Significance of Paper Properties on Print Quality in Continuous Ink Jet Printing

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In this article, we discuss the relationship between a high-speed continuous ink jet system and the printing substrate. Non-absorbent materials, with different surface topographies were used to evaluate the importance of the droplet impact and spreading without capillary penetration. Commercial papers were also used to evaluate the potential of the existing grades, and to find their essential performance parameters. A laboratory scale testing environment was used 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 and analyzed in this testing environment on the time scale of microseconds up to several minutes. The image technical performance of the samples was measured with an image analysis system which was specially designed for the analysis of print quality with non-impact printing techniques.

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Introduction

Although drop-on-demand printing has become the most dominant technology in low-end printing, continuous ink jet (CIJ) systems are the technology of the future, especially in high-speed digital color printing applications. More knowledge of the basic mechanisms of dynamic interaction to produce a more reliable and appropriate specification of the quality requirements for the paper grades is needed, and it would be useful in the product development of the paper industry. The purpose of this study is to clarify these paper-based interaction mechanisms.

It is well known that the absorption properties of paper have a distinct effect on the drying and spreading of aqueous inks, and in this way, on the print quality. The importance of paper roughness is often also stressed because it affects the final size and the shape of the dot. However, it is difficult to discern the relevance of these two factors in commercial paper grades. It is possible to decrease the surface roughness of paper by calendering but then also the total pore volume will decrease.

To overcome this problem, two non-absorbent plastic sheets with different topographies were used to evaluate the importance of the mechanical droplet impact and spreading without any capillary penetration. The adjusted process parameters were the distance of the printing nozzle from the surface which affects the impact velocity of the drop, and the velocity of the printing surface. Moreover, eight commercial coated and uncoated papers were selected and the dynamic development of the image technical properties were measured on different time scales.

TABLE I. Test Materials

Sample	Coating	IGT oil absorption	PPS roughness
Plastic 1			2.3
Plastic 2			4.9
Paper 1	Uncoated	12.5	3.7
Paper 2	Uncoated	21.4	3.8
Paper 3	Uncoated	22.6	8.8
Paper 4	Coated	7.3	1.1
Paper 5	Coated	7.7	1.8
Paper 6	Coated	7.8	1.2
Paper 7	Coated	7.9	1.9
Paper 8	Coated	8.9	3.4

Experimental

In this study, the ink drops were generated by an industrial multideflection CIJ device. The inner diameter of the nozzle was 70 µm and the drop production rate 77 kHz. The exit velocity of the drops was 18 m/s. The recommended printing distance for the printer was 12–17 mm. The viscosity of the water-based ink was 3.3 cP. A motor driven, balanced drum was set up to move the substrate. The peripherical velocity of the paper-carrying cylinder was adjusted to be 0–8 m/s. The test substrates consisted of two plastic sheets and eight commercial paper grades. Some properties of the test materials are shown in Table I. The plastic sheets were selected so that the roughness of the first sample (Plastic 1) approaches the roughness of the coated paper and the roughness of the second sample (Plastic 2) approaches the roughness of the uncoated paper. The

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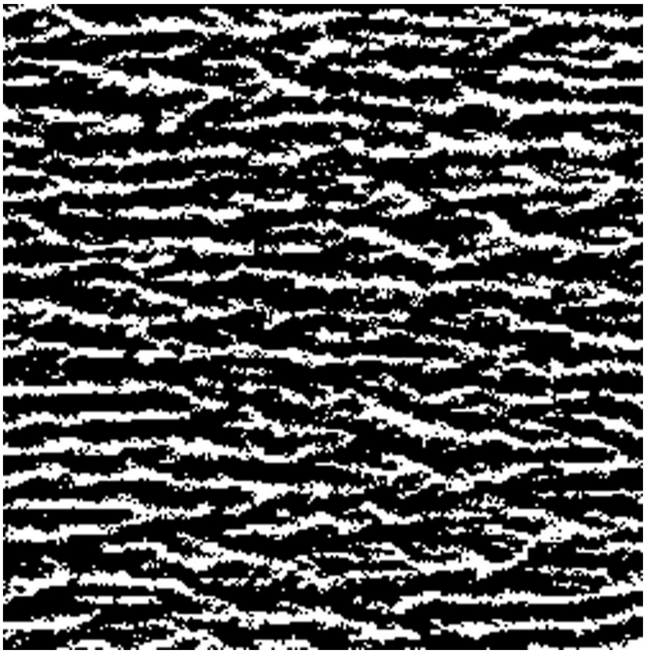

