INFLUENCE OF PRINTING CONDITIONS ON IMAGE QUALITY

Sanz, V. [1]; Bautista, Y. [1]; Belda, A. [1]; Coll, N. [1]; Pato, B [1]; Gonzalez, J. [2]

[1] Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE). Universitat Jaume I. Castellón. Spain

[2] Coloronda S.L., Onda, Spain

ABSTRACT

Digitisation and the absence of contact between the applicator and the surface to be decorated have made inkjet printing a particularly suitable decorating technique for ceramic tiles.

In order to assure high quality of the printed images, all the parameters that affect the printing process, such as drop formation and drop impact on the ceramic substrate, as well as its integration into the firing process, need to be controlled.

The drop formation process in ceramic inks has to date been the most extensively studied phase, the dependence on drop formation being evaluated with parameters such as viscosity, density, and surface tension.

This study focuses on the phase in which the drop impacts on the surface of the ceramic substrate. In this process, owing to the interaction between the substrate and the drop, dot size is conditioned by ink properties as well as by the properties of the porous surface on which it is applied.

This study evaluates the influence of ink properties (chemical nature of the vehicle) and of the properties of the application surface (nature of the glaze, temperature, and moisture content) on dot formation.

1. INTRODUCTION

Ceramic tile decoration by inkjet printing is based on ink drops being ejected onto the ceramic surface, where they become the dots that make up the image. In order to obtain quality images and have a robust manufacturing process, control of drop impact on the application surface is of vital importance (Holman et al., 2002; Maattanen et al., 2010).

In other industrial sectors, dot consolidation on the substrate takes place by a chemical reaction or by evaporation of the vehicles. In the case of ceramic inks, these mechanisms do not occur, therefore making it necessary to understand in greater depth the wetting, spreading, absorption, and penetration processes of liquids through porous substrates.

Drop impact on a non-porous surface can be described by a series of mechanisms or processes that depend not only on the physical properties of the solid and the liquid, but also by the interaction that both undergo (Denesuk et al., 1993).

Thus, according to Hutchings (2007) and Hsiao (2011), four phases can be identified in the conversion of a liquid drop into a solid dot after impact:

- Kinetic phase, described by the impact drop velocity and initial drop diameter. The liquid deforms on impacting on the solid surface.
- Drop spreading phase. This depends closely on the viscosity of the liquid, so that lower viscosity values lead to greater spreading diameters.
- Relaxation phase, described by the surface tension of the liquid and the wetting angle between the liquid and the substrate.
- Wetting phase, in which equilibrium conditions are reached, a deposit or solid dot being obtained on the substrate.

Unlike non-porous substrates, on which only wetting and spreading phenomena take place (Magdassi, 2010; Kettle et al., 2010), on porous substrates these processes develop together with absorption and capillary penetration phenomena. The drop spreading and infiltration rate is controlled by the capillarity forces corresponding to the ceramic substrate. In this sense, the capillary forces tend to suppress the spreading processes, concurrently favouring the infiltration of the liquid through the solid (Holman et al., 2002).

The above highlights the importance of the surface roughness and porosity of work substrates as ways of modifying surfaces, which lead to a considerable decrease in wetting and consequently favour absorption and capillary penetration in detriment to the spreading processes that take place on the surface (Alam et al., 2007). Using this working premise, the quality and added value of the decorations made by inkjet printing systems can be enhanced.

Numerous studies are currently available on impact, wetting, spreading, and absorption processes, in addition to the dynamic analysis of drops, in which it is attempted to analyse the influence of liquid and substrate properties on image quality (Hutchings, 2009; Derby, 2010). However, the great majority of these investigations do not refer to porous substrates (Magdassi, 2010) and, when they do, they are only applicable to paper substrates (Zhmud, 2003; Maattanen et al., 2010; Hsiao 2011).

In accordance with the studies conducted by various authors, the moisture content and temperature of the solid surface thus significantly influence the drop–dot conversion processes. This fact, together with the organic nature of the inks used in the ceramic sector by the inkjet systems (Magdassi, 2010), makes it necessary carry out a compatibility study of the inks used by these systems and the surface moisture of the work substrates.

