Abrasion Resistance of Aqueous Pigmented Inkjet Inks on Coated Paper

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Abstract

High-speed water-based inkjet printing has recently made inroads into traditional commercial printing because of its reasonable cost and environmental friendliness. In the commercial printing fields dealing with magazines, fliers, and brochures, low penetrative gloss coated paper is generally used. When inkjet droplets are impacted on that type of paper, their liquid components evaporate and penetrate into the paper very slowly, while solid components, such as pigment and polymer, are filtered and form an ink layer on the paper. Since impacted droplets dry slowly and the formed ink layer is directly exposed to external forces, abrasion resistance of inks on coated paper is a serious problem in comparison with that on porous plain paper. In this study, the mechanism of abrasion resistance of pigmented inkjet inks on coated paper was investigated in terms of surface friction, strength of ink layer and adhesion to substrate. The result indicated that the strength of ink layer was the major factor, and we could impressively improve abrasion resistance performance by controlling that factor from a rheological view point

Introduction

Offset printing has been used in commercial printing market which requires enormous volume prints because of its high productivity, low cost and high print performances. More recently, digital printing has begun to be used for just-in-time printing, web-to-print and variable printing with the changing of customer's demand in the commercial printing market. Digital printing mainly means electrophotography (EP) and inkjet (IJ) printing. The former has been adopted for photobooks, self-published books and direct mails, while the latter, especially high speed IJ, is beginning to be used for transactions, books, magazines, fliers, and brochures, and has an advantage of cost over EP because of its simplicity of design. Since water based IJ inks produce no VOCs and are non-toxic, non-flammable, and non-combustible, remarkable improvements of print speed, quality and reliability in recent years have been accelerating IJ technology to make inroads into the commercial printing market.

Print performance of IJ printing is determined by printers, inks and substrates. Since water based IJ inks are required to have enough capacity of pigment dispersion, print quality (OD, gloss and durability etc.) and jetting stability at the same time, the quantity and kinds of pigments, polymers and co-solvents that are contained in IJ inks are extremely limited and the limit gives IJ inks much harder problems of drying time and print durability than offset or EP printing [1, 2]. In the consumer market, these problems have been solved by using dedicated IJ substrates which can improve print quality and drying speed dramatically by having absorption and imaging layer on base paper. On the other hand in the commercial market, it is not impossible to use dedicated IJ substrates from the aspect of cost and IJ technology is required to be available for low-penetrative commercially used coated paper and non-penetrative plastic films in terms of printer and ink to be suitable for the market. Although it is proposed to mount drying equipment into a printer, it is more desirable to use no drier or a low temperature drier, considering increase of environmental awareness and problems of CO2 emission.

In this study we investigated the performance and the mechanism of abrasion resistance, especially after drying, of aqueous pigmented inkjet inks on commercially-used coated paper, and we attempt to develop high abrasion resistance IJ inks without any heating procedures.

Experimental

Preparation of encapsulated pigment dispersion

To make encapsulated pigment dispersion, we adopted acrylic polymer for water-insoluble polymers. First of all, 20g of the neutralized polymer and 80g of Pigment Violet 19 (or Pigment Yellow 74 or Pigment Blue 15:3 or Pigment Black 7) were mixed with 100g of MEK and 400g of ion exchanged water. The mixture was dispersed with a homogenizer. The dispersion was concentrated with an evaporator by removing MEK and some water, and centrifuged to remove the large size particles. The content of the dispersion was adjusted to 20wt% by adding ion exchanged water.

Ink preparation and printing

Inks for this study were made from 30% of pigment dispersion, 10% of triethyleneglycolmonobutylether, 1% of acetyrenol E100 (Kawaken Fine Chemicals Co.,Ltd.), 1% of various organic agents (such as alcohol or ether) which can change ink property, approximately 20% of glycerin which can control ink viscosity and the rest of water. All inks were filtered with a membrane filter (1.2 µm) just before the experiments.

