The Effect of the Drop Size on the Print Quality in CIJ Printing

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Abstract

Only scant attention has been paid in the literature to the influence of the drop size on the dynamics of spreading and the final dot quality with different paper grades. In this study, the development of the image properties was observed on a time scale of a few milliseconds and upward, by using a special high-speed imaging environment (introduced at NIP13) and CIJ printers, with different nozzle sizes but similar water-based ink compositions.

The results clearly show that there is a strong paper-dependent affiliation between the size of the ink jet drop and the high-speed dynamic phenomenon of dot spreading and drying. With coated paper grades, the interrelation between the drop size and the magnitude of the surface structure was found to be important, compared with the final shape of the dot. With uncoated papers, the growth of the dot is dependent on the size of the drop. The final intensity of the print was found to be the outcome of the characteristics of the ink and the absorption properties of the paper.

Introduction

VTT Information Technology has completed its four-year project, "Dynamic Interactions and Image Quality in Ink Jet Printing", which focused on the high-speed ink jet printing methods of the future. The aim of the project was to analyse and model the interactions between ink and paper in the continuous ink jet technique (CIJ) and to develop testing methods for ink jet substrates.

Although drop-on-demand printing has become the most dominant technology in low-end printing, CIJ systems are the technology of the future, especially in high-speed digital colour printing applications. A better knowledge of the basic mechanisms of dynamic interaction is needed to produce a more reliable and appropriate specification of the quality demands for the paper grades. VTT Information Technology has carried out several studies[1,2,3] to clarify what paper properties are important in ink jet printing and what is their significance.

It is obvious that the size of the drop has a strong bearing on the final print quality, because, for example, it determines the smallest size of the dot. At the present level of ink jet technology, drops as small as 3 pl are commercially utilised both in drop-on-demand and continuous ink jet printers. In some printers even the size of the drop is varied. Unfortunately, only scant attention has been paid in the literature to the influence of the drop size on the dynamics of spreading and the final dot quality with different paper grades.

In this study, two commercial CIJ printers, with different nozzle sizes but similar water-based ink compositions, were used. The development of the intensity and the size of a single drop dot were traced on a time scale of a few milliseconds up to eight seconds. The size, density and roundness of the final dots were also measured. Thirteen coated and uncoated paper grades were used in the tests. Two of them were special ink jet papers.

Experimental Work

In this study ink drops were generated by using two industrial multi-deflection CIJ devices. The inner diameter of the nozzle of Printer 1 was 35 µm and the viscosity of the water-based (water content > 50 %) ink was 2.5 cP. The inner diameter of the nozzle of Printer 2 was 70 µm and the viscosity of the water-based ink was 3.3 cP. The exit velocity of the drops was 18 m/s and the printing distance was 30 mm. The test substrates consisted of five coated and six uncoated paper grades. The coated paper grades were designed for conventional printing methods and they were selected so that their IGT oil absorption was less than 8. The uncoated paper grades were so-called multipurpose papers with an IGT oil absorption over 20. Moreover, two special ink jet papers were also used. One of them was a so-called swelling glossy paper, which is a PE (polyethylene) film coated with water soluble polymer. The other special paper was a silica-coated, highly absorbent ink jet paper.

The image properties of the printed samples were measured by using an image analysis system, designed especially for the analysis of print quality with non-impact printing techniques. The system consists of a microscope, a CCD camera and a PC with tailored analysis software. The size, roundness and density of a single drop dot on different paper grades were measured after a drying time of several hours.

The samples were also analysed in a laboratory-scale testing environment for the high-speed imaging of ink jet drops. The impact, spreading, absorption and drying of the ink droplets on the samples can be observed in this testing environment on a time scale of a few microseconds up to several minutes. This environment is based on a high-speed CCD camera (2250 frames/sec), a stroboscopic flashlight and a PC. A detailed description of the experimental arrangement has been reported earlier.[3] High-speed images were analysed and the average development of the dot size and intensity were considered on different time scales.

Results

The comparison between the size of the dots printed by the test printers is shown in Figure 1. As expected, smaller dots are generated by Printer 1, which has a smaller nozzle size. Excluding the special ink jet papers, a linear correlation (R=0.92) can be found between the printers with all the coated and uncoated paper grades. The correlation is very strong (R=0.97) when the coated papers are compared and weaker with uncoated papers (R=0.90). For coated grades the variances in the sizes are larger with Printer 1 and for uncoated grades they are larger with Printer 2. Quite interestingly, with Printer 1 comparatively small dots are generated on some of the uncoated samples. Very small dots can also be printed on the swelling paper. With pigment coated paper, small dots can be printed by Printer 1, but the dots produced by Printer 2 are quite large.