2. OBJETIVES

The study addressed the following objectives:

- To develop an experimental procedure that would allow ink drop behaviour on ceramic work substrates to be evaluated.
- To evaluate the influence of the nature of the inks and the ceramic substrate used on the dot formation process.
- To evaluate the influence of certain manufacturing process variables, such as glaze temperature and moisture content at the moment of printing, on ink dot formation.

3. EXPERIMENTAL

To perform the study, three inks formulated with vehicles of very different chemical nature were selected. The first ink was formulated with a very high water content, so that it could be considered to have high polarity and a high affinity for the substrate, whether this was in a dry or a wet state. The second ink was formulated with an oil and was thus of very low polarity and without affinity for the wet substrate. The third ink was formulated with a glycol of relatively high molecular weight, so that its polarity was intermediate and its affinity for water low.

The properties of the inks used were in the appropriate ranges for use in industrial printheads.

The substrates used were porous single-fired tiles, alternately glazed with three industrial glaze compositions of different nature (B1, B2, and B3). The differences in their physical properties were small, as was subsequently observed in glaze behaviour. The substrates were conditioned at each temperature by placing them in a laboratory oven for the necessary time. The final conditioning of the substrates at each moisture content was performed by spraying on the necessary water, followed by a rest time. The combined effect of the two variables could not be studied because of the transient nature of the drying process.

For drop generation and subsequent dot formation, two very different techniques were chosen. On the one hand, large-sized drops (30 µL) were generated using an automatic laboratory micropipette. These drops are much larger than those produced by an inkjet printhead, which might partly distort the resulting behaviour; however, the great advantage of this technique is its availability, price, and suitability for any type of ink. On the other hand, drops were also generated using a piezoelectric printhead in a Dimatix laboratory printer. The printhead drop size used was 10 pL.

A high number of drops and their corresponding dots were generated in every case, with a view to statistically averaging the results.

A spreading ratio (SR) was defined for the two test drop sizes from the following formula:

$$SR = \text{Dot diameter}/\text{Drop diameter}$$

Owing to the definition of the SR, the SR values were always larger than unity and could reach relatively high values when a drop spread significantly. It was further verified that the SR values were sensitive to drop size and impact velocity, probably because of the influence of surface tension and impact dynamics, so that the spreading ratios calculated with drops generated by different devices should not be compared.

The SR is directly related to the concept of dot gain used in the graphic arts to refer to differences in drop spread on different substrates, given certain fixed printing conditions. Correcting dot gain, when different substrates are used, is a basic adjustment in printing process adjustment.

4. RESULTS AND DISCUSSION

4.1. INFLUENCE OF SUBSTRATE TEMPERATURE

The influence of substrate temperature on the spreading ratio obtained with large drops (30 µL) of the three types of test inks are shown in Figures 1, 2, and 3. In every case the glazes were dry.

