Microporous Paper for Use in Toner-Based Marking

Shuichi Maeda, Yasuhiro Oba, Toru Nakai, Makoto Shinozaki, Akira Nakamura, and Masaru Kato
Oji Paper Company, Tokyo, Japan

Keiji Ohara
Oji Scientific Instruments Inc., Hyogo, Japan

Chizuru Koga, Ryosuke Nakanishi, Kiyoshi Hosoi, and Hiroyoshi Hosomura
Fuji Xerox Co., Ltd., Kanagawa, Japan

We have developed a paper sheet that has a microporous surface layer that meets the demands for matte-type printing in toner-based marking. The microporous layer reduces the differential gloss (the difference between the maximum and minimum gloss) of the printed sheet. The toner particles which are transferred on to the surface of the sheet are easily embedded into the microporous layer during the fixing process by heat and pressure; and the microporous layer maintains its porosity even during the printing process, thereby reducing the gloss. The low differential gloss makes the printed images easier for observers to look at. In comparison, in the case of plain and pigment-coated paper, the areas that are covered with fused toner become smoother than the non-printed areas and hence the differential gloss is greater. We also show that the other print qualities of our microporous paper, in terms of line quality and uniformity, are higher than those observed for plain and pigment-coated paper. Thus, the microporous paper is better suited to matte-type printing in toner-based marking.

Journal of Imaging Science and Technology 46: 165–170 (2002)

Introduction

There has been increasing demand for higher print quality in digital printing. Therefore it is necessary to develop more advanced printing systems and appropriate paper. Several groups have scrutinized porous paper as candidates to fulfill this demand. Imoto and co-workers[1] have reported that an intermediate porous layer enhances the sensitivity of the receiving sheet in thermal dye diffusion transfer printing due to its heat insulating nature and elastic property. Both Yamada and co-workers[2] and Tanaka and co-workers[3] have described a thermal wax transfer system which utilizes a large number of fine pores distributed on the surface of the ink receiving sheet. In this system, the molten ink permeates into the porous surface layer due to the large number of capillaries; the ink receiving layer, which contains fine pores, is prepared via an indirect method as follows. First of all, a resin-coated layer containing a water-soluble component is formed; then the water-soluble component is extracted and, in so doing, voids are created.[4]

However, from an industrial point of view, a direct method is clearly preferable. In our own research program, in order to make microporous paper, we have discovered a direct and easy method: a sheet substrate is coated with a mixture containing fine air bubbles. We believe our microporous paper sheet prepared in this way can be used in a wide range of applications in digital printing. This is because the microporous layer acts as an ink receiving layer, a heat insulating layer and a cushioning layer, due to its high affinity to ink, low thermal conductivity and high compressibility, respectively. In our previous work, we have focused on thermal wax transfer printing because this requires all three characteristics described above.

Recently we have discovered a fourth and more interesting characteristic of our microporous paper, namely its optical properties. In this present work we focus on these optical properties of our paper, namely gloss and differential gloss. We also describe the quantitative measurements of its print quality in toner-based marking, with particular emphasis on the line quality and mottle.

Experimental

Preparation of the Microporous Paper

Preparation of a typical microporous paper sheet was undertaken as follows. A mixture of air and a coating liquid (solid content of 31%, viscosity of ca. 2000–3000 mPa.sec) having the composition given in Table I, was stirred in a closed system. The mixing volume ratio of air/liquid was 0.6/1.0; the mixture was stirred at a constant rate of 800 rpm, using a continuous whipping machine. A schematic diagram of a continuous whipping machine is shown in Fig. 1. In this method, air and

Original manuscript received June 5, 2000

Supplemental Materials—Figures 2 and 4 can be found in color on the IS&T website (www.imaging.org) for a period of no less than 2 years from the date of publication.