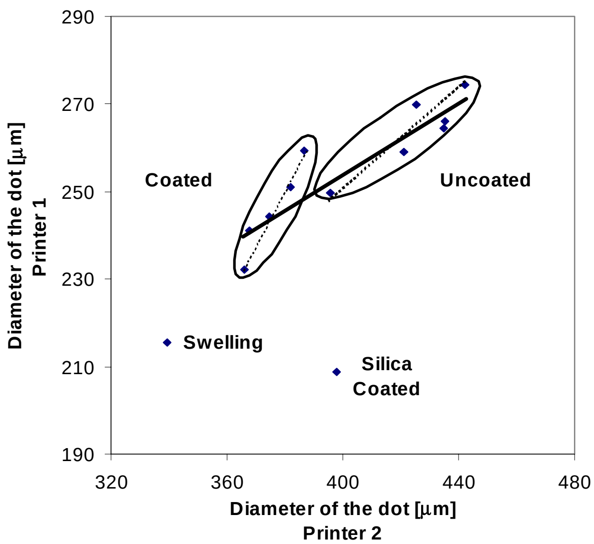

Figure 1. The size of the dots printed by the test printers.

The comparison between the roundness of the dots produced by the test printers is shown in Figure 2. The roundness values range from 0 to 1, with 1 reprecenting a perfect circle. With coated paper grades much rounder dots are generated. A strong linear correlation (R=0.93) can be found in the coated paper grades. With coated grades the variances in roundness are twice as large with Printer 1 than with Printer 2. With uncoated papers, no correlation can be found and the level of roundness is also very low. Rounder dots are printed by Printer 1 when pigment coated paper is used. With swelling paper the dots are much rounder with Printer 2.

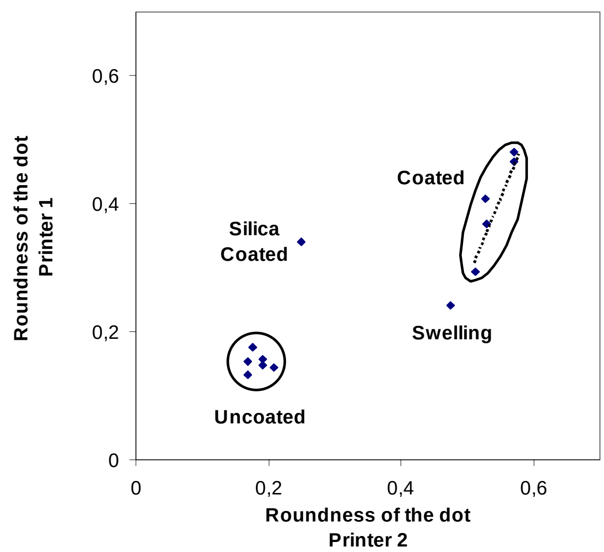

Figure 2. The roundness of the dots printed by the test printers.

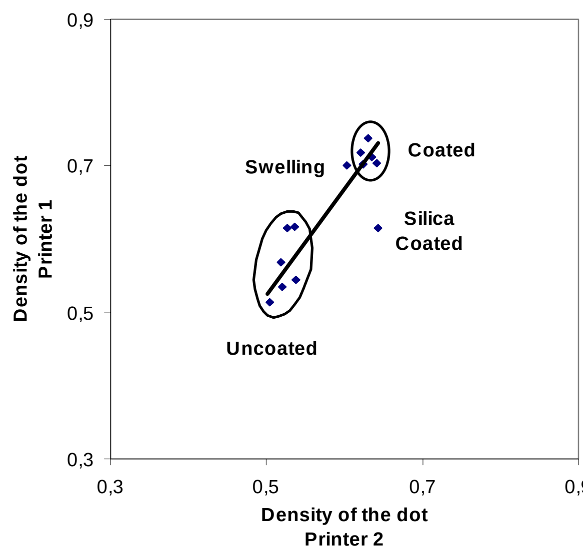

Figure 3. The density of the dots printed by the test printers.

The comparison between the density of the dots produced by the test printers is shown in Figure 3. Much darker dots can be generated with coated papers. The variance in the densities is also smaller. A linear correlation (R=0.94) can be found with all the conventional paper grades, but within the groups no correlation can be found. With pigment coated paper a very high density can be achieved by Printer 2.

