# Effect of Drop Size on the Print Quality in Continuous Ink Jet Printing

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Very little attention has been paid in the literature to the impact of the drop size on the dynamics of spreading and on 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 upwards, by using a special high speed imaging environment and continuous ink jet (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 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.

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## Introduction

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

Obviously, the size of the drop is of great importance to the final print quality because it determines, for example, the smallest size of the dot. At the present level of the ink jet technology, drops that are as small as 3 pL are utilized commercially both in drop-on-demand and continuous ink jet printers. The size of the drop may be varied in some printers also. Unfortunately, very little attention has been paid in the literature to the impact of the drop size on the dynamics of spreading and on the final dot quality with different paper grades.

In this study, two commercial continuous ink jet 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 was traced on a time scale of a few milliseconds up to eight seconds. The size, the density and the 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.

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## Experimental

In this study, ink drops were generated by using two industrial multi-deflection continuous ink jet 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 of over 20. Two special ink jet papers were also used. One was a so-called swelling glossy paper that comprises a PE (polyethylene) film, coated with a 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, especially designed 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 diameter, the roundness, and the density of a single drop dot were measured on various paper grades after a drying time of several hours. The diameter is expressed as the diameter of a circle with an area equivalent to that of an irregular dot.

The samples were also analyzed in a laboratory scale-testing environment for 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/s), a stroboscopic flashlamp and a PC. A detailed description of the experimental arrangement has been reported earlier.[3] High-speed images were analyzed, and the average

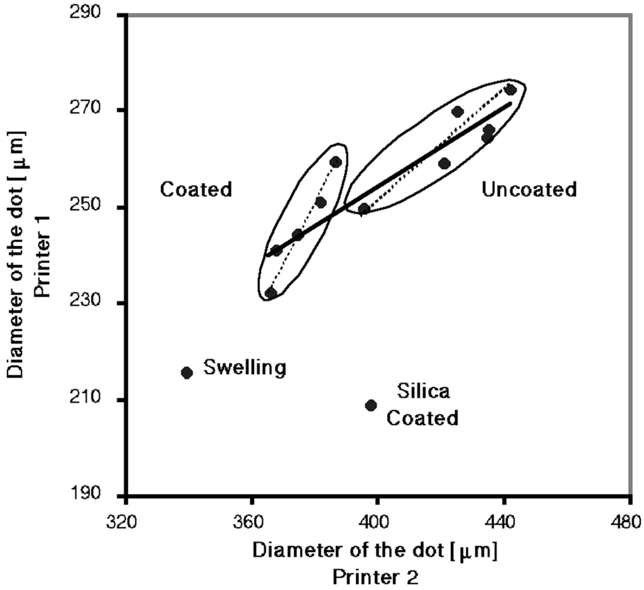


**Figure 1.** The sizes of the dots printed by the test printers.

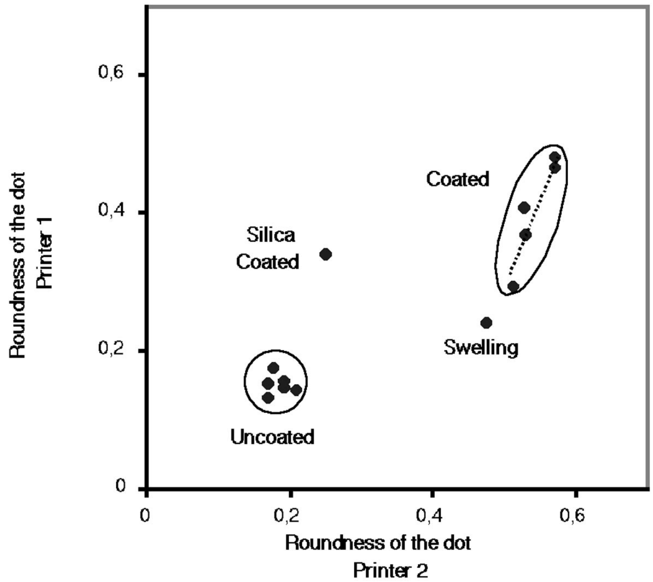


**Figure 2.** The roundness of the dots printed by the test printers.

development of the dot diameter and the intensity were considered on different time scales.

## Results

The comparison of the sizes of the dots printed by the test printers is shown in Fig. 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 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). On coated grades, the variances in the sizes are larger with Printer 1, and on 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. On pigment coated paper, small dots can be printed by Printer 1, but the dots produced by Printer 2 are quite large.

A comparison of the roundness of the dots produced by the test printers is shown in Fig. 2. The roundness values range from 0 to 1, where 1 is a perfect circle. Much rounder dots are generated on coated grades. A strong linear correlation ($r$ = 0.93) between the results obtained with the two printers can be found in coated paper grades. On coated grades, the variances in roundness are twice as large with Printer 1 than with Printer 2. No correlation can be found on uncoated papers and the level of the roundness is very low as well. Rounder dots are printed by Printer 1 when pigment coated paper is used. On swelling paper, the dots are much rounder with Printer 2.