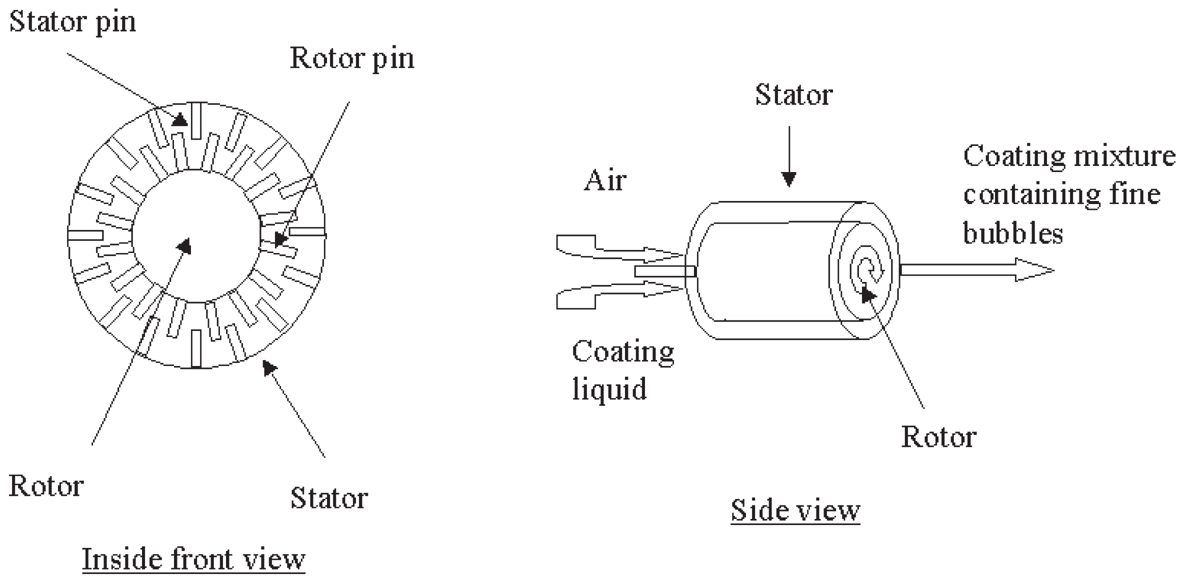

Figure 1. Schematic diagram showing a typical continuous whipping machine.

TABLE I. Composition of the Coating Liquid

Component	Part by solid weight
Aqueous resin: Polyurethane	100
Foam stabilizer: Salt of long-chain fatty acids	4.0
Viscosity control agent: Cellulose derivative	2.0

coating liquid were continuously fed into the closed system at a rate of 0.17 kg/min. A large number of fine and dispersed air bubbles were observed in the resulting mixture.

Immediately after the bubbling treatment was completed, an approximate 'equivalent circle' number average and maximum bubble size were determined for the coating mixture by counting more than 10,000 bubbles on several optical micrographs using a Dot Analyzer-5000S digital image analyzer (DA-5000S), manufactured by Oji Scientific Instruments Inc. (OSI).

One surface of a plain paper sheet having a weight of 127.9 g/m^2, a Bekk smoothness of 80 sec. and a gloss of 7 pt., was coated with the fine bubble-containing mixture using an applicator bar. The coating was then dried at a temperature of 100°C for 5 min. and its dry weight was 10 g/m^2. (Sample ID. MP5). The same procedure was carried out to prepare other samples, except that the mixing volume ratio and stirring speed of the continuous whipping machine were changed as stated in Table II (Sample ID: MP1-4, 6 and 7).

Both plain paper (J paper, sold by Fuji Xerox Co., Ltd.) and pigment-coated paper (JD paper, sold by Fuji Xerox Co., Ltd.) were used for comparing the print quality of the microporous paper (MP).

Characterization of the Microporous Layers and the Microporous Paper

The microporous layers have been characterized in terms of their morphology, density and pore size. Scanning electron microscopy (SEM) studies were made using a JEOL JSM-5800LV instrument at an operating voltage of 10 kV. The densities of the microporous layers were calculated from the thickness and weight data of the corresponding microporous paper sheets (MP1-7) and the substrate paper sheet by simple subtraction. An approximate 'equivalent circle' number average and maximum pore size were determined for the microporous surface layers by counting more than 10,000 pores on several optical micrographs using the DA-5000S analyzer.

Print Quality of the Microporous Paper

The plain paper (PP), the coated paper (CP) and the microporous paper (MP) were evaluated for use in toner-based marking in terms of their optical properties, line quality and mottle. Several test targets designed by Quality Engineering Associates Inc. (QEA) and/or OSI were printed on these sheets using a DC 1250 printer manufactured by Fuji Xerox Co., Ltd. and/or a LP-8000C laser color printer manufactured by EPSON Co., Ltd. These test targets consist of basic image elements such as dots, lines and solid areas, specially designed for print quality measurement.

The gloss at 75° of these paper sheets was measured using a gloss meter manufactured by Murakami Shikisai Co., Ltd. The DA-5000S was used to quantify the line quality of PP, CP and MP5 in terms of blurriness and raggedness with the ISO-13660 draft standard. The mottle of PP, CP and MP5 was measured using the method developed by Quality Engineering Associates (QEA)[5] with the DA-5000S.

