DIGITAL CERAMIC GLAZING WITH LOW G/M2 LAYDOWN

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1. ABSTRACT

In recent years, inkjet digital technology has been widely implemented in ceramic tile glazing and decoration lines. This technology has not only been used to apply pigments in decoration, but has also enabled various ceramic surface finishes, such as glosses, lustres, matts, glues, grits, and metals, to be obtained.

However, the application of higher g/m^2 laydowns, such as those used in glazing and protective coatings, remains difficult owing to the limited amount of material that can be applied by current inkjet printheads and to the constraints on the inks used (density, viscosity, and particle size).

In the manufacture of large formats, the application of glazes or other coatings by inkjet technology affords great advantages over traditional techniques, as the latter fail to provide the necessary uniformity. The surface finish of inkjet applications depends on multiple parameters, such as applied g/m^2 laydown, printing pattern, body surface roughness, body temperature and moisture content, number of applied layers, and nature of the glaze.

This study was undertaken to analyse these variables with a view to determining their influence and establishing an appropriate method for evaluating the glaze surface. To do so, ink jetting was analysed, and the printed images were examined by microscopy, image analysis, and colorimetry. The results enabled optimisation of application conditions and obtainment of uniform coatings by inkjet digital technology. Finally, tiles were obtained that evidenced the advantages of digital glazing.

2. INTRODUCTION

Continuous, uniform glaze applications are currently performed using *bell waterfall*, *spray gun or airless spray, disk* or *pneumatic linear curtain glazing* systems. In *bell waterfall* or *linear curtain glazing* applications, the unfired tile crosses a curtain of glaze, whereas the *spray gun or airless spray* system sprays the glaze under pressure onto the tile. In the *disk* system, centrifugal force is used to spray glaze onto the tile. Traditional glazing processes apply a glaze layer of 300–500 g/m^2.

Inkjet technology applies much thinner layers (20–80 g/m^2 at standard production line speeds) to decorate the tile surface using pigment inks and effect inks [1][2][3].

Achieving larger inkjet ink g/m^2 laydowns (above 80 g/m^2) would allow tiles to be digitally glazed. However, this application has hardly been implemented owing to the constraints of the available printheads and the difficulty of developing the glaze suspensions [4].

Implementing digital glazing techniques (known as Full Digital) requires development of tools that characterise the behaviour of digital glazing machines and enables the influence of the operating variables on the glazing process to be determined, in order to optimise working conditions [5][6].

3. EXPERIMENTAL PROCEDURE

Four white digital inks (NDS 10, NDS 28, NDS 30, and NDS 50) were applied, using two porcelain tile bodies of different roughness (SMOOTH and ROUGH), both with a black colour after firing, as application substrate. The colour of the body was selected to provide an appropriate contrast with the applied white glaze and thus enable the quality of the application to be observed/quantified.

The test inks were formulated to meet the following requirements: particle size below 1 µm; surface tension: 30 mN/m; viscosity between 24 and 29 mPa·s (at 25°C and 10 s^{-1}); and density: 1.3 g/cm^3.

Before application, ink jettability was studied and printhead operation was optimised (development of the waveform) for each ink. The printheads were calibrated, determining the real g/m^2 laydown at each nominal printhead laydown value. These tests were performed using a System Ceramics HEAD TESTER for laboratory tests, with DIMATIX LCHF printheads.

A matrix of twelve patches (N1 to N12) was designed that allowed the application's grey level (*% printed area* occupied by dots) to be varied from 5 to 100%. The levels of grey were applied in square patches of 2x2cm for the colorimetric measurements. Although the matrix used by SYSTEM is random, it being optimised for reproducing images, for this study a matrix with ordered dots (Bayer 8x8) and twelve levels of grey was used, as repetition of the dot positions facilitated detection of possible glazing defects and evaluation of the effect of the operating variables. The first six levels of the matrix (5, 10, 15, 20, 30, and 40% *printed area*) are shown in Figure 1.

Printing tests were conducted under different conditions with the selected matrix to study the system's response on modifying various parameters. The test pieces were fired in an electric kiln using a standard porcelain tile cycle at a peak temperature of 1200ºC.

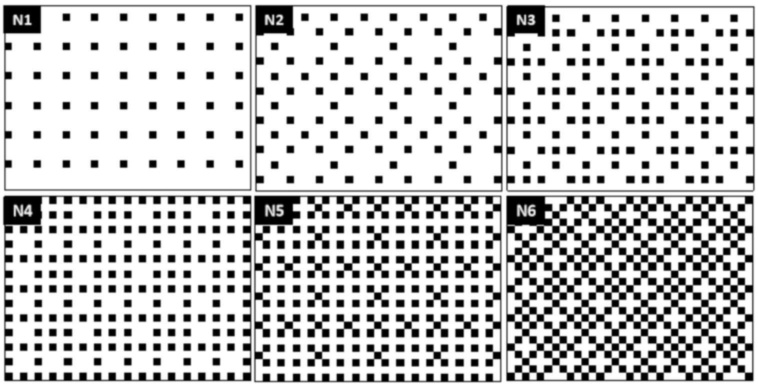

Figure 1. *Layout of the dots applied in the first six levels of grey of the Bayer 8x8 matrix.*

The patches were observed and photographed with a NIKON SMZ-U stereo microscope, keeping the magnifications and lighting conditions constant.

