Drying Technology Using Laser Exposure for High-speed Inkjet Printing

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Abstract

To ensure reliability with high-speed inkjet printing devices that print at 200 m/min using water-based ink, it is important for ink to penetrate and dry at high speeds. With current drying devices that use heating drums, heat is applied to the entire surface of the paper from the back side of the printed surface. Since it is not possible to avoid the rise in temperature to portions of the paper where ink is not applied, differences in the amount of paper deformation occur between printed areas where expansion/cockling occurs due to water and non-printed areas of the paper that shrink. As a result, this causes creases to the paper. To avoid this problem, the authors examined the use of infrared laser exposure for drying. With laser exposure, ink is directly heated and strong drying energy can be applied instantaneously, enabling for only the ink to be dried and for drying to occur in nearly the same time span as ink penetration. As a result, an increase in the temperature of the non-printed areas is prevented, and deformation of the paper is controlled no matter the amount of ink applied; by controlling ink penetration, feathering/line-bleeding is reduced and image quality is improved.

Introduction

Fuji Xerox's high-speed inkjet continuous feed printer, "2800 Inkjet Color Continuous Feed Printing System® (2800ICCFPS)", realizes high-speed printing of 200 m/min (3.3 m/sec) at a resolution of 600 dpi. In this system that uses water-based ink, fast penetration of ink and drying are important. [1]

Since printing speeds of household printers are slow, after water-based ink penetrates the paper, it dries by natural evaporation. By contrast, with the 2800ICCFPS, there are two drying mechanisms. The 2800ICCFPS is equipped with a metal drum of 700 mm in diameter that is heated to up to approximately 100 °C and directly dries the ink from the back side of the printed surface of the paper. A heater is installed to blow hot air onto the print surface.

Here, the problem caused by drying is excessive or deficient power. When drying power is deficient, the ink transfers onto the roller, and is then retransferred to the paper, creating a roller offset problem. On the other hand, when the drying power is excessive, the paper shrinks, causing creases due to deformation.

Although water-based ink is advantageous in terms of safety and its effects on the environment, there are fundamental problems that include deformation of paper due to swelling, feathering, and show-through of the ink on the back side of paper. In particular, when fast-penetrating ink is combined with plain paper, there is significant bleeding along the paper's fibers, and at the same time, concentration of the ink is reduced. As a means of preventing these problems, there is a method of aggregating colorant on the paper surface using reactive ink [2]. With this method, although reduction in image quality can be prevented, paper deformation cannot be improved since more water is applied to the paper.

Thus, the authors examined drying based on infrared exposure using laser diode (LD). Since LD directly heats ink, it has the advantage of not heating the non-printed areas of the paper. In this report, we discuss the fundamental behavior of drying based on LD exposure as well as impacts on paper deformation, impacts on image quality, and observation of penetration of ink onto paper for the purpose of mechanism analysis [3].

Figure 1. *2800 Inkjet Color Continuous Feed Printing System*

Basics of 2800ICCFPS

Figure 1 shows Fuji Xerox Co., Ltd.'s high-speed inkjet continuous feed printer 2800ICCFPS. The printing process of this device is in the order of front side printing, front side drying, cooling using a chiller, back side printing, and back side drying. It is characterized by a head for front side printing located vertically in relation to a head for back side printing, and drums for drying aligned horizontally beneath the printing heads. Since the structure enables double-sided printing to be performed inside its main unit by means of feeding paper in the order described above, the amount of installation area of the device surface area has been minimized.

Experimental Procedure

1) Measurement of paper water content and deformation

The water content was measured in two locations; on the section immediately after front surface printing and on the paper winding section after the paper passes through the dryer. A grid line was printed on the front side of the paper, and the same grid was printed in the same location on the back side. In doing so, the grids on the front and back sides perfectly match up if there were absolutely no paper deformation. However, if an image with a high printing coverage rate is printed near the grid, the paper swells, and if unprinted sections near the grid are excessively dried the paper shrinks. In either case, a mismatch arises between the grids on the front and back sides. In addition, the following types of ink and paper were used.