Results and Discussion

Characterization of the Coating Mixtures and the Microporous Layers

Our experimental data on the coating mixtures and the microporous layers including the non-bubbled polyurethane resin coated (PUC) are presented in Tables II and III, respectively. The key technology in obtaining a successful microporous paper sheet is in controlling the pore size distribution in the microporous layer. In other words, regulating the bubble size distribution in the coating mixture is critical because there is a clear correlation between the size distribution of the bubbles and the pores, as shown in Tables II and III.

TABLE II. Experimental Data on the Coating Mixture

Coating mixture	Stirring speed of whipping machine(rpm)	Air/Liquid volume ratio	Bubble size (µm) Average diameter	Maximum diameter
MP1	1200	3.0/1.0	4.4	9.7
MP2	1200	2.0/1.0	5.3	13.8
MP3	800	2.0/1.0	7.7	18.1
MP4	1200	0.6/1.0	10.1	22.1
MP5	800	0.6/1.0	12.3	25.1
MP6	600	0.6/1.0	15.5	29.9
MP7	400	0.6/1.0	18.8	35.4

TABLE III. Experimental Data on the Microporous Layers and the Polyurethane Resin Coated Layer

Microporous layer	Density (g/cm^3)	Pore size (µm) Number average	Maximum diameter	Gloss (pt.) Minimum	Maximum	Differential
MP1	0.15	4.7	11.4	22	55	33
MP2	0.21	5.5	14.8	18	45	27
MP3	0.22	7.9	19.2	15	33	18
MP4	0.45	10.4	23.0	5	16	11
MP5	0.46	12.8	27.0	5	15	10
MP6	0.45	16.4	30.3	3	13	10
MP7	0.48	20.1	38.7	4	14	10
PUC*	1.00	—	—	60	85	25

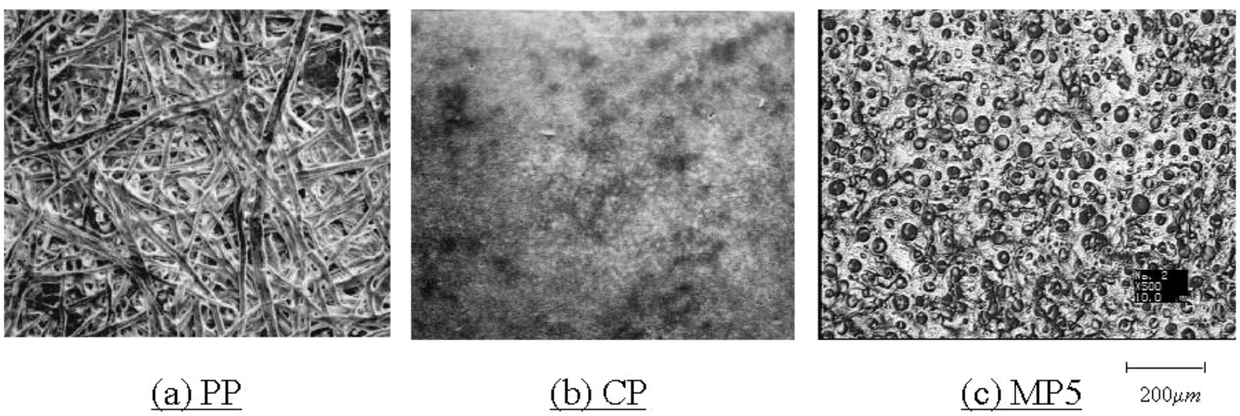

Figure 2. Scanning electron micrographs showing the non-printed surfaces of PP, CP and MP5. *Supplemental Materials can be found in color on the IS&T website (www.imaging.org) for a period of no less than 2 years from the date of publication.*

The bubble size in the coating mixture is clearly influenced by the stirring speed of the whipping machine and the mixing ratio of air with coating liquid, with rather smaller bubbles being obtained at higher stirring speeds and increased air volume. We have already reported in detail, the effect of these factors on controlling the bubble size distribution elsewhere.[6,7]

Optical Properties of the Microporous Paper Sheets

Gloss. Over the years, we have investigated matte-type paper for use in toner-based marking. In general, plain paper has lower gloss relative to coated paper due to the rough surface of the former, as shown in Fig. 2(a); this leads to light scattering. On the other hand, coated paper has a smooth surface, as shown in Fig. 2(b); this leads to light reflection. Therefore, it might seem as if plain paper could be used as matte-type paper. As a matter of fact, the plain paper (PP) has lower gloss than the coated paper (CP) on non-printed areas, which in most cases exhibit the minimum gloss as shown in Table IV.