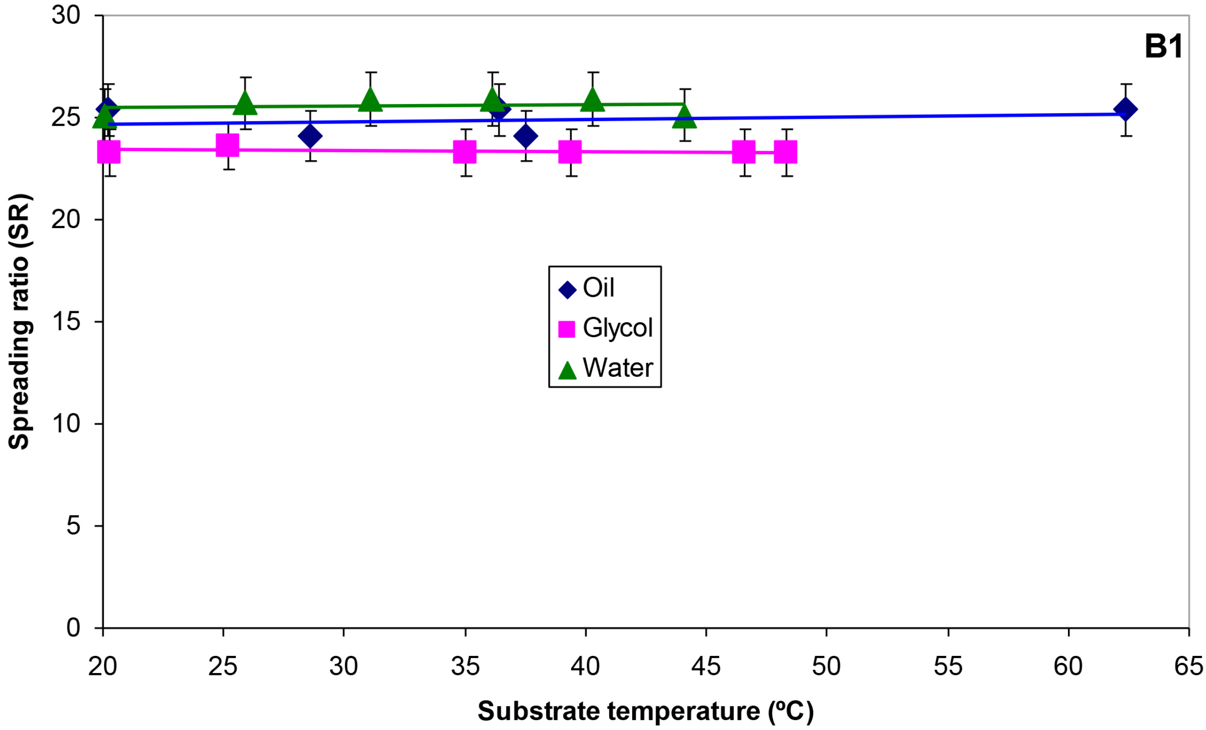

Figure 1. Influence of temperature on the spreading ratio of the different test inks. Macro scale (30 μL). Substrate B1.