A print test was made with a Ricoh ink jet printer (GX-5000). Xerox 4200 (Xerox), PM photo paper (Epson) and OK topcoat+ (Oji paper) were used as plain paper, coated IJ paper and coated paper respectively.

EP prints were made by DocuCentre Color f450 (Fuji Xerox) and commercially available brochures were used as offset prints.

Measurement

For abrasion resistance test, we printed a 20cm by 26cm patch of the primary colors (Y, M, C, Bk) at 100% tints on each kind of A4-size paper and cut them into 3 strip specimens. Each specimens was set on the AB-201 Sutherland ink lab tester (Tester Industrial) equipped with 1.8kgf weight and test was carried out for a total of 100 cycles (43 cycles/min). BEMCOT M-3 (Asahikasei) was used as abrasive. The degree of pigment detachment from the paper was evaluated by visual observation on a scale of 0.1 to 5.0. The score of 5.0 corresponds to the state that any pigments on the paper are not removed, and that of 0.1 corresponds to the state that all of the pigments on the paper are removed.

SEM images of each paper surfaces were taken by using S4000 FE-SEM (Hitachi). Photographs of cross sections of prints were taken by using VK-8510 microscope (Keyence) and cross section samples were made by using EM UC-7 ultramicrotome (Leica).

Surface friction of prints was measured by using TENSILON RTC-1150A (Orientec) based on JIS P8147. AFM measurement was done by using VN-8000 Nanoscale Hybrid microscope (Keyence).

Results and Discussion

Figure 1 shows the comparison of abrasion resistance performance (after drying) of IJ(magenta) prints made by using different kinds of paper and coated paper shows the worst performance in them (Magenta was chosen because it was the worst in Y, M, C, and Bk, as described later).

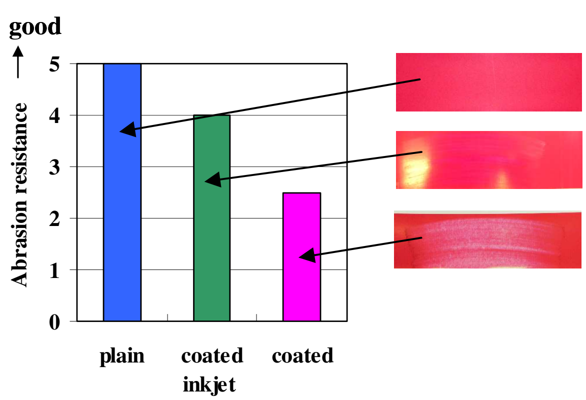

Figure 1. Comparison of abrasion resistance performance of offset, EP, IJ-M ink on plain paper, coated IJ paper and coated paper.

Figure 2 shows surface images of those three kinds of paper (plain paper, coated IJ paper and coated paper) taken by using SEM technique. Plain paper has enough porosity for pigments to penetrate into the gap of paper fibers. On the other hand, the surfaces of coated IJ paper and coated paper are covered with porous silica and tubular shaped filler respectively, and pigments are filtered on the paper as shown in Figure 3. Since ink layer of coated IJ paper and coated paper are directly exposed to external forces, abrasion resistance on these papers is a more serious problem than on porous plain paper. Moreover, it is noted that the absorption layer of coated IJ paper improves abrasion resistance performance after drying compared with coated paper.

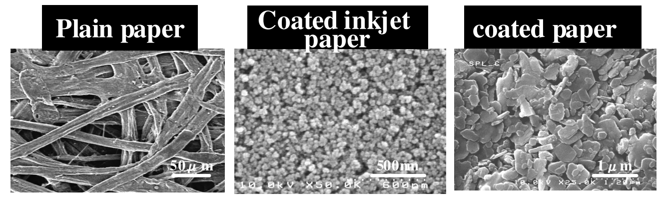

Figure 2. SEM images of various paper surfaces (unprinted).