TABLE IV. Minimum, Maximum and Differential Gloss of PP, CP and MP5

Paper sheets	Gloss (pt.) Minimum	Maximum	Differential
PP	7	47	40
CP	35	83	48
MP5	5	15	10

Moving our attention to the microporous paper, the minimum gloss of the microporous paper (MP5) was as low as that of PP. This is perhaps surprising as MP5 also has a coated surface layer. However MP5 has a porous surface, as shown in Fig. 2(c), which acts as a kind of rough surface and reduces the gloss.

Differential Gloss. Figure 3 shows how the gloss changes as the solid fill area covered with fused toner increases. As the area increases, the gloss of both PP and CP increases up to a certain point, while the gloss of MP5 does not change very much.

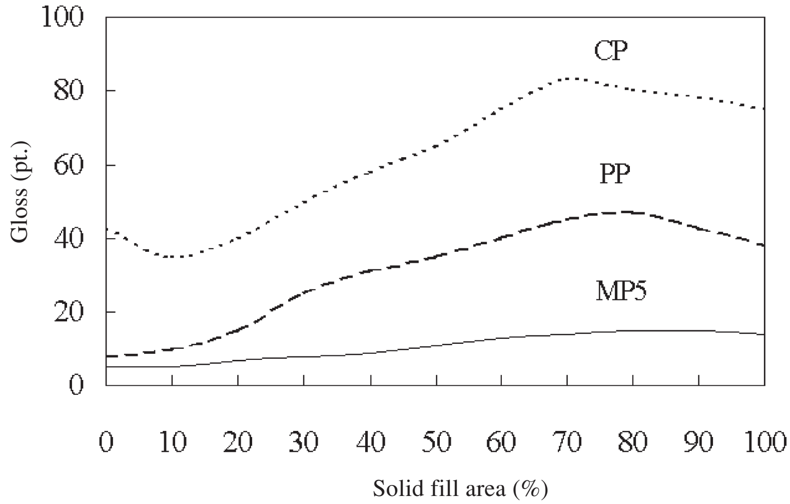

Figure 3. Gloss of PP, CP and MP5 as a function of solid fill area.

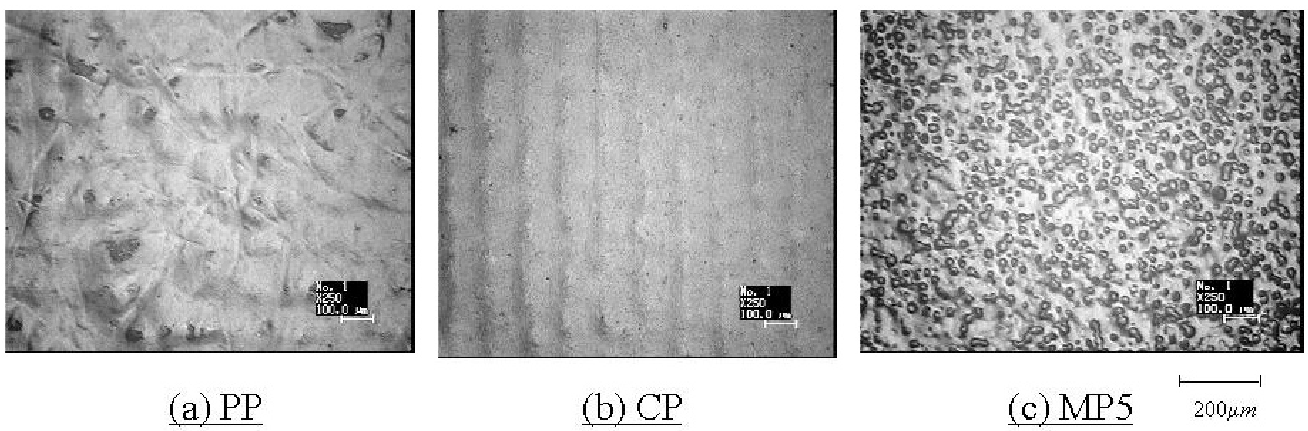

Figure 4. Scanning electron micrographs showing the surfaces of PP, CP and MP5 at solid fill area of 80% with the fused toner. *Supplemental Materials can be found in color on the IS&T website (www.imaging.org) for a period of no less than 2 years from the date of publication.*

We found that the problem with using plain paper as a matte-type paper is its relatively high maximum gloss at high solid fill areas and its high differential gloss, which is defined as the difference between the maximum and minimum gloss. These data are reported in Table IV.