Figure 1. The strongly orientated topography of plastic sheet 2.

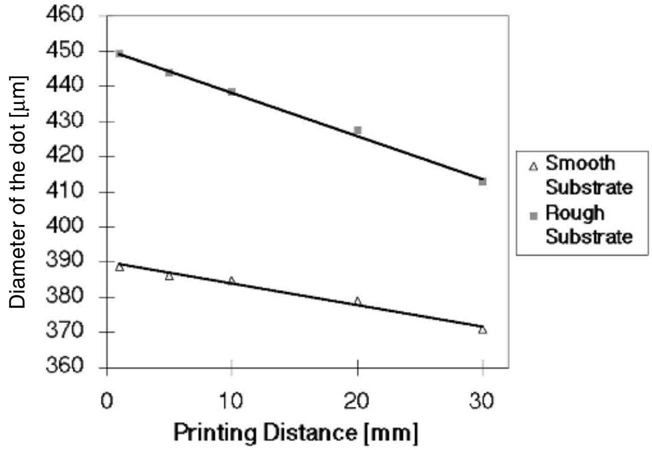

Figure 2. The diameter of the dot as a function of the printing distance.

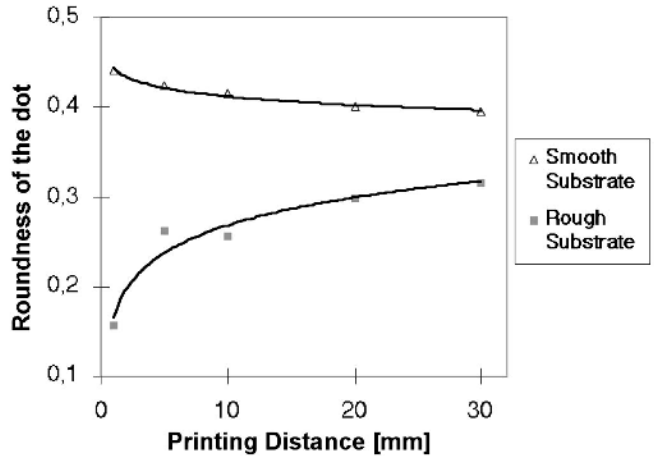

Figure 3. The roundness of the dot as a function of the printing distance.

topography of Plastic 2 was strongly orientated, as seen in Fig. 1.

Two test series were carried out using the plastic sheets. In the first series, the printing nozzle was set at various distances from the surface, i.e., 1, 5, 10, 20 and 30 mm. In the second series, the distance between the surface and the nozzle was kept constant, but the speed of the rotating cylinder, to which the samples were attached, was changed. The printing distance in the speed series was 50 mm, and it was selected so that the impact of the drop speed would be as low as possible. The speeds used were 0, 2, 4, 6 and 8 m/s.

Three samples were used in the speed series. The first sample was Plastic 1. The second sample was Plastic 2, which was attached to the rotating cylinder, so that the direction of the orientation was parallel to the cross-machine direction (CD). The third sample was Plastic 2, which was attached to the rotating cylinder, so that the direction of the orientation was parallel to the machine direction (MD). After printing, the image technical properties were measured by using an image analysis system specially designed for the analysis of the print quality with non-impact printing techniques. The system consists of a microscope, a CCD camera and a PC with tailored analysis software.