The chromatic coordinates (L*, a*, b*) were measured with a Macbeth Color-Eye 7000A diffuse reflectance spectrophotometer under the following conditions: CIE standard D65 illuminant, CIE standard 10º observer, ultraviolet component included, and specular component included.

The size and roundness of the dots, covered area, and average level of grey were measured in the images. Initially it had also been intended to measure the inter-dot spacing to characterise the uniformity of the application, but this measurement was discarded as dot layout was found to be very uniform.

4. RESULTS

4.1. JETTING CALIBRATION

The resulting calibration for each ink, using the optimum waveform developed for each, is plotted in Figure 2. It shows that, for NDS 10, the variation was very linear and, in addition, the values of the real g/m^2 laydown were very close to the nominal ones. For inks NDS 30 and NDS 50, the resulting variation was also linear across the full test range, but the g/m^2 laydowns were slightly lower than the nominal laydowns in the case of 30 NDS and almost the half the nominal laydowns for ink NDS 50. Finally, NDS 28 laydown was the least linear, which made it difficult to control, but led to higher laydowns (about 200 g/m^2).

The dots obtained on jetting the four inks, at different g/m^2 laydowns, with the 5% area matrix are depicted in Figure 3. The graph on the left shows how dot size (measured by image analysis) increased on raising the g/m^2 laydown. Dot size can vary from 75 to almost 200µm and depends mainly on the laydown, regardless of the glaze used. The images reveal that the dots were, in every case, quite round and well distributed. At high laydowns, the dots overlapped, thus losing their identity.

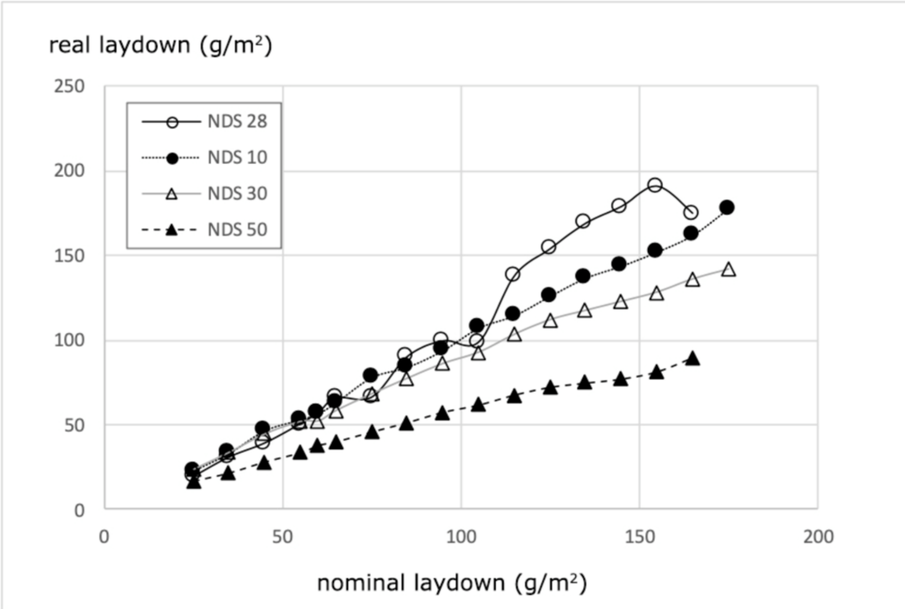

Figure 2. *Calibration of the real g/m² laydown, using the waveform developed for each ink.*