Our scanning electron microscopy studies, undertaken after printing, show that the fibers of PP are completely covered with fused toner, while MP5 maintains its porous surface structure (see Fig. 4). The areas of PP covered with fused toner become smoother than the non-printed areas and hence the differential gloss becomes larger. On the other hand, MP5 retains its low gloss even after printing and exhibits a lower differential gloss relative to PP and CP. This is presumably because the transferred toner particles on the surface of MP5 are embedded into the pores.

The low differential gloss of the microporous paper makes printed images easier for observers to look at. For the reasons above, it can be said that our microporous paper is the most appropriate for matte-type images.

Differential Gloss as a Function of Pore Size

As mentioned above, the pores on the surface of our microporous paper (MP) play an important role in achieving the low gloss and differential gloss. We assumed that the pore size distribution on the surface of MP affects the differential gloss.

Figure 5 illustrates the differential gloss of MP as a function of the average diameter of the pores. We found that the differential gloss of the MP is, in fact, closely related to pore size, with low and constant differential gloss being obtained from large pores. Up to the average diameter of ca. 10 μm, as the pore diameter increases, differential gloss decreases.

Considering that the average diameter of the toner particles which we used was ca. 7 μm, a pore of diameter 7 μm or larger has a toner embedding quality. Presumably the microporous layers with large pores whose average diameter is larger than 10 μm (MP4-7) have sufficient toner-embedding capacity. Whereas, in the case of the microporous layers having smaller pores (MP1-3), the proportion of pores whose diameter is 7 μm or above may affect the differential gloss of the cor-

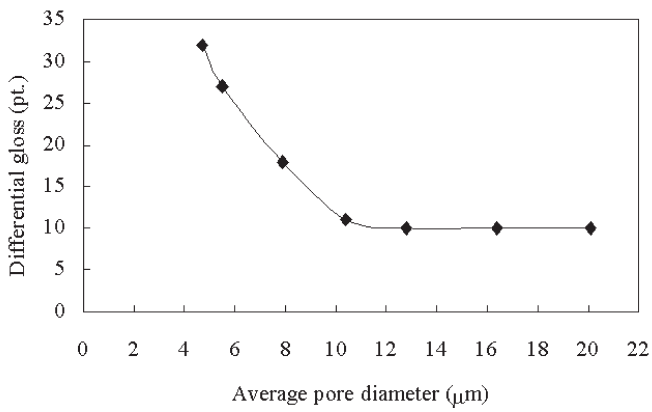

Figure 5. Differential gloss of MP as a function of the average pore diameter.

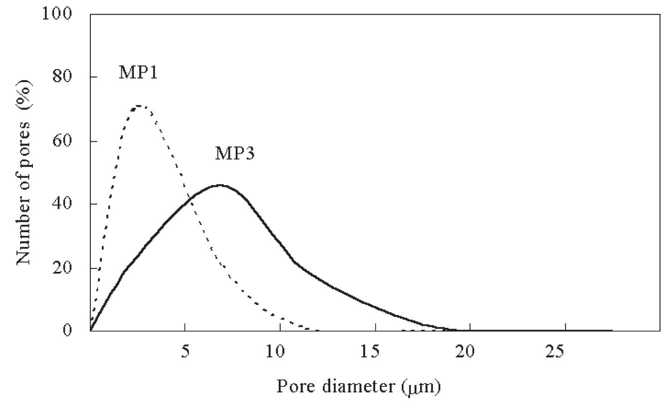

Figure 6. Pore size distribution of MP1 and MP3 as determined by DA-5000S.

responding microporous paper. As shown in Fig. 6, we find that the pore size distribution curve of MP1 is narrow and the proportion of pores of 7 μm and above is 15%. On the other hand, MP3 exhibits a broad distribution and the corresponding proportion is 50%.

We also note that the difference in gloss of the non-toner covered area before and after printing is lower relative to the differential gloss, although not considered in detail here. Therefore, the relatively high differential gloss of MP1, MP2 and MP3 is not an effect of microporous layer compression during printing.

Although not dealt with in this paper, defects in the microporous paper become apparent if the pore size is too large, for example where the average diameter is greater than 15 μm.[8] We conclude that it is preferable to restrict the average diameter of the pores to the range 10 to 15 μm in order achieve a satisfactory balance between the differential gloss and the appearance of defects.