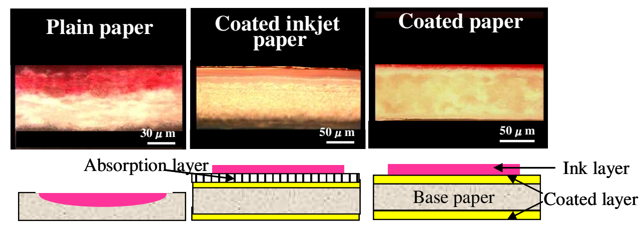

Figure 3. Photos of cross section of several kinds of paper that are printed with IJ-M

Figure 4 shows the comparison of abrasion resistance performance of offset, EP and IJ (Y, M, C and Bk) prints after drying (one numerical data is shown about offset and EP because they have little differences among 4 colors) and the performance of IJ prints are worse than those of offset and EP prints.

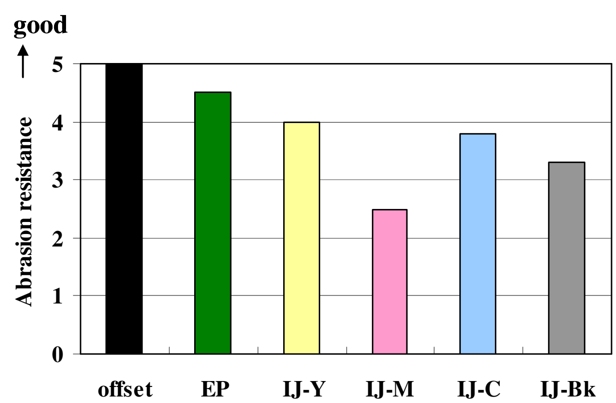

Figure 4. Comparison of abrasion resistance performances of offset, EP and IJ(Y, M, C, Bk) prints on coated paper.

Offset and EP prints are understood to be better than IJ prints because they can use a greater amount and variety of polymers and co-solvents which can improve abrasion resistance. It is noted that 4 IJ colors showed different performances in spite of containing the same components other than pigments. Then we investigated the mechanism of abrasion resistance of aqueous pigmented inkjet inks on coated paper in terms of surface friction, strength of ink layer and adhesion to substrate, and those factors are shown in Figure 5.

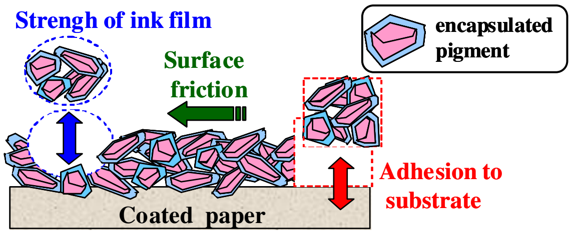

Figure 5. *Three factors that are considered to affect abrasion resistance performance.*

To clarify the mechanism of abrasion, we compared IJ-M print which is the worst with IJ-Y print which is the best of all IJ prints. Figure 6 shows moved distance vs. dynamic friction curves and surface 3D AFM images of IJ-M and IJ-Y prints. Although IJ-M shows higher dynamic friction than IJ-Y, there was little difference between both Ra (Arithmetic Mean Deviation of the Profile) values.

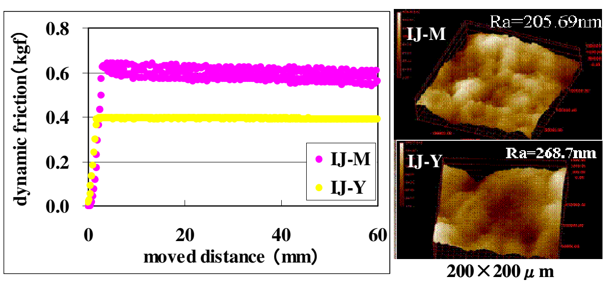

Figure 6. *Dynamic surface friction and surface 3D profiles of IJ-M and IJ-Y prints.*

Figure 7 shows dynamic friction of prints surfaces at each abrasion cycle and their corresponding SEM images.