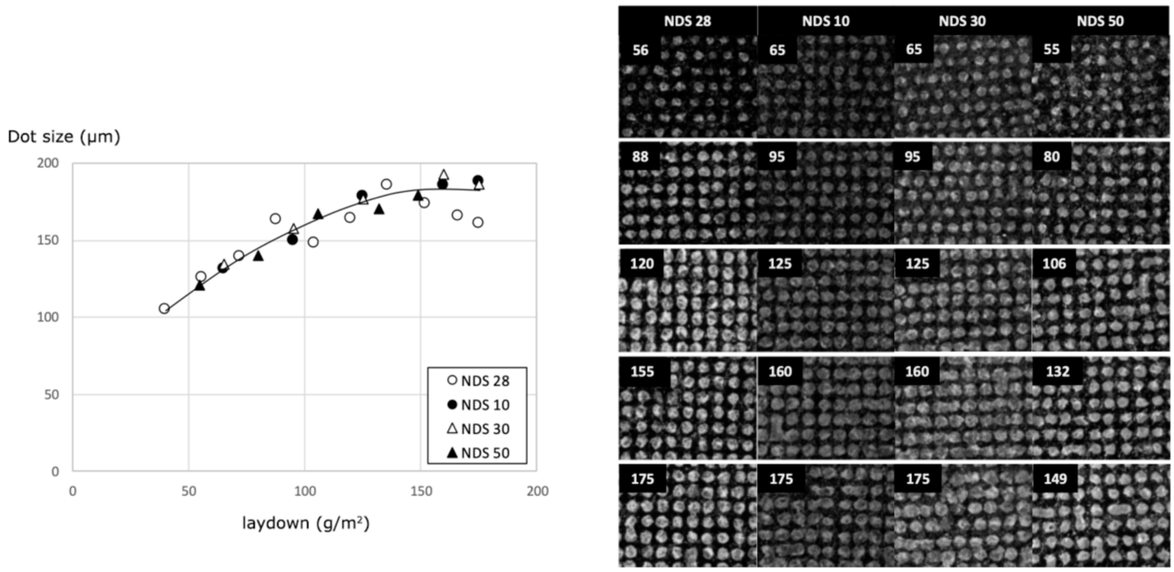

Figure 3. *Size and distribution of the dots obtained with the four inks applied with the 5% matrix at different g/m² laydowns, indicated on the label of each image.*

4.2. INFLUENCE OF THE GLAZE, PRINTING PATTERN, AND g/m^2 LAYDOWN

These tests were performed by depositing the inks on the dry SMOOTH body at room temperature.

The appearance of inks NDS 28, NDS 10, NDS 30, and NDS 50, applied with the different grey levels of the Bayer 8x8 matrix is compared in Figure 4. Jetting laydown was adjusted such that in every case 60g/m^2 was deposited. As was to be expected, in the case of inks NDS 10, NDS 30, and NDS 50, the tone became increasingly lighter as the dot-covered surface area increased. It may also be observed that NDS 30 and NDS 50 whiteness was very similar and considerably greater than NDS 10 whiteness. However, in the case of ink NDS 28, the tone lightened up to the 20% patch, then decreased sharply up to the 30% patch, after which it slowly rose again as the *printed area %* increased.

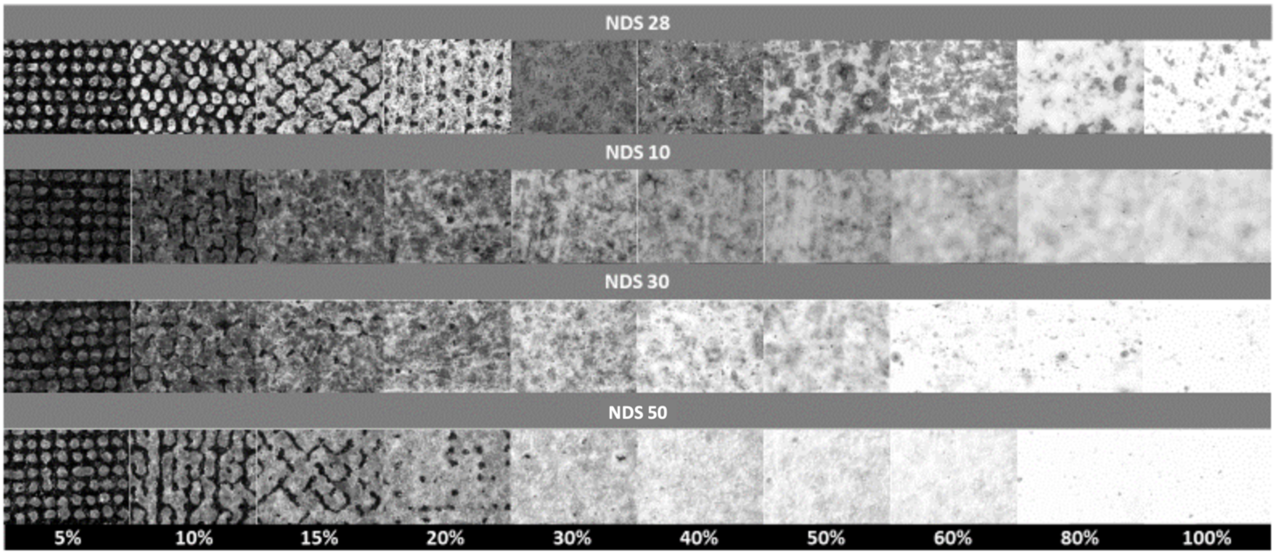

Figure 4. *Appearance of the NDS 28, NDS 10, NDS 30, and NDS 50 ink applications, with the different Bayer 8x8 matrix grey levels and 60g/m^2 laydown (considering only the solids).*

The effect of the g/m^2 laydown was studied by printing the four inks at laydowns of 25 to 175 g/m^2, with the twelve Bayer matrix grey levels. Figure 5 shows photographs of some NDS 30 ink patches and the evolution of the lightness (L*) value. On raising *laydown* and *printed area,* lightness (L*) increased steadily (without maximums or minimums). The results of the NDS 10 and NDS 50 inks were again very similar to those of NDS 30 (though NDS 10 lightness (L*) was always lower), which is why they were not included in this study.