The commercial paper grades were 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 microseconds up to several minutes. This testing environment is based on a high speed CCD camera (2250 frames/sec), a stroboscopic flashlamp, and a PC. A detailed description of the experimental arrangement has been reported earlier.[1] In this series, the printing distance was 50 mm and the printing substrate was held still. The high-speed images were analyzed and the development of the image technical properties was considered on three different time scales: from 0 to 20 ms, from 0 to 200 ms and from 0 to 1,500 ms after the impact.

Results and Discussion

Effect of Printing Distance on Print Quality

The significance of the printing distance, a process parameter that affects the striking speed of the drop, was verified by using smooth and rough plastic surfaces. The results are shown in Figs. 2 and 3. The diameter of the dot decreases linearly when the printing nozzle is moved farther away from the surface. The dot is at all distances notably smaller on a smooth substrate. The effect of a distance adjustment is, however, greater on a rough substrate.

The dot becomes rounder when the printing distance increases on a rough surface. The roundness values range from 0 to 1, so that 1 is a perfect circle. The roundness of the dot can be totally destroyed if the printing distance is small, especially with a high speed of the substrate. A study of the splashing of the ink drops has been published earlier.[1]

Quite surprisingly, the roundness of the dot decreases when the printing distance is increased on a smooth surface. An explanation for this could be that the hydrodynamic pressure of the spreading drop exceeds the weak surface forces and small irregularities of the print-

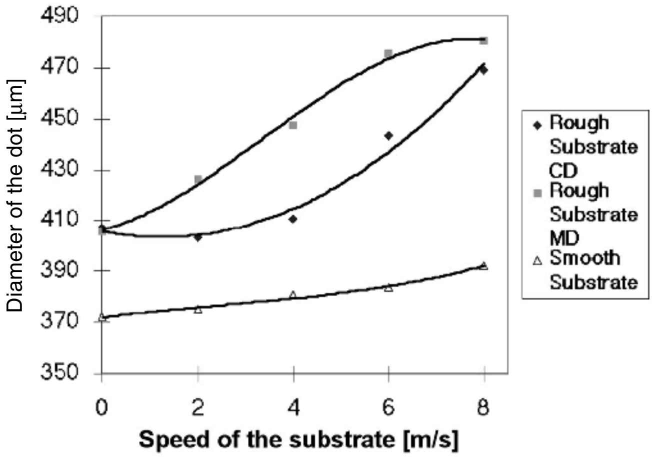

Figure 4. The diameter of the dot as a function of speed

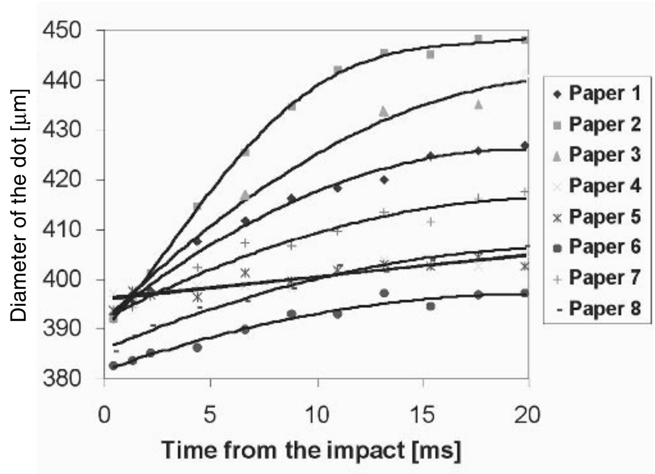

Figure 6. The diameter of the dot as a function of time.