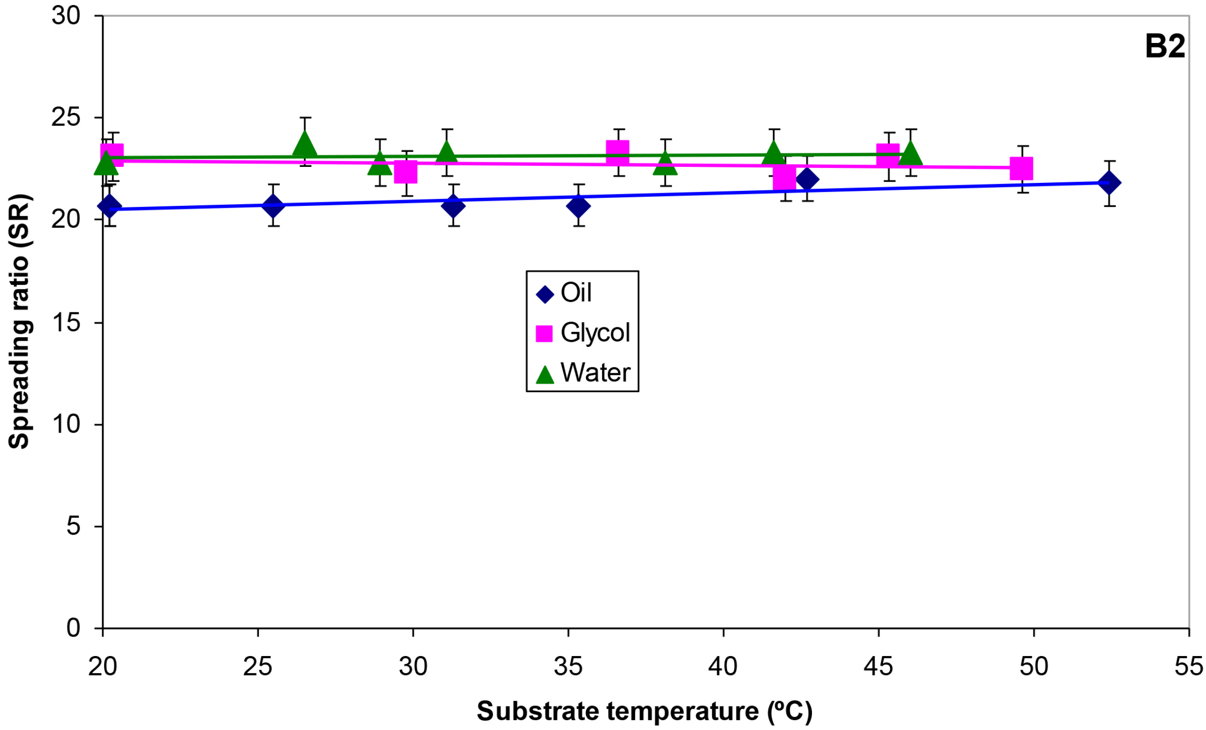

Figure 2. Influence of temperature on the spreading ratio of the different test inks. Macro scale (30 μL). Substrate B2.

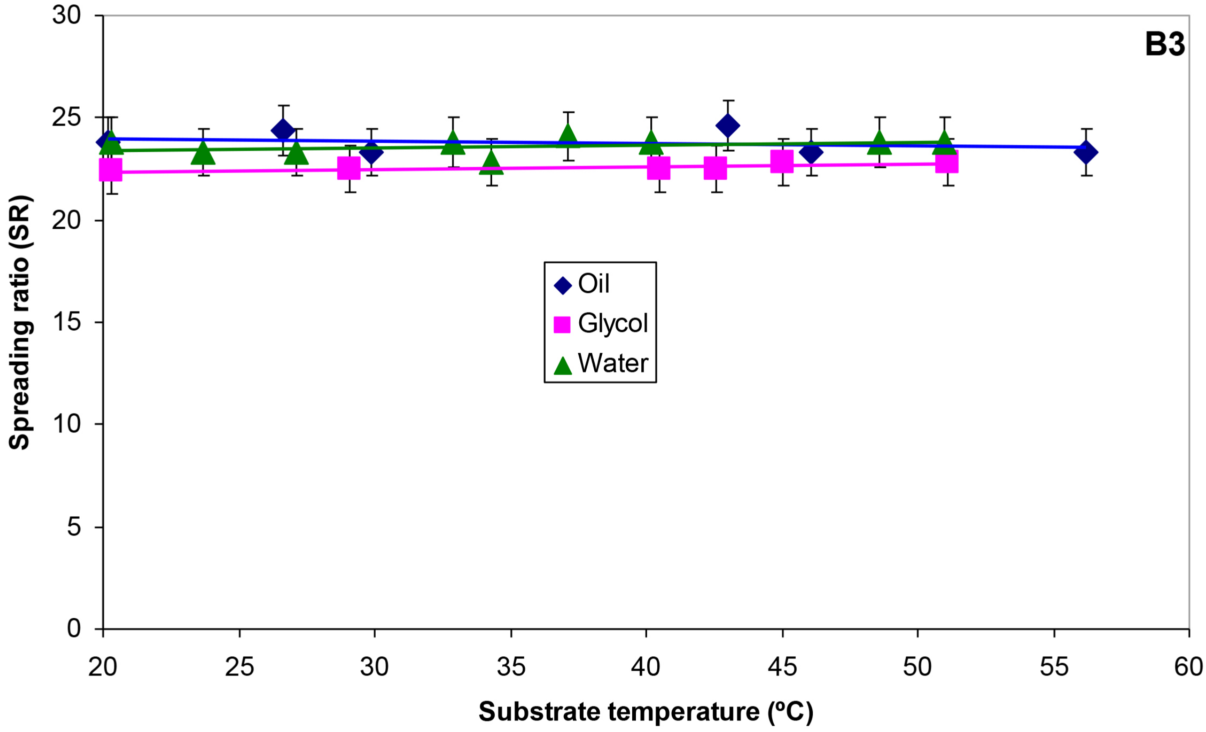

Figure 3. Influence of temperature on the spreading ratio of the different test inks. Macro scale (30 µL). Substrate B3.