Figure 6 corresponds to ink NDS 28. Unlike what occurred with NDS 30, all curves exhibited a local maximum and minimum L* on varying the *printed area*.

As the laydown increased, these maximums and minimums shifted to patches with a smaller *printed area*. At 25 g/m^2, the highest L* appeared at 80% and the local minimum at 100%. At 60 g/m^2, the maximum shifted to 30% and the minimum to 40%. At 95 g/m^2, the local maximum corresponded to the 15% patch and the minimum appeared at 30%, but the highest L* value was obtained with the 100% application. At

115 g/m^2, there was also a local maximum at 15%; the minimum now shifted to 20% and the absolute maximum again occurred with the 100% application.

The photographs in Figure 6 show that these minimums represented the moment at which the surface of the piece was *flooded* with glaze and possibly stemmed from migration of colloidal-sized ink components.

The L* measurements enabled an iso-lux diagram to be constructed, yielding the pairs of values *g/m^2 laydown – % application*, which enabled a certain whiteness to be obtained. By way of example, Figure 7 shows the diagrams obtained for inks NDS 30 and NDS 50. These diagrams could be used to regulate the application tone.

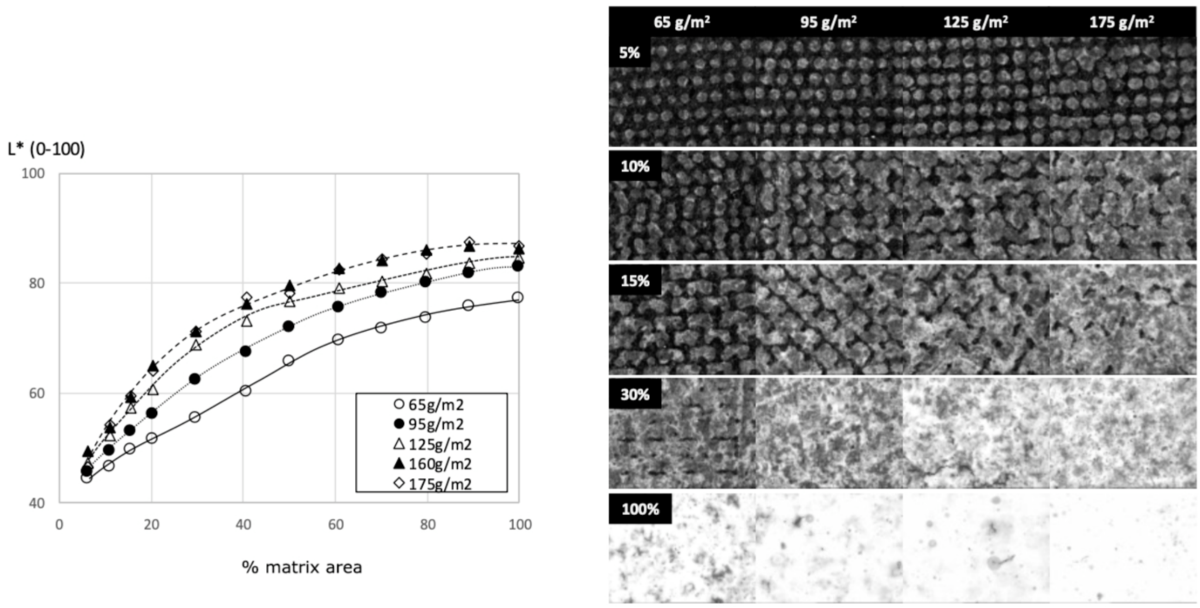

Figure 5. *Ink NDS 30. Appearance of applied patches and L* value on modifying application laydown.*