Line Quality. According to the definition described in the ISO-13660 draft standard, blurriness means hazy or indistinct in outline; a noticeable transition of blackness from background to character. It is reported as distance in micrometers. The lower the blurriness, the better the line quality. The blurriness of MP5 is acceptably low relative to those of PP and CP as shown in Table V.

The definition of raggedness is also given in the ISO-13660 draft standard. Raggedness is the geometric distortion of an edge from its ideal position. It is measured as the standard deviation of the residuals from a line fitted to the edge threshold. A ragged edge appears rough or wavy rather than smooth or straight. Therefore, the lower the raggedness, the better the line quality. The raggedness of MP5 is lower than that of PP and CP as shown in Table V.

Mottle. Mottle shows the uniformity of the printed area of the samples. Here we followed the QEA method,[5] which is an improvement on the ISO-13660 draft standard. With this method, the region of interest is divided into smaller regions called tiles. Then the mottle can be calculated as the standard deviation of the average gray scale within each tile. The tile size is variable here. When interpreting mottle data, larger values indicate more non-uniformity and smaller values indicate uniformity. Figure 7 shows mottle measurements as a function of tile size. It is clear that the mottle of MP5 is lower than that of PP and CP, particularly at smaller tile size.

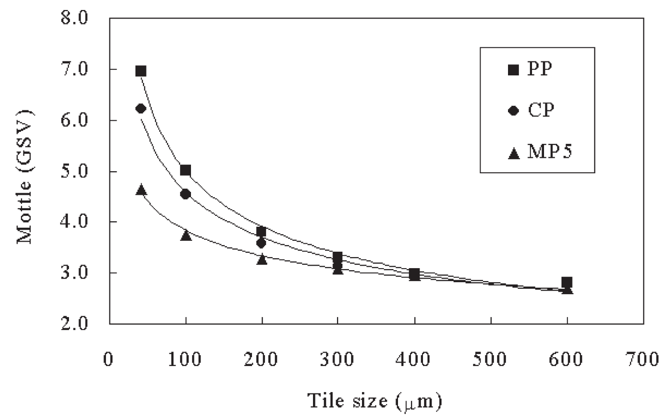

Figure 7. Mottle measurement as a function of tile sizes for PP, CP and MP5.

TABLE V. Line Qualities of PP, CP and MP5

Paper sheets	Blurriness (μm) Lead	Blurriness (μm) Trail	Raggedness (μm) Lead	Raggedness (μm) Trail
PP	11.0	13.3	9.2	9.7
CP	13.5	16.9	8.9	9.5
MP5	10.5	11.5	7.4	8.5

We found that the microporous layer improves the print qualities in toner-based marking in terms of line quality and mottle. This is presumably because the microporous layer prevents excess fused toner from spreading out on to the surface; excess toner is instead embedded into its pores.

Conclusions

Our microporous paper exhibits excellent characteristics required of matte-type paper for toner-based marking. Some of our samples (MP4-MP7) have lower gloss and lower differential gloss than plain and coated papers. The other print characteristics of MP5, such as line quality and uniformity, are higher than those of PP and CP. Therefore, there is no doubt that

MP can improve print quality in matte-type, toner-based marking.

Acknowledgment. We thank Quality Engineering Associates Inc. for their assistance with the print quality measurements.

References

1. K. Imoto, S. Narita and Y. Kamikubo, *Proc. of IS&T's 12th International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1996, p. 248.
2. K. Yamada, M. Takahashi and M. Katoh, *Proc. of IS&T's 12th International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1996, p. 250.
3. H. Tanaka and Y. Hakamada, US Patent 5,521,626 (1996).
4. K. Kazui and K. Fukuda, Japanese Patent 2,684,559 (1997).
5. N. Jones, S. J. Sargeant, K. Sargeant, J. C. Briggs, and M.-K. Tse, *Proc. of IS&T's 12th International Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 1998, p. 161.
6. S. Maeda, T. Nakai, A. Nakamura, M. Hakomori and M. Kato, *J. Imaging Sci. Technol.* **44,** 410 (2000)
7. S. Maeda, J. Jpn. Soc. Colour Mater. (SHIKIZAI) **74,** 118 (2001)
8. S. Maeda, M. Hakomori, T. Nakai, A. Nakamura, and M. Kato, *Jpn. Tappi J.* (KAMIPAGIKYOSHI) **55,** 1750 (2001).