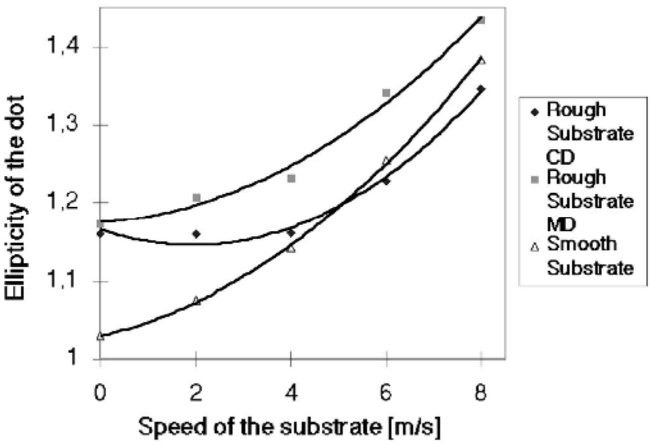

Figure 5. The ellipticity of the dot as a function of speed.

ing substrate, and creates bigger and calculatorily rounder dots. The difference between the smooth and the rough surface decreases when the printing distance is increased.

Effect of Printing Speed on Print Quality

The significance of the printing speed was assessed by using non-absorbent materials with a smooth surface and two rough surfaces with different directions of orientation. The results are shown in Figs. 4 and 5. If the printing speed is increased, the dot also grows on all substrates.

On a rough surface with an orientation in the machine direction (MD), the diameter grows rapidly when the speed is increased and begins to decelerate after about 6 m/s. When the orientation is in the cross machine direction (CD), the size of the dot first increases slowly but after 4 m/s it begins to grow rapidly. At a speed of 8 m/s, the differences between the two samples are small. A possible explanation for the difference is that the CD-orientated surface blocks the drop and prevents its free flow on the surface when the speed of the sample is increased. On the MD-orientated surface, the liquid can flow quite freely and the size of the dot increases rapidly. Most of the total dot growth is caused by the roughness of the substrate because on a smooth substrate the diameter of the drop grows slowly when the speed is increased.

The ellipticity of the dot increases on all substrates when the printing speed is increased. Ellipticity is the ratio of dot width to the dot height. The ellipticity of the MD sample increases faster than that of the CD sample. This confirms the previous conclusion: the cross-directional topography of the surface significantly impedes the flow of the liquid. The free flow of the liquid also causes the ellipticity of the dot to increase very rapidly on a smooth surface.

Effect of Absorption on Print Quality

The significance of absorption and the development of the image technical properties as a function of time were evaluated by using eight commercial paper grades. The diameter of the dot within the first 20 ms is shown in Fig. 6.

After the impact, the drop immediately begins to spread on all paper grades. It is generally suggested that there is a so-called wetting delay, ranging from 5 ms to several seconds before the capillary penetration begins. No sign of such a delay was found in this study. An explanation for this could be that the high kinetic energy of the CIJ droplet ensures an immediate, pressurized contact with the paper surface and in this way, fast wetting. After 20 ms post-impact, there is already a difference of 50 µm in the diameter of the dot between Paper 2 and Paper 6.

The first 200 ms from impact of the drop are shown in Fig. 7. The diameter of the dot increases very rapidly in the uncoated samples 1, 2 and 3, due to the fast capillary penetration. There are still considerable differences in the spreading times of the uncoated papers. For example, while the dot on Paper 2 spreads to its maximum size within the first 50 ms, it takes over 200 ms on Paper 3. The changes are much smaller in coated papers although considerable differences are observed. All in all, the changes in the dot size are extremely fast. In fact, a 98% correlation can be calculated between the dot size at 120 ms and the final dot site after a drying time of several hours.

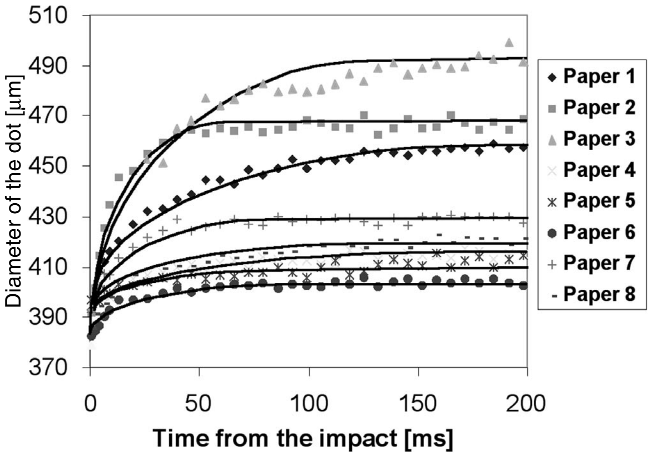

Figure 7. The diameter of the dot as a function of time.