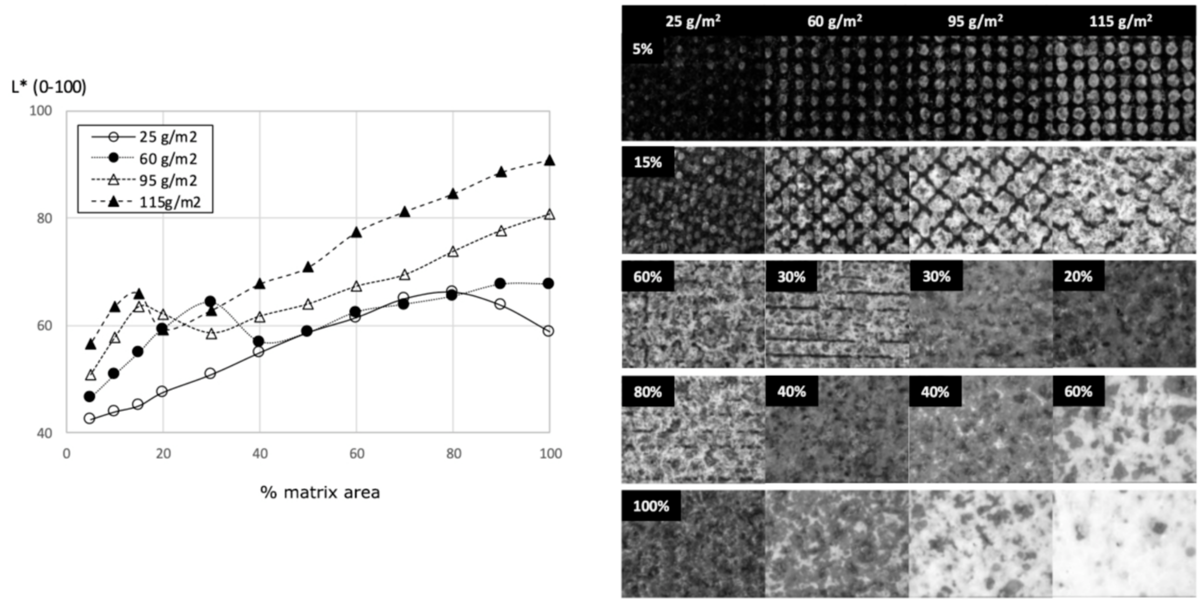

Figure 6. *Ink NDS 28. Appearance of applied patches and L* value on modifying application laydown.*

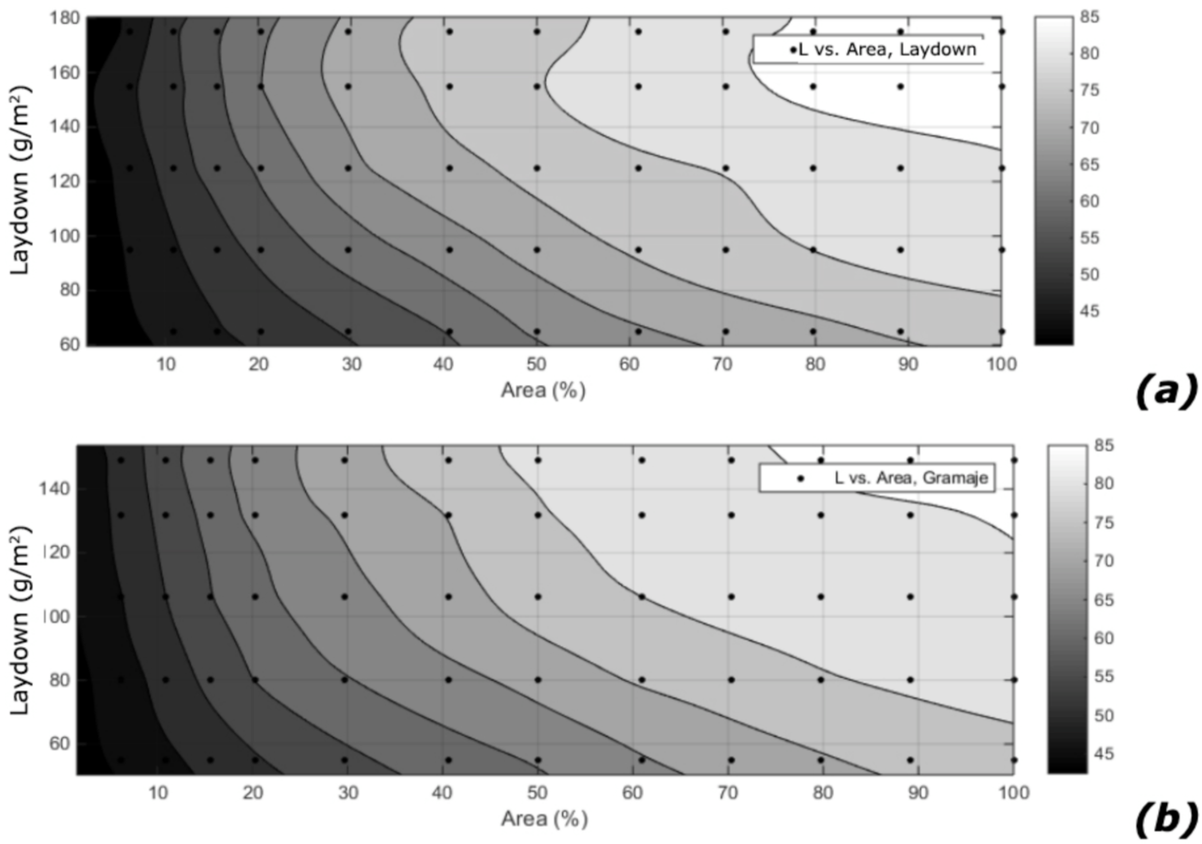

Figure 7. *Lightness map as a function of applied laydown (W) and % grey level (A) of the patch, for inks NDS 30 and NDS 50.*