As may be observed, under the test conditions used the trend lines were practically horizontal, indicating the independence of the spreading ratio with relation to substrate temperature.

Under these conditions, the unfired glaze may be considered a porous solid, in which the transformation of the drop into a printing dot essentially depends on suction. When the drop enters into contact with the glaze, it spreads owing to its weight, surface tension, and contact angle with the substrate; however, the high suction rate of the substrate causes the ink to flow into it and limits the degree of attainable spread.

The influence of the properties of the porous substrate (porosity, pore size) and of the liquid (viscosity, surface tension, contact angle) on the kinetics of the liquid suction process has been widely studied in the literature. However, the differences observed with the three test inks on each of the glazes were small and often lay within the experimental error.

4.2. INFLUENCE OF MOISTURE

4.2.1. Large drops (30 µL)

The variation of the spreading ratio with glaze moisture content at room temperature is shown in Figures 4, 5, and 6. Significant differences may be observed between the behaviour of the different inks and glazes.

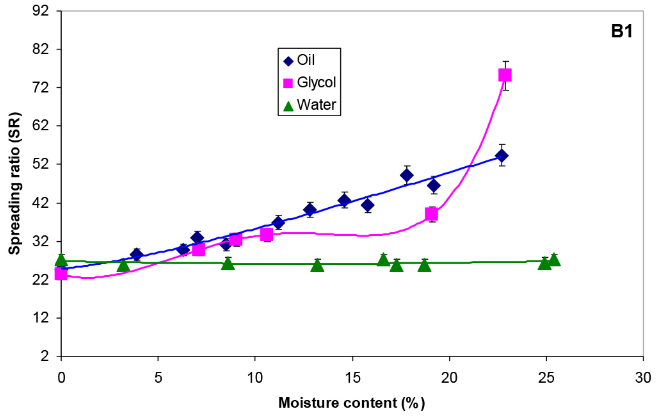

Figure 4. Influence of moisture on the spreading ratio of the different test inks. Macro scale (30 µL). Substrate B1.

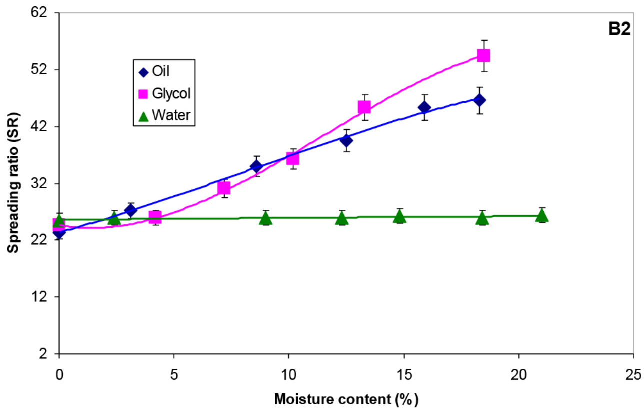

Figure 5. Influence of moisture on the spreading ratio of the different test inks. Macro scale (30 µL). Substrate B2.

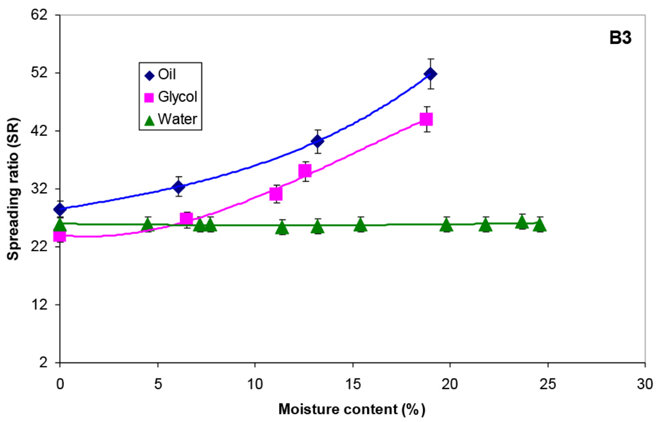

Figure 6. Influence of moisture on the spreading ratio of the different test inks. Macro scale (30 µL). Substrate B3.