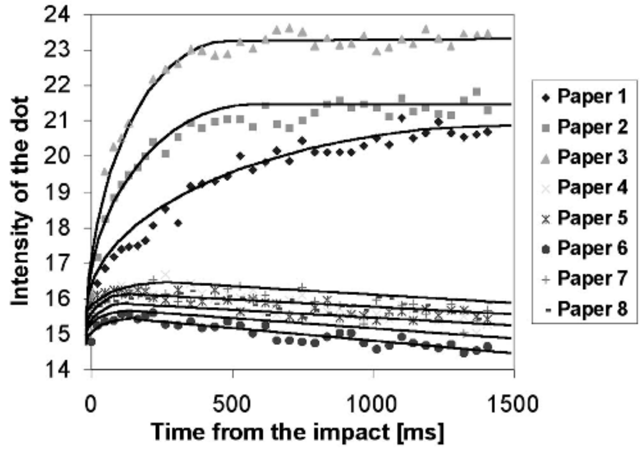

Figure 9. The intensity of the dot as a function of time.

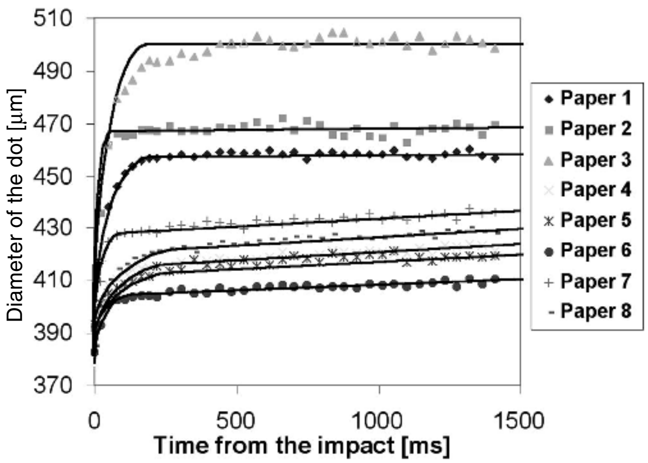

Figure 8. The diameter of the dot as a function of time.

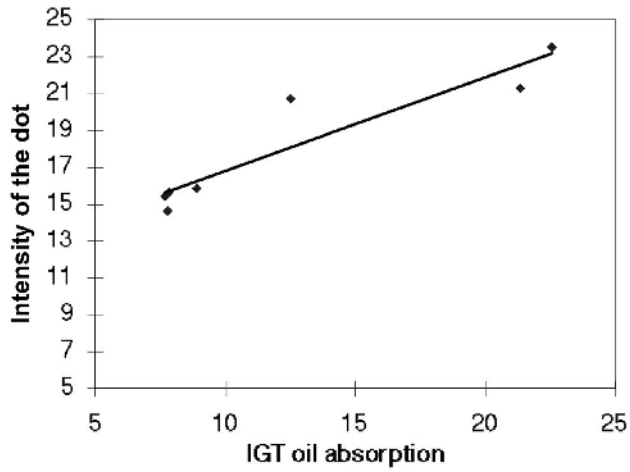

Figure 10. The intensity of the dot as a function of IGT oil absorption.