4.3. INFLUENCE OF SUBSTRATE MOISTURE CONTENT AND TEMPERATURE

The effect of moisture content and temperature was studied on applying ink NDS 28, with different laydowns (45, 75, 115, and 175 g/m^2), on an unfired SMOOTH body. Moisture content was studied by printing on a body with 0, 3, 5, and 8% moisture content at room temperature. The temperature tests were performed on a completely dry body, heated at 40, 50, 65, and 95°C. With glaze NDS 28, all lightness (L*) curves exhibited the local minimum described in the previous section, which corresponded to the moment at which the surface was *flooded* with liquid.

Figure 8 shows the effect of moisture content corresponding to the application at 75 g/m^2. Comparison of the appearance of the 5% printed area patch, in which the printed dots did not yet overlap, reveals significant dot spread on raising body moisture content: dot size increased and dot lightness decreased (the dot became increasingly less white). It may also be observed that the local minimum of the L* curves shifted to patches with a smaller *printed area* as body moisture content rose, indicating that surface *flooding* had occurred previously. From this moment on, the L* curves overlapped, and body moisture content had absolutely no effect.

Figure 9 shows the effect of temperature at 75g/m^2 laydown. The size of the individual dots (5% patch), as well as dot lightness, did not seem to vary too much with temperature. However, if the patches prior to *flooding* (ranging from 20 to 40% *printed area*, depending on the application laydown) are observed, the test piece obtained at 50°C always seemed to have more defined edges and better resolution (less scattered design) than the other pieces, whereas the test piece at the highest temperature tended to have the worst resolution. Again, for high printed areas, all L* curves were superimposed, and body temperature did not influence the appearance of the glaze layer.

In general, the influence of body temperature was much lower than that of moisture content.

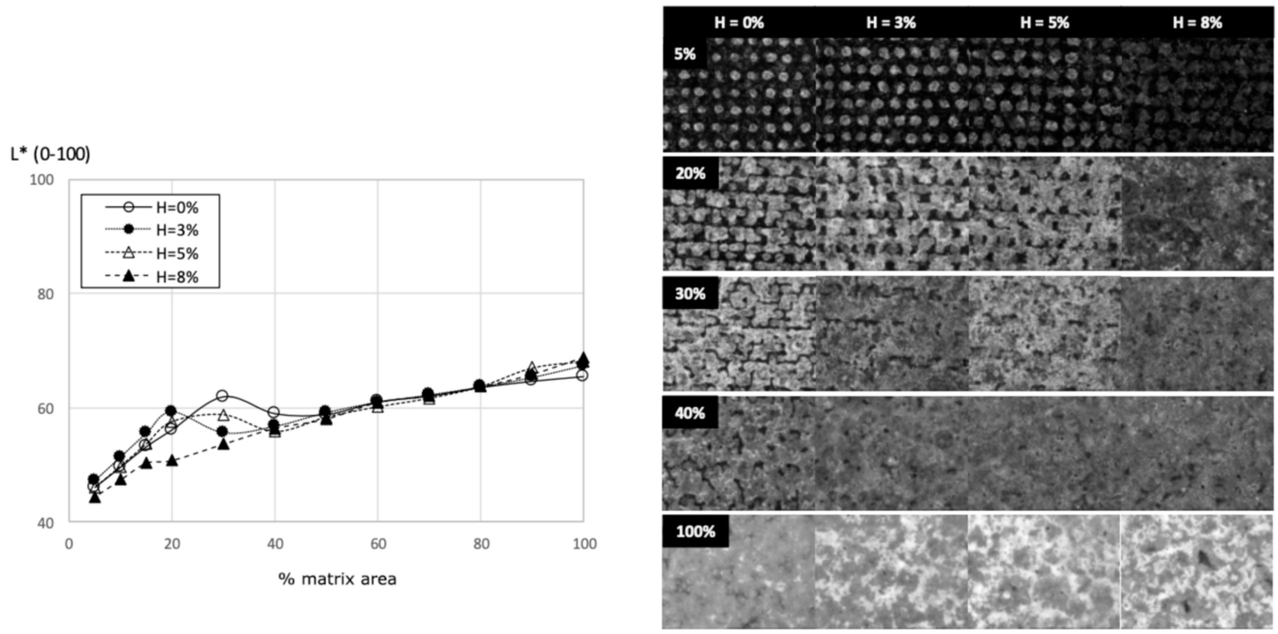

Figure 8. *Effect of body moisture content on ink NDS 28 application. Laydown: 75 g/m^2.*

