos, files are saved.

- Greater versatility in design modification.
- Elimination of problems owing to differences between photolithos of the same design causing shades in glazed tiles.
- Highly accurate positioning of the design on the screen, reducing the need for subsequent adjustments the screen-printing machine on replacing one screen by another.