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

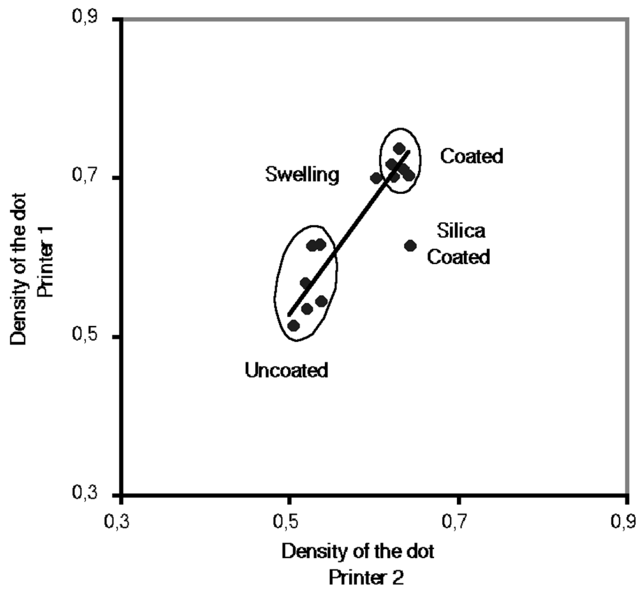


**Figure 3.** The densities of the dots printed by the test printers.

Dot diameters during the first 200 ms after the impact of the drop on the absorbent samples (uncoated grades and pigment coated paper) are shown in Fig. 4. The pigment coated paper is by far 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 the setting times of the papers, the shapes of the average spreading curves of the printers are quite similar. The final size of the dot is reached earlier by Printer 1.

Dot diameters during 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 Fig. 5. The growth of the dot is considerably smaller than on absorbent papers and the final size of the dot is reached