Ink: 2800 ICCFPS/Fuji Xerox Co., Ltd.

IJ paper: NPi Form Next-IJ® 55/70/135

Plain paper: NPi Form® 55/70/135

(Manufactured by NIPPON PAPER INDUSTRIES CO., LTD.)

Here, the values indicate the weight (kg) of 1000 sheets of 788 × 1091 mm^2 paper, equivalent to 64.0 / 81.4 / 157.0 gsm respectively. Generally, a heavier weight represents thicker paper.

2) Fixture for IR Laser Exposure

The testing equipment of laser exposure was comprised of a paper-feeding stage that travels linearly, a fixed print head and laser-exposure device. After jetting, laser exposure was performed, and by changing the distance from the print head to the laser, the time from jetting to drying was changed.

For printing, a matrix-type piezo inkjet head [4] was used. The maximum speed of paper feeding was 1,000 mm/sec, and the minimum time from jetting to laser exposure was 20 msec. In addition, the time during in which the laser was radiated was 20 msec.

Ink surface temperature after laser exposure was measured using a radiation thermometer, and paper deformation was measured using a laser displacement sensor. In addition, the change in weight before and after laser exposure was measured and changes in water content were also measured.

3) Fixture for Observation of Ink Penetration

The penetration observation bench was comprised of a linearly-moving stage equipped with a printing head, a fixed feed paper base, and a high-speed camera. The head prints while scanning, and penetration into the paper was observed from the side using the high-speed camera.

Experimental Results

1) Deformation of paper by ink

Figure 2 shows results of measured water content of printed sections after passing the paper through the dryer at various printing speed of the 2800ICCFPS. 0% of the amount of water was normalized to that initially contained in paper. Also 100% of the amount of the water was normalized to that fully printed of 200% printing. A negative number in the amount of water represents the fact that all of the water content inside the ink and originally in the paper evaporated.

Figure 2 shows that when printing speed is slow and drying time is long, the amount of water decreases. At a speed of 50 m/min, the water decreases to negative 30 % regardless of the printing coverage rate. This indicates that a longer drying time allows for sufficient drying; it is assumed that at 50 m/min, all of the water in the paper has evaporated. At 200 m/min in an area with a printing coverage rate (or solid print) of 200 %, the amount of remaining water is 40 %, suggesting that there is the possibility of offset of non-dried ink onto the roller.

Figure 3 shows the measurement results of paper deformation at various printing speed with printing coverage rate of 0, 100, and 200%. Here, the amount of paper deformation was measured the increase or decrease in length of a 120 mm portion of paper that has been printed with a solid image, and this is expressed as a "cockle." The paper shrank by making the printing speed slower and the drying time longer. When the printing speed was 25 m/min, the amount of paper deformation was approximately negative 0.7 mm for all printing coverage rates. Although difference from this result was small, as the printing speed became faster, the amount of paper deformation was shown to vary among different printing coverage rates. In particular, at 150 m/min, paper expanded at a printing coverage rate of 200 % and shrank at a rate of 100 % or less, suggesting that paper undergoes complex deformation depending on the printing pattern.