The spreading ratio of the water-based inks remained constant when the substrate moisture content increased. This behaviour was due to the compatibility of the water with the ink vehicle.

However, the spreading ratio of the glycol-based and oil-based inks displayed a significant dependence on the substrate moisture content: the greater the substrate moisture content, the larger was the spreading ratio. This trend was very small at low moisture values. The behaviour repeated itself in the three test substrates.

Figure 7 shows the photographs taken after the experiment was performed with the B2 substrate, using the three types of test inks, in each case at two moisture contents of the application surface. It may be observed that the drop spread of the glycol-based and oil-based inks increased with substrate moisture content, whereas the water-based ink was practically unaffected by this substrate variable.

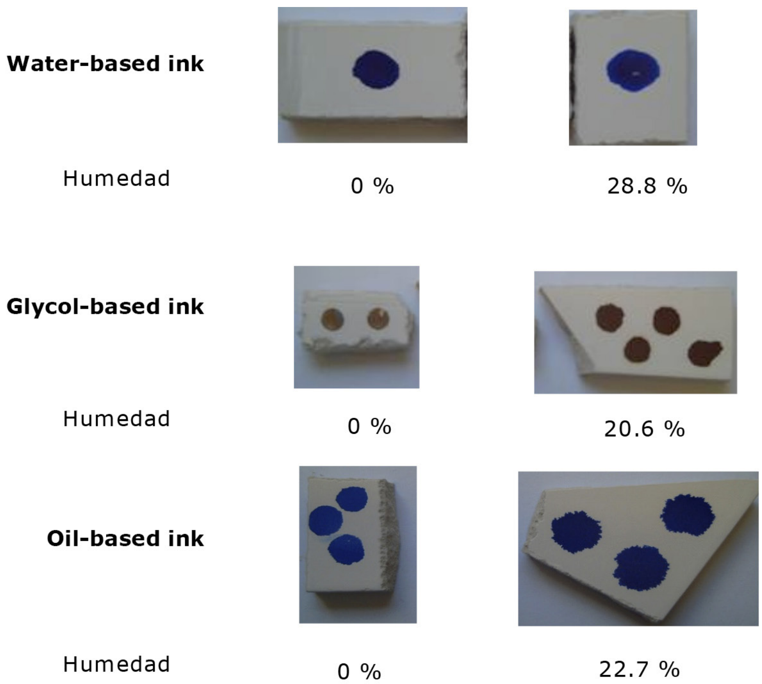

Figure 7. Influence of substrate moisture content on the spread of the test inks on substrate B2 (drop of 30 μL).

4.2.2. Small drop (10 pL)

The variation of the spreading ratio of the inks with glaze moisture content at room temperature, for drops obtained with a piezoelectric printhead, are shown in Figures 8, 9, and 10. Although the values of the spreading ratio were very different from those of the large drop, the behaviour was verified to be analogous.

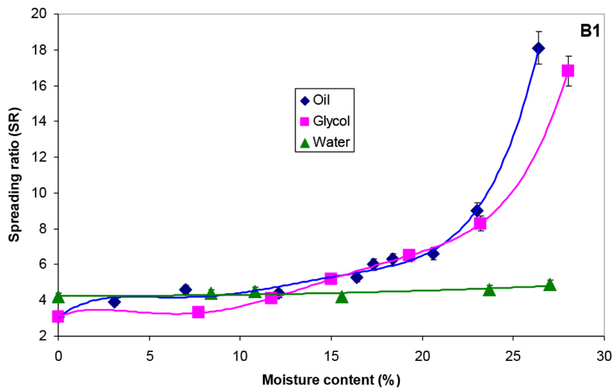

Figure 8. Influence of moisture on the spreading ratio of the different test inks. Micro scale (10 pL). Substrate B1.