The first 200 ms after the impact of the drop in the absorbent samples (uncoated grades and pigment coated paper) are shown in Figure 4. The pigment coated paper is easily the fastest with both printers: the dot reaches its final size within the first 50 ms, while in some of the multipurpose paper samples it takes almost 500 ms. Although there are considerable differences in setting times between the papers, the shape of the average spreading curves of the printers are quite similar. The final size of the dot is reached earlier with Printer 1.

The first 200 ms after the impact of the drop on the non-absorbent samples (coated grades and swelling ink jet paper) are shown in Figure 5. The growth of the dot is considerably smaller than in absorbent papers and the final size of the dot is reached within the first 100 ms. Growth is smaller and a little faster with swelling ink jet paper.

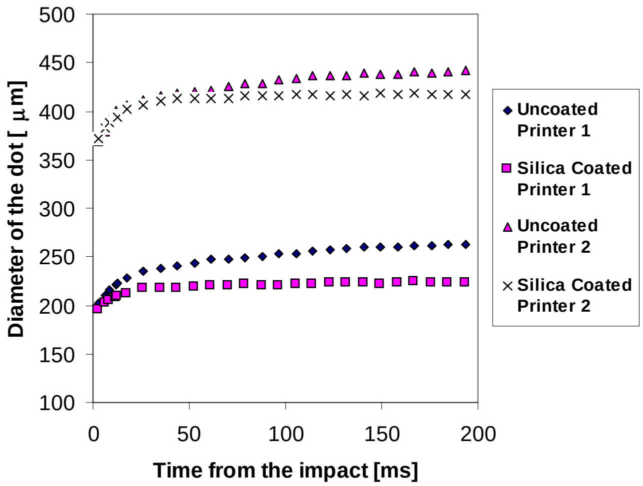

Figure 4. The diameter of the dot as a function of time with the absorbent samples.

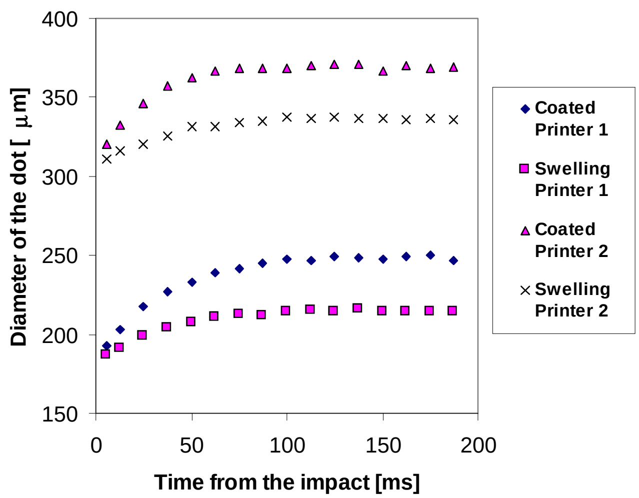

Figure 5. The diameter of the dot as a function of time with the non-absorbent samples.

Although the maximum size of the dot is reached within about 200 ms on uncoated papers, the intensity of the dot takes much longer to develop. The intensity value indicates the darkness of the print: the lower the value is, the darker the print will be. The development of the intensity is presented in Figure 6. While the final darkness of the print with Printer 1 is reached within 250 ms, it takes 500 ms for Printer 2 to reach a stable level. Although there are considerable differences in the darkness of the dot with uncoated samples, almost the same high darkness level is reached with pigment coated paper.

The development of intensity with non-absorbent paper samples is shown in Figure 7. While the final darkness of the dot is reached with Printer 1 within the first 5 seconds, it takes over a second longer with Printer 2 to reach the final intensity level. With both printers, the swelling sample reaches its final darkness earlier than the other coated samples.

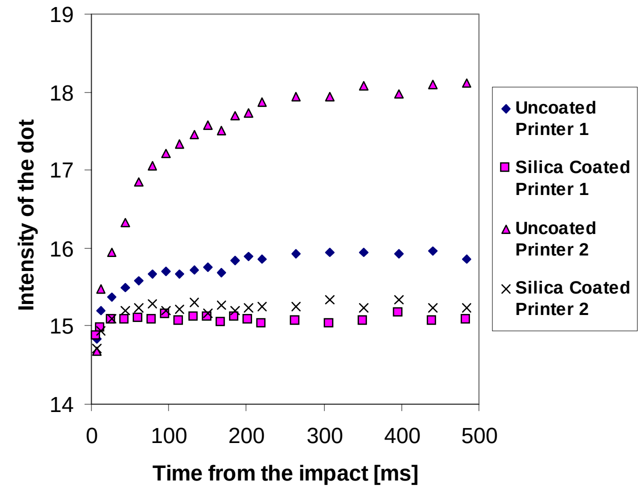

Figure 6. The intensity of the dot as a function of time with the absorbent samples.