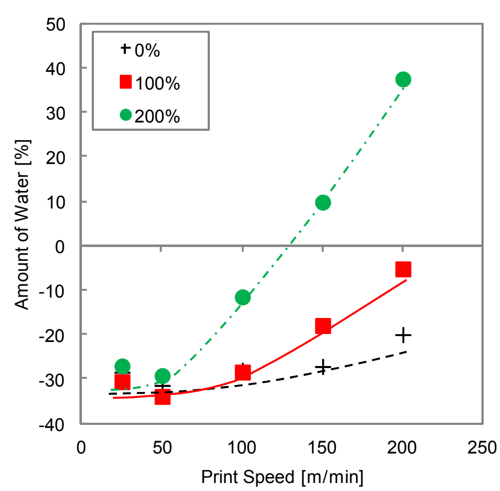


***Figure 2.** Water amount both on and inside Paper after Printing and Drying*

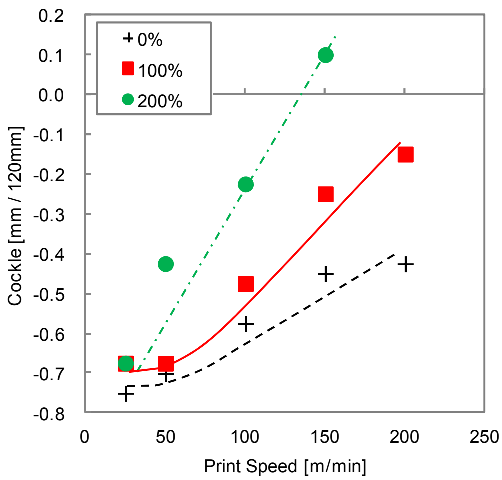


***Figure 3.** Paper Deformation by Wetting and Drying*

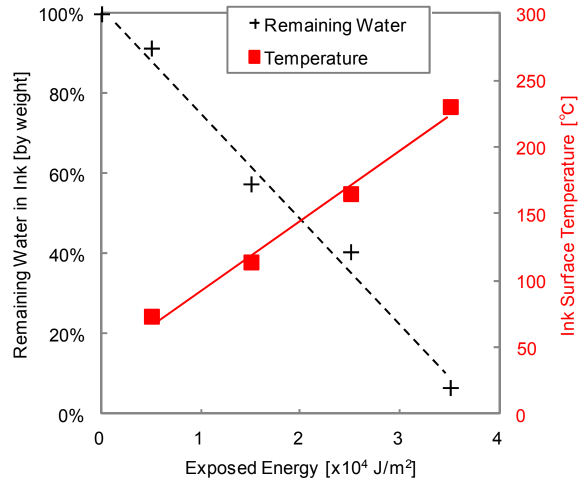


***Figure 4.** Water Evaporation and Temperature Changes*

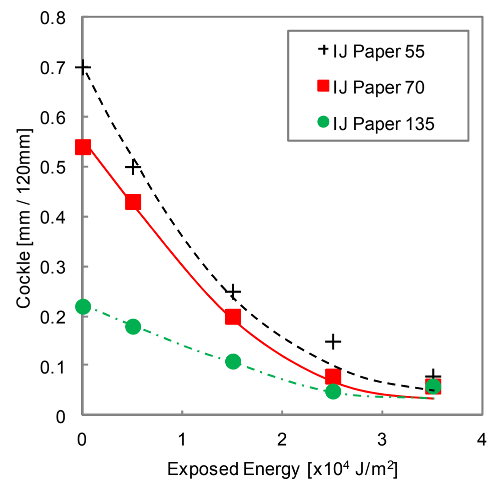


***Figure 5.** Paper Cockle (expansion) by ink wetting at each paper thickness*

2) Ink Drying Based on Laser Exposure

Figure 4 shows the ink temperature as well as the remaining water measured by the experimental set up using the laser-exposure device with various exposed energies.

It was indicated that at laser energy of 1.5×10^4 J/m^2, the ink temperature exceeded 100 °C, and approximately 40 % of the water in the ink evaporated. Furthermore, when energy was increased to 3.5×10^4 J/m^2, the ink temperature exceeded 200 °C, and the water in the ink evaporated almost entirely.

Figure 5 shows the results of measuring the amount of paper deformation in relation to the laser energy at 60 seconds after jetting, and subtracting 0.14 mm, which represents unevenness of the paper surface. As with Figure 3, the paper length here is 120 mm, and increases beyond 120 mm are referred to as "cockle." When the paper is particularly thin, expansion of paper due to ink is large, but as the laser energy increases, paper deformation of the printed section decreases, and paper length difference at 3.5×10^4 J/m^2 was nearly eliminated. In non-printed areas, no paper deformation was observed, regardless of the laser intensity.