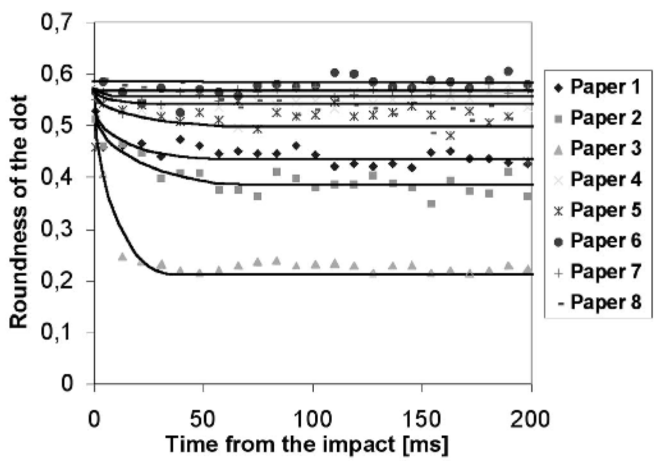

Figure 11. The roundness of the dot as a function of time.

The first 1.5 seconds of spreading are shown in Fig. 8. As one can see, on this time scale there is a slow increase in the dot size on coated papers. The slow spreading continues until most of the solvent has evaporated. The percentage rate of the dot increase is quite small during this time, but under dynamic conditions, the slow drying causes severe bleeding, especially in multicolor processes.

Although the maximum size of the dot is reached within about 200 ms on uncoated papers, the intensity of the dot takes a much longer time to develop. 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 on Paper 3 is reached after 500 ms, it takes more than three times longer for Paper 1 to reach a stable level. This is easy to explain by an examination of the papers: Paper 3 is rough and porous, a paper with fast penetration and spreading, while Paper 1 is smooth and dense. The intensity of the dots on coated papers decreases on this time scale due to the slow drying of the drop. Much higher darkness levels can be reached with coated papers—at the expense of slow drying. A linear correlation (r = 0.94) was found between the intensity of the dot and the IGT oil absorption of the paper: the more absorbent the paper, the lower darkness the print will have (Fig. 10).

The roundness of the dot in the first 200 ms is shown in Fig. 11. The roundness decreases rapidly on uncoated

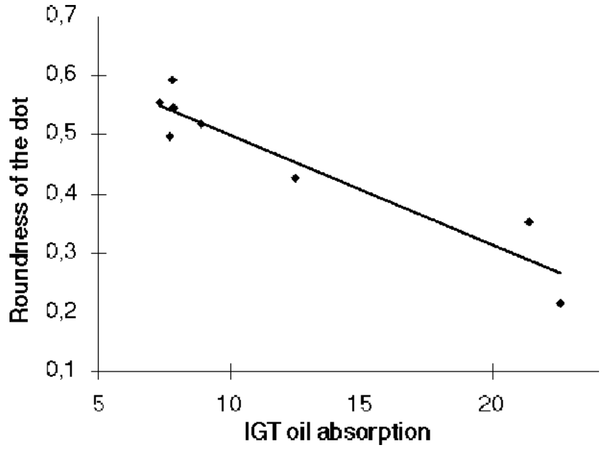

Figure 12. The roundness of the dot as a function of IGT oil absorption.

papers in the first 100 ms. The decline in quality is strongest in Paper 5 where the shape of the dot is totally destroyed. Much rounder dots can be achieved with coated papers. A linear correlation (r = –0.94) can be found between the roundness of the dot and the IGT oil absorption of the paper: the more absorbent the paper, the less round the dots will be (Fig. 12).

Conclusions

The roughness and the absorption properties of paper were found to be of great significance to the print quality in CIJ printing. Plastic sheets with different topographies were used to evaluate the mechanical droplet impact without capillary penetration. It was found under varied process conditions that the roughness and the orientation of the printing surface had a strong impact on the final size and the shape of the dot.

The absorption and the development of the image technical properties of commercial paper grades were examined in a high-speed imaging test environment. The dot was found to approach its final size extremely fast: a 98% correlation could be calculated between the dot size at 120 ms and the final dot size after a drying time of several hours. The intensity of the dot develops more slowly than the size of the dot does. While the final dot size was reached in about 200 ms, the final intensity of the dot was reached on uncoated papers after 1,500 ms. On coated papers, neither the size nor the intensity of the drop reached the final level on the time scale of 1,500 ms.

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