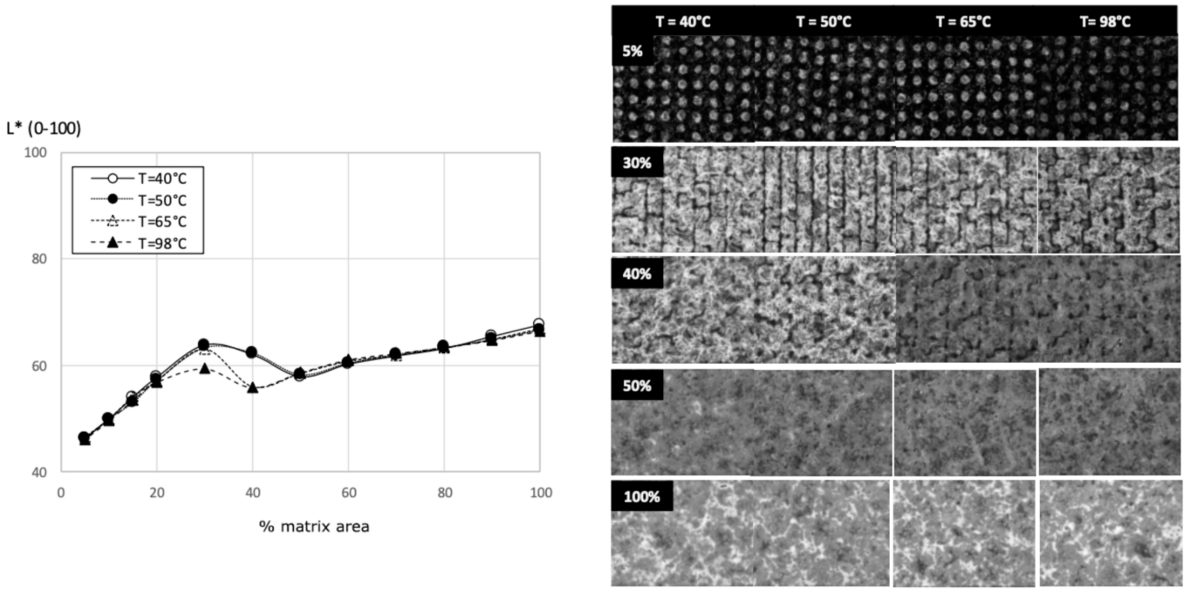

Figure 9. *Effect of body temperature on ink NDS 28. Laydown: 75 g/m²*.

4.4. EFFECT OF BODY ROUGHNESS

The influence of roughness was studied with ink NDS 28 and the two types body (SMOOTH and ROUGH) at several laydowns. After *flooding*, body type did not influence patch L*. However, before *flooding*, roughness slightly influenced lightness, higher L*values always being obtained with the SMOOTH body. On the other hand, smoothness or roughness greatly affected dot size (Figure 10, 5% patch at various laydowns). On the ROUGH body, the dots spread, overlapping each other, and were much larger and considerably darker in tone than those printed on the SMOOTH body, this being confirmed on plotting the values of L* and dot size. This last parameter was only measured in the non-overlapping dots.