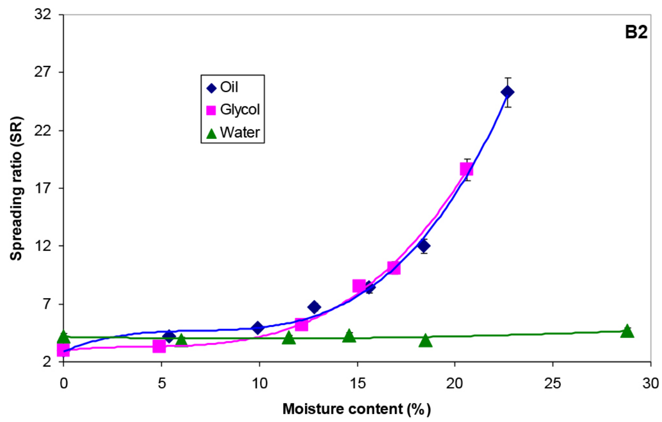

Figure 9. Influence of moisture on the spreading ratio of the different test inks. Micro scale (10 pL). Substrate B2.

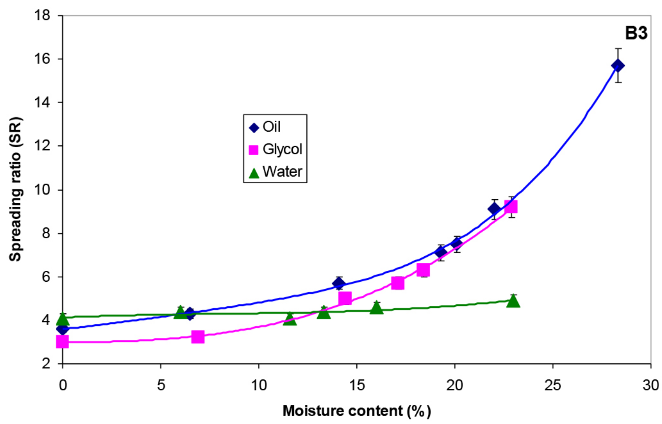

Figure 10. Influence of moisture on the spreading ratio of the different test inks. Micro scale (10 pL). Substrate B3.

The spreading ratio of the water-based ink remained independent of application surface moisture content.

On the other hand, for the glycol-based and oil-based inks, two ranges with different behaviour could be distinguished. When the moisture content of the application surface was below 10%, the influence of this variable on the spreading ratio was very small. However, when the moisture content of the application surface was above 15%, the spreading ratio varied markedly with moisture. In substrate B3, this change was progressive, and it could be represented by means of an exponential-type equation.

By way of example, the dots obtained with the piezoelectric printhead on substrate B2, using the three types of inks, are shown in Figure 11. It can be clearly observed that the spread of the glycol-based and oil-based inks increased with substrate moisture content, whereas the water-based ink spread was practically unaffected by this substrate variable. Qualitatively similar results were found with the two other substrates (B1 and B3).