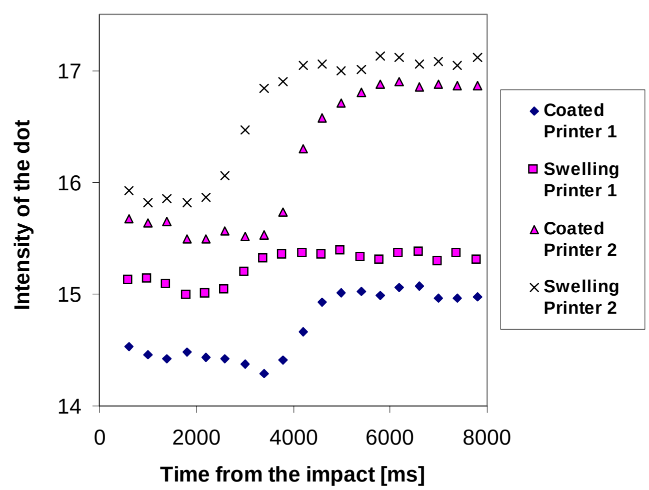

Figure 7. The intensity of the dot as a function of time with the non-absorbent samples.

Discussion

It was noticed that with coated grades the variance in roundness was twice as large with Printer 1 than with Printer 2. The size of the dot also varies more with Printer 1. The coated papers were measured on a macroscale by a commercial measuring device and it was confirmed that they were at the same roughness level. However, a close microscale inspection revealed that very small differences in the paper's surface topography strongly affect the size and the shape of the dot, when the printed dot is small. With larger dots the same kind of topography causes only smallish edge unevenness.

The final intensity of the print was found to be the outcome of the characteristics of the ink and the absorption properties of the paper. The tone value of the ink determines the highest density level of the dot, but the paper properties, especially absorption, can strongly reduce the darkness of the final print. With special papers, like pigment coated grades, very high density levels can be achieved.

The amount of liquid in a drop strongly affects the dynamics of spreading as well. In our earlier study /1/ it was noticed that in continuous ink jet printing the drop begins to spread immediately after the impact and no wetting delay was found. The high kinetic energy of the CIJ droplet makes the mechanical hitting phase more important than it is in drop-on-demand printing, because it ensures an immediate, pressurised contact with the paper surface and in this way extremely fast wetting. When the hitting speed is high the drop also spreads over a larger area and a smaller amount of liquid spreads by means of absorption or surface energetic factors. In our study, bigger drops spreads more strongly in uncoated paper grades. This is due to the larger amount of solvent per unit area.

The more significant effect of the volume of a drop seems to be on its drying. Absorptive drying is strongly dependent on the pore volume of the surface and in our studies the drying time has been noticed to last from a few hundred milliseconds to several seconds. In this study, it was noticed that smaller drops dry twice as fast as larger one. This is due to the smaller amount of solvent per unit area. Pigment coated paper was noticed to be extremely fast, which makes it especially suitable for high-speed colour printing processes.

Moreover, clear differences in drying times between different drop sizes were noticed with non-absorbent surfaces. This is easy to understand, because with similar solvents the drying rate is constant. No differences between the drying times with the same drop size were found in coated paper grades. Only swelling paper was faster. Presumably the interaction between ink and soluble polymer assists faster setting of the drop.

Conclusions

Although there were differences between the inks, e.g. viscosity, and the size of drops were different, the paper grades of this test series seemed to act very linearly when the printers were compared. There were extensive differences between the papers, but the same grades were good for both printers. This means that at least with these two printers, a high quality, printer-independent paper could be tailored. Although excellent dot quality can be achieved by using expensive special ink jet papers, it seems to be possible to optimise even conventional papers as high quality media for ink jet printing.

References

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Biography

Jali Heilmann is a research scientist with Printed Communications at VTT Information Technology (VTT stands for the Technical Research Centre of Finland). In his Master of Science thesis, he developed new electrophotography research methods. After graduating in 1995, he worked at the Media Laboratory of Helsinki University of Technology on projects dealing with colour electrophotography. He has worked at VTT since 1997. His present focus is digital printing technologies, especially ink jet. Mr. Heilmann is a postgraduate student. The author's e-mail address is Jali.Heilmann@vtt.fi.