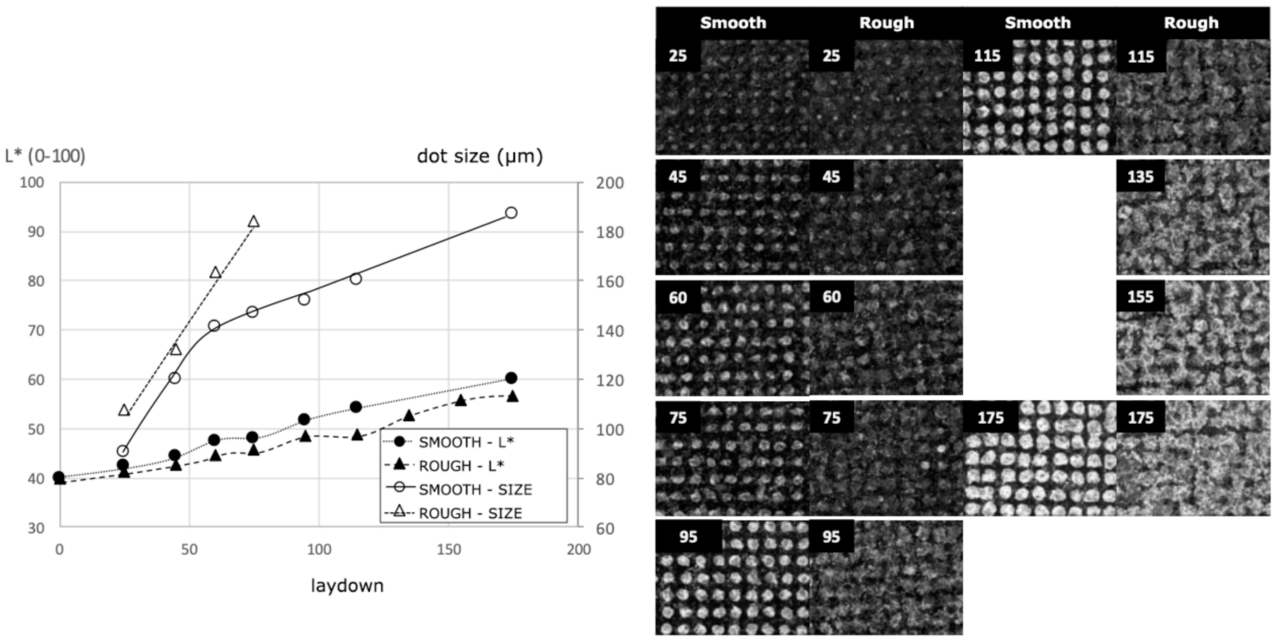

Figure 10. *Comparison of lightness (L*) and dot size of the 5% patch applied on the SMOOTH body and the ROUGH body at different laydowns.*

4.5. EFFECT OF THE NUMBER OF APPLICATIONS

The effect of the number of applications was studied with ink NDS 28 on a smooth body using the ordered dot matrix developed for this study (P) and the SYSTEM proprietary random matrix (A), at various laydowns. Figure 11 shows the results of the 95g/m^2 laydown. In the photographs, the test pieces display the design *area* corresponding to their patch: the rows compare the zones with the same amount of glaze.

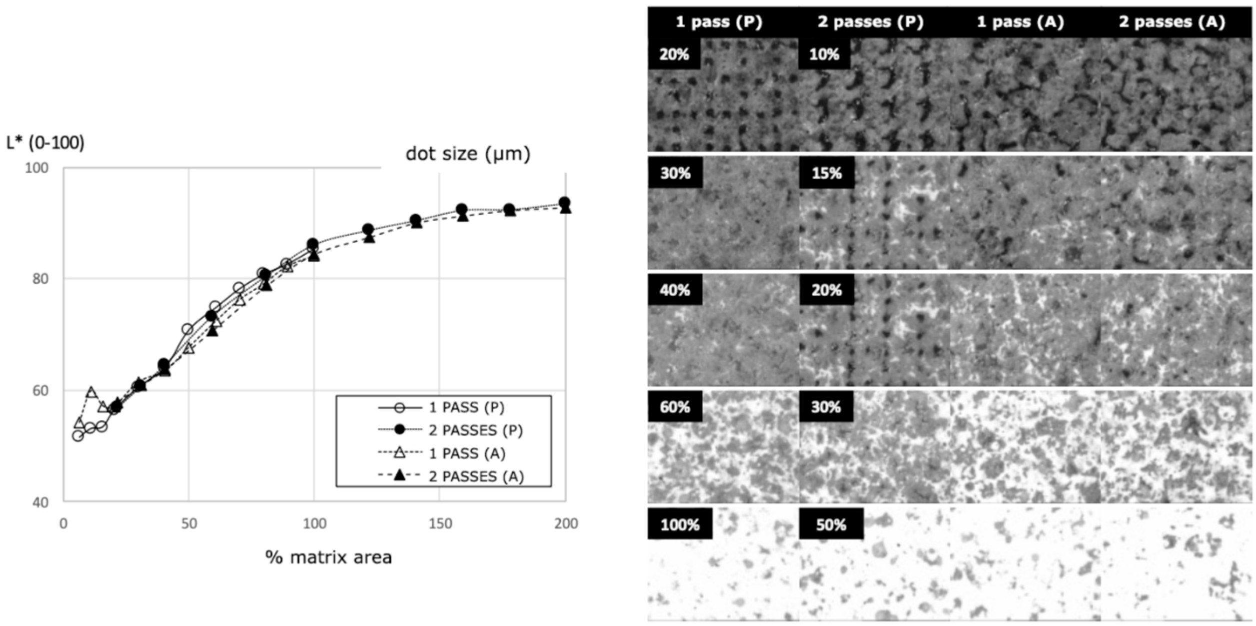

Figure 11. *Effect of the number of application passes (1 or 2). Ink NDS 28 and SMOOTH body. Laydown: 115 g/m^2.*

It may be observed that, when the same amount of glaze was applied, the lightness values coincided, regardless of whether the printing was performed in one or two passes, or whether the ordered dot matrix or the random dot matrix was used.

5. CONCLUSIONS

Appropriate analysis procedures for characterising digital glaze performance were developed. The amount of glaze deposited, dot gain, and the covering ability of various glazes were measured, evidencing the differences between them.

It was verified that the roughness and moisture content of the surface to be printed significantly affected glaze application performance. In contrast, the temperature of the surface to be printed had no noticeable effect in this regard.

Both the applied area and g/m^2 laydown determined the printing result when it was sought to obtain a continuous layer. Joint analysis of the two parameters enabled iso-lux curves to be obtained, which could be used as a control tool in obtaining tiles of the same shade.

6. REFERENCES

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