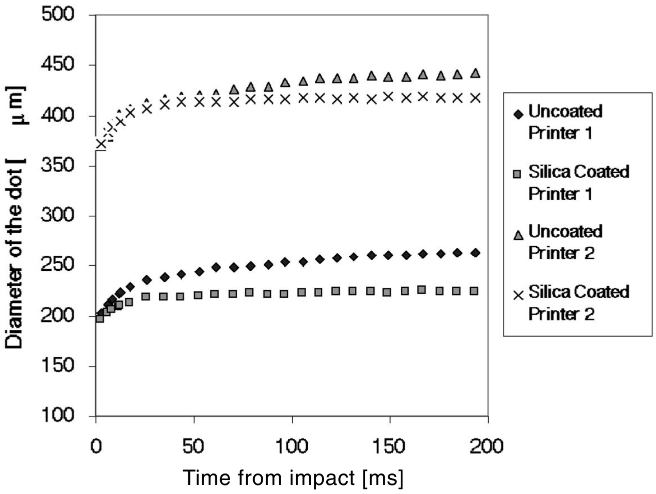


**Figure 4.** The diameter of the dot as a function of time on the absorbent samples.

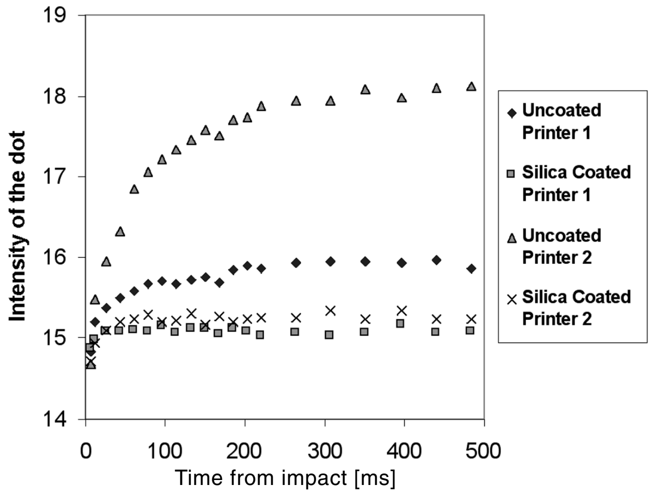


**Figure 6.** The intensity of the dot as a function of time on the absorbent samples.

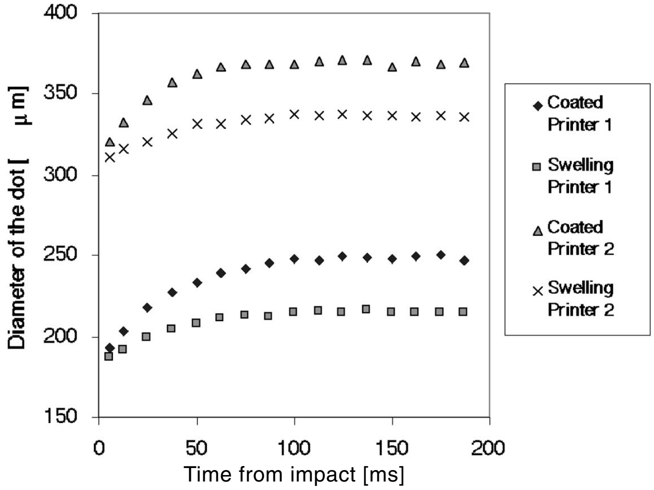


**Figure 5.** The diameter of the dot as a function of time on the non-absorbent samples.

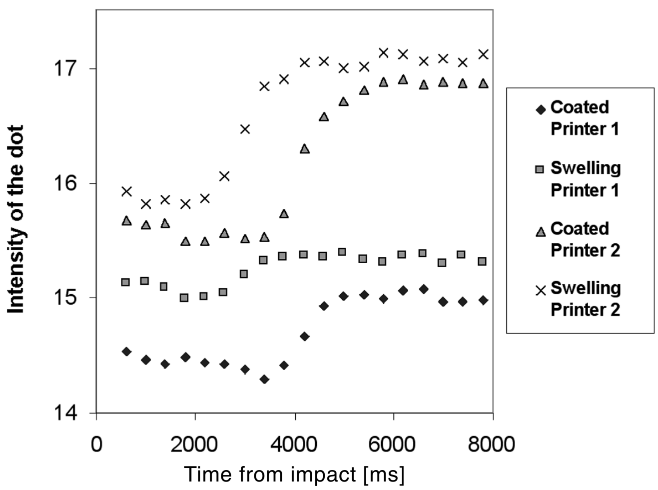


**Figure 7.** The intensity of the dot as a function of time on the non-absorbent samples.

within the first 100 ms. Growth is smaller and a little faster on the swelling ink jet paper.

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 development of the intensity is shown in Fig. 6. The intensity value indicates the darkness of the print: the lower the value is, the darker the print will be. The total number of the intensity levels produced by an 8-bit CCD camera is 256, where 0 is black and 255 is white. While the final darkness of the print is reached by Printer 1 within 200 ms, it takes 400 ms for Printer 2 to reach a stable level. Although there are considerable differences in the darkness of the dot on uncoated samples, almost the same high darkness level is reached with the pigment-coated paper.

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

## Discussion

On uncoated papers, the size of the dot is often relatively large because the liquid has a strong tendency to spread in the lateral direction. In addition, the unevenly distributed capillaries often produce ragged dots. The density of the dots is low because of the strong absorption and the large capillaries, whereby the colorant penetrates into the fiber structure. Much smaller, rounder and darker dots are produced on non-absorbent samples because of the small and even spreading. The weak point with coated samples is that the drying time of the ink is often too long for ink jet printing. By using special coatings, e.g., pigment and swelling coatings, the amount and the speed of the spreading and the absorption can be controlled effectively. The pigment coating absorbs the solvent rapidly and leaves the dye near the surface to produce small and dark dots. The swelling coating blocks the solvent and spreading is small, which also produces very small and dark dots.

On coated grades, the variance in roundness was found to be twice as large with Printer 1 than with Printer 2. In addition, the size of the dot varies more with Printer 1. The coated papers were measured on a macroscale by a commercial measuring device, confirming that they were at the same roughness level. However, a close microscale inspection revealed that very small differences in the surface topography of the paper strongly affect the size and the shape of the dot if the printed dot is small. With larger dots, the same topography causes only some unevenness on the edge.

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 tonal 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. Very high-density levels may be achieved with special papers e.g., pigment coated grades.

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

The volume of a drop seems to have a more significant effect on drying. Absorptive drying is largely dependent on the pore volume of the surface and in our studies, the drying times from a few hundred milliseconds to several seconds were found. We also discovered that the smaller drops dry twice as fast as the larger ones. This is due to the smaller amount of solvent per unit area. Pigment coated paper was found to be extremely fast, which is why it is very well suited for high speed color printing.

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

## Conclusions

In this study, the size and the shape of a single drop dot were found to be largely dependent on the size of the drop. Obviously, a bigger drop produces larger dots, but also the shape of a smaller drop dot was found to be much more dependent on the small-scale topography of the surface. Naturally the tone value of ink has a strong effect on the final density of the dot, but also the properties of the paper; absorption and spreading are especially significant. As we studied the high-speed dynamics of absorption and spreading, we found that small drops spread and dry faster than bigger drops both on coated and uncoated paper grades.

Although there were differences between the inks, e.g., viscosity, and the sizes of the drops were different, the paper grades of this test series seemed to act quite linearly when the printers were compared. There were large differences between the papers, but the same grades were suited for both printers. This means that a high quality, printer independent paper could be tailored. Although an excellent dot quality can be achieved by using expensive special ink jet papers, it also seems possible to optimize conventional papers as high quality media for ink jet printing.

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