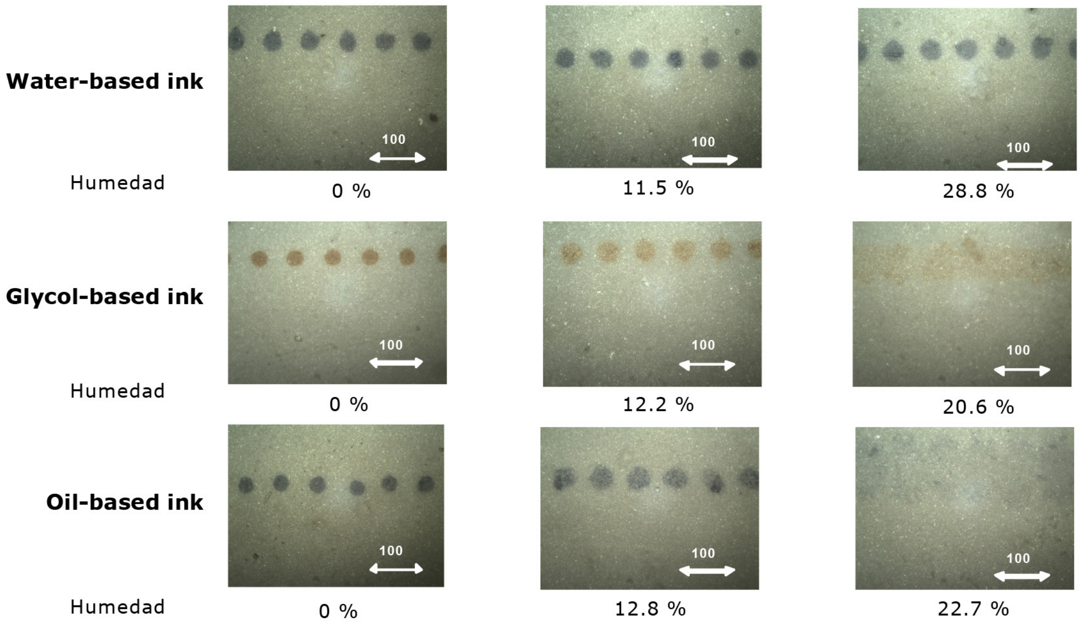

Figure 11. Photographs showing the effect of moisture content on the drop spread of the different test inks on substrate B2.

These results suggest that when the moisture content of the application surface was low, this behaved like a porous solid, and dot spread depended mainly on suction. When this moisture content was high, the surface behaved as if it were not porous: suction no longer played a major role in drop spread, and the effect of the compatibility between the ink vehicle and the water in the substrate predominated. Consequently, when vehicles that are incompatible with water are used on very wet substrates, the drop expands on the surface, subsequently penetrating into the substrate when the moisture decreases.

As a result, this behaviour leads printing on wet surfaces to produce diffusion of the dot, possibly even causing it to disappear. This effect becomes even more pronounced during firing, when greater dissolution of the pigments occurs. For the same reason, variations in moisture content in printing substrates will produce variations in dot spread and, hence, colour variations in the images.

5. CONCLUSIONS

Two techniques have been developed for studying and controlling printing dot spread, and a ratio has been defined that quantifies this.

It was verified that printing conditions can considerably affect the spreading ratio of the dot and, hence, the quality of the images.

Different inks and substrates were shown to display different sensitivities with relation to printing conditions.

Although the spreading ratio was shown to be a powerful tool in selecting the materials and optimising the process, it should not be used just by itself. The optimisation of an industrial ink also needs to include other critical factors.

REFERENCES

[1] Alam, P.; Toivakka, M.; Backfolk, K.; Sirvio, P. Chemical Engineering Science 62, 3142-3158. (2007)

[2] Denesuk, M.; Zelinski, B.J.J.; Kreidl, N.J.; Uhlmann, D.R. Journal of Colloid and interface science 168, 142-151. (1994).

[3] Derby, B. Inkjet printing ceramics: From drops to solid.

[4] Derby, B.; Annual Review of Materials Research 40, 395-414. (2010)

[5] Holman, R.K.; Cima, M.J.; Uhland, S.A.; Sachs, E.; Journal of Colloid and Interface Science 249, 432-440. (2002)

[6] Hsiao, W.-K.; Hoalth, S.D.; Martin, G.D.; Hutchings, I. M.; Chilton, N.B.; Jones, S. Proc Nanotech 2011 Conference, Boston, (2011).

[7] Kettle, J.; Lamminmaki, T.; Gane, P. Surface and coatings Technology 204, 2103-2109. (2010).

[8] M. Hutchings, in V. Saile, K. Ehmann and S. Dimov (eds.) Proc. 4M/ICOMM Int. Conf. on Multi-material Micro Manufacture (4M/ICOMM 2009), Karlsruhe, Germany, (2009).

[9] Maattanen, A.; Ihalainen, P.; Bollstrom R.; Toivakka, M; Peltonen, J. Colloids and Surfaces A: Physicochem. Eng. Aspects 367, 76-84. (2010).

[10] Magdassi, S. ISBN: 978-981-281-821-8. World Scientific Publishing. (2010)

[11] Zhmud, B. Pira International conference: Ink on Paper, Crowne Plaza Hotel – Brussels, Belgium (2003).