Figure 6 shows the results obtained upon observing effects on character image quality when performing laser exposed at 20 msec after jetting. With IJ paper, feathering is reduced and line optical density becomes higher at 1.5 and 2.5×10^4 J/m^2 indicating the improvement of image quality. On the other hand, at 3.5×10^4 J/m^2, there were spots of ink around the printed area, and probably due that the ink temperature became so high the ink was boiled and scattered. With plain paper as well, an increase in image quality was also seen at 1.5×10^4 J/m^2. However on the contrary, the width of the line had increased and had extended to non-printed areas when the laser energy is increased to 2.5 and 3.5×10^4 J/m^2. A similar scattering as observed with IJ paper had occurred on the surface of the plain paper probably.

Figure 7 shows the optical density of the printed ink with various exposed energy at 20ms after jetting. Optical density shows a peak in relation to the laser energy, and its value is 1.5×10^4 J/m^2 for IJ paper and 2.5×10^4 J/m^2 for plain paper. This figure also shows that the amount of increase of optical density is 0.3 for IJ paper and 0.2 for plain paper.

Decrease in optical density was observed when the laser energy was increased. The reason is thought to be attributed to a transformation of the ink and paper due to excessive laser exposure. When high energy is applied, paper burning is also observed, and this implies that there is an appropriate value for the exposure of laser energy.

Figure 8 shows the results of optical density measurements on the back side of the printed surface in relation with laser energy. The optical density on the back (show-through) decreased for both IJ paper and plain paper with the increase of laser energy, and remained constant at energy of 1.5×10^4 J/m^2 and higher.

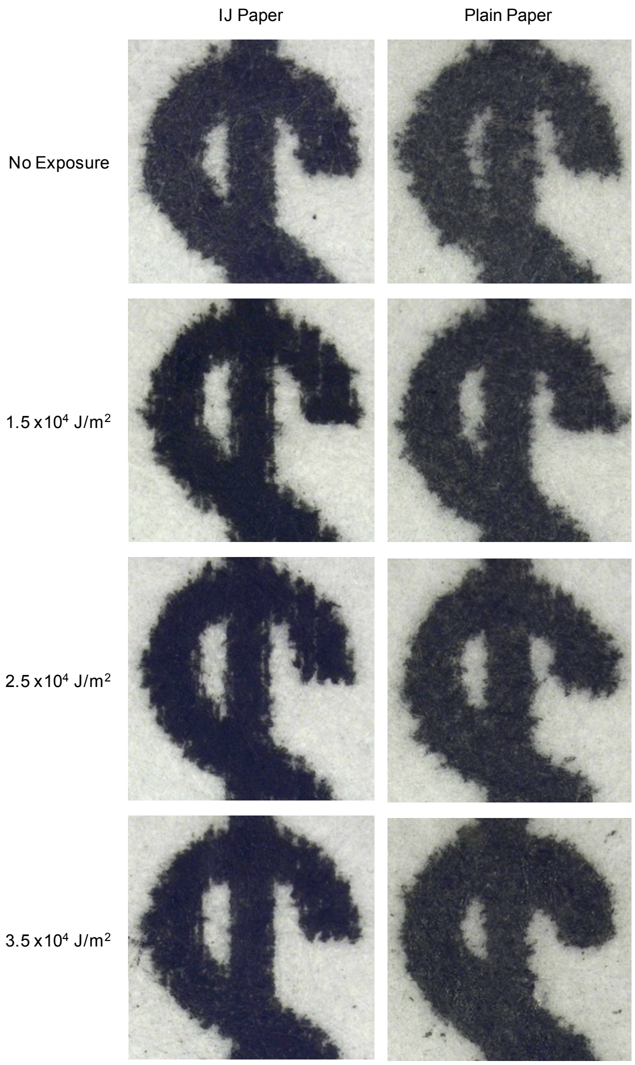


Figure 6. *Observed Images Quality by Laser Intensity changes*

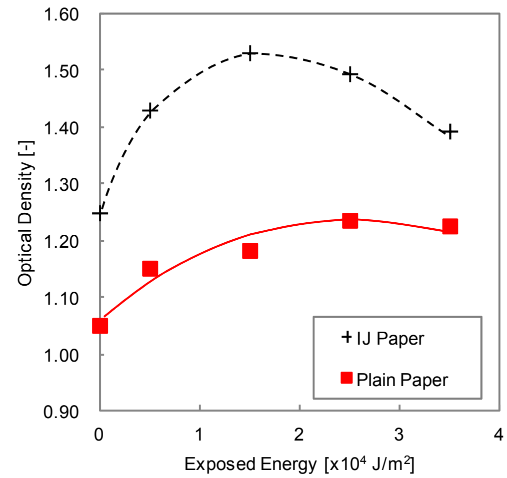


Figure 7*. Optical Density changes on Solid Patch*

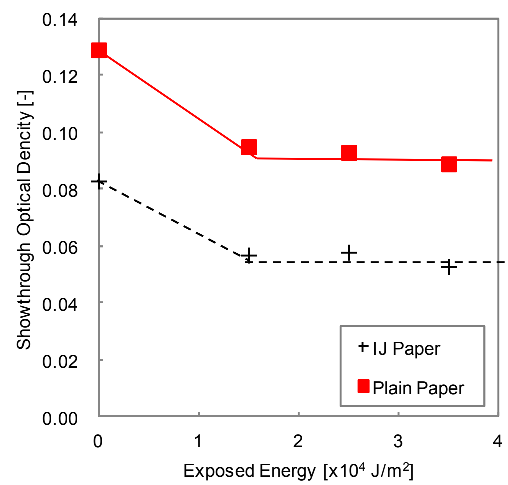


Figure 8. *Show through (Paper back side) Density Changes*

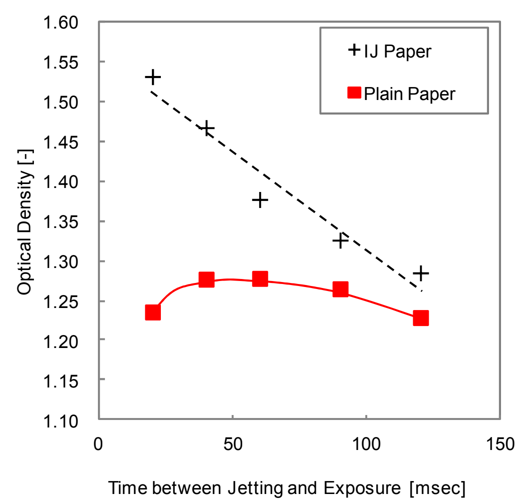


Figure 9. *Optical Density on Solid Patch by Interval Time changes*

Figure 9 shows the optical density with various interval of time between jetting and exposure. The laser energy applied for the purpose was 1.5×10^4 J/m^2 for IJ paper and 2.5×10^4 J/m^2 for plain paper. For IJ paper, optical density becomes higher as the time interval before laser exposure is shorter within the measurements of 20 to 120 msec. On the other hand, for plain paper, the optical density was at its highest when the time interval before laser exposure was set to 40 to 60 msec. Here, the difference of the characteristics in interval of time to obtain high density was resulted from the difference in ink penetration speeds, and it is also considered that a certain amount of time for penetration is necessary to achieve higher density.

Figure 10 shows the results of observing raggedness (feathering) of printed lines upon changing time interval after jetting and before laser exposure. When time interval before exposure is shorter, raggedness is low for both IJ paper and plain paper. Accordingly, this tendency differs from the tendency seen for the concentration curve of images with high printing coverage rate shown in Figure 9 and the difference in behavior between the density of images with high printing coverage rate and the line

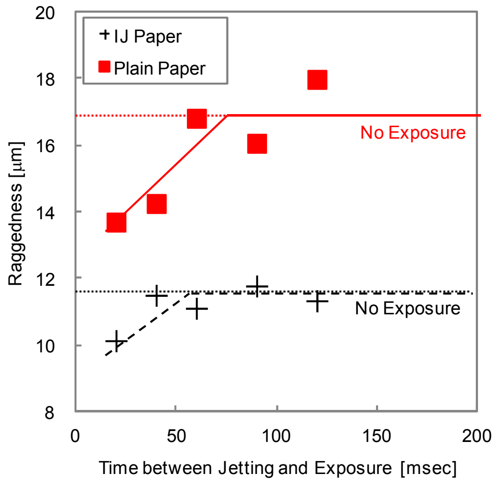


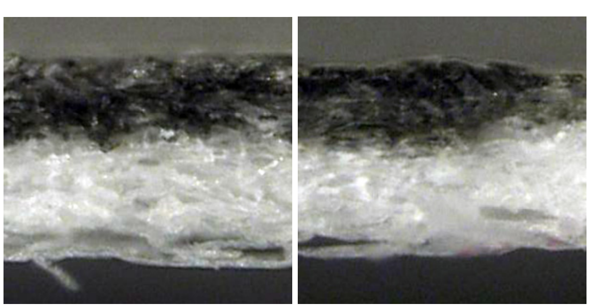
Figure 10. *Line Raggedness by Interval Time changes*

raggedness are thought to result from differences in their penetration behavior.

3) Observation of Ink Penetration into Paper

Figure 11 shows cross-sections of paper (thickness about 100μm) in order to compare the states of ink penetration in paper with and without laser exposure. When paper is exposed to laser, the most concentration of ink is observed on the outermost surface of paper. However, when there is no laser exposure, the area that is 20 microns inside the outermost surface shows the most concentration. Accordingly, it is thought that laser exposure prevented colorant from entering into the paper at the moment of ink penetration and this, in turn, has caused concentration in the outermost surface to increase.

Figure 12 shows the results of observing penetration of a one-dot line into IJ paper using a penetration observation bench. As there is unevenness on the paper surface, in the figure, the landing surface of drops is shown in the curve. Ink droplets are jetted in such a way that they form a line on the paper surface from the right to the left together with the passing of time. Specifically, a drop is jetted between 0 to 0.05 msec and subsequent drops are jetted by 0.2 msec, forming a belt-like line. Afterwards, the ink is absorbed by the paper and penetration is completed approximately 30 msec later. Here, ink is penetrated almost evenly, but in some areas, penetration is slow, and this is thought to be a result of fine variations in the characteristics of the paper surface.



No Exposure 2.5 x10^4 J/m^2

Figure 11. *Cross Section of Pigment Penetration in Plain Paper*

Figure 13 shows the results of penetration time measurements upon changing the paper type and printing pattern. Here, the penetration time was set as the time from when ink lands on paper to when there are no longer any changes to the ink on the paper. Upon comparing IJ paper and plain paper, the average penetration time for IJ paper was short and approximately half that of plain paper, but with little variation.

In addition, it was shown that penetration time becomes slower when the printing pattern is changed from dot to line and from line to image with a high printing coverage rate (solid print image). This is thought to result from the degree of freedom in the penetration direction. This means that it is possible to penetrate in all direction on paper with the dot while the penetration is limited to one direction perpendicular to the surface for the solid pattern.

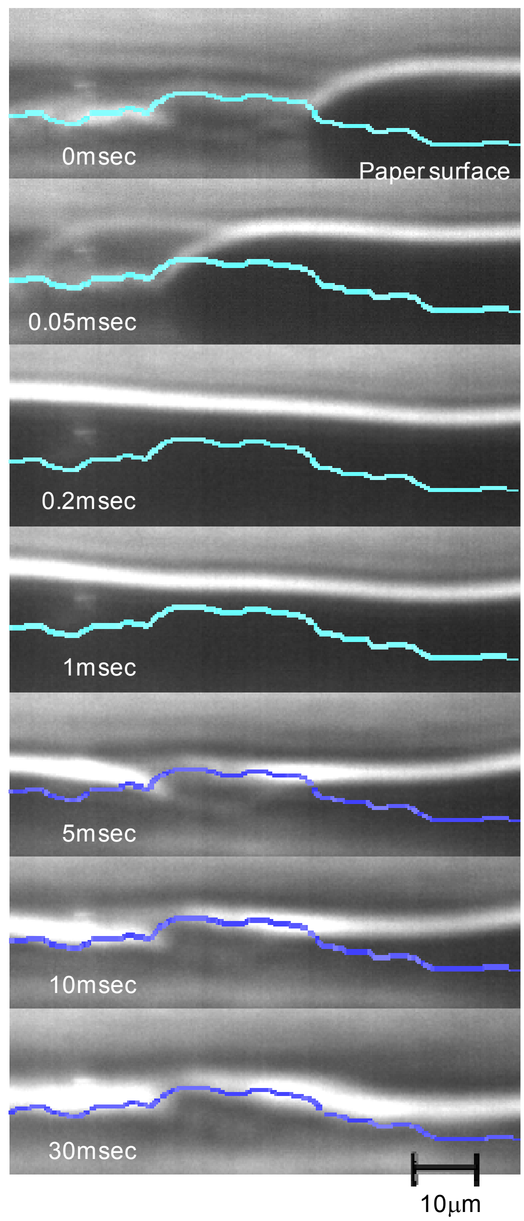


Figure 12. *Ink Line Penetrations on Plain Paper (solid line: paper*

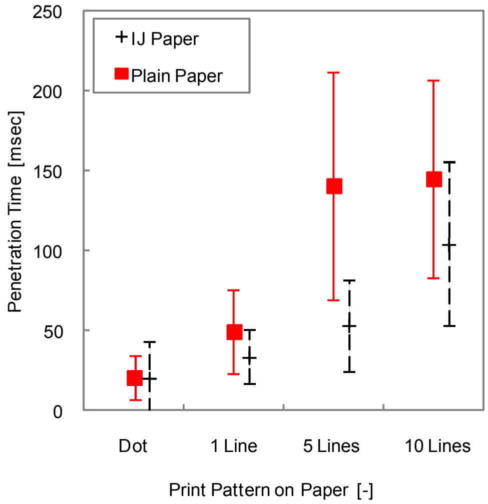


Figure 13. *Ink Penetration Speed on IJ and Plain Paper*

Accordingly the penetration is restricted and slowed down depending on the printed patterns.. The difference in image quality in relation to the change in time intervals before the start of laser exposure in Figures 9 and 10 between solid print images and line is thought to be based on this difference in penetration behavior.

Discussion

The results shown in Figure 9 suggest that penetration time of ink is shorter for IJ paper than for plain paper, and this was confirmed by measurement of penetration time shown in Figure 13.

In addition, High concentration in the outermost surface was achieved for IJ paper within 20 msec interval of time between the jetting and the exposure, whereas the values that are closest to this are 20 to 50 msec on the faster side of the variations in penetration speed for IJ paper in Figure 13. The optimum interval of time for plain paper ranges from 40 to 60 msec. The closest to this is around 70 msec on the faster side of the variation of penetration time for normal paper as shown in Figure 13. Thus, fast penetration seems to be important for image quality rather than average penetration.

In order to increase of the optical density with plain paper, it seems to be preferable to increase exposure time long enough to dry the ink up on the paper surface. The time of laser exposure was fixed at 20 msec in the experiment shown in Figure 9. The fact that ink was remaining on the paper surface implies that there was water remaining due to a lack of drying energy and it is inferred from this that penetration had continued even after the end of laser exposure. As a result, colorant penetrated to the inside of the paper, lowering the concentration of outermost surface.

Conclusion and Future Works

Laser exposure has the characteristic which makes it possible that ink is dried in high energy density and is only heated directly, enabling to dry ink in a short period of time, which in turn, helps to prevent the paper deformation and the occurrence of creases.

Furthermore, with laser exposure, time required for drying is similar to that of ink penetration. Accordingly, it is confirmed that laser exposure had large effects on the improvement in optical density, feathering, and show-through associated with penetration of water, which were fundamental problems with conventional water-based inkjets.

In the future, approaches will be made toward issues such as cost reduction, ensuring laser safety, and sensitivity of IR in color inks for laser drying devices.

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Manabu Numata received B.E. and M.E. degrees in imaging science and engineering from Chiba University in 2000 and 2002. He joined Fuji Xerox co., Ltd. in 2002 and has engaged in inkjet R & D group. He has been working on research and development of novel image processing and printing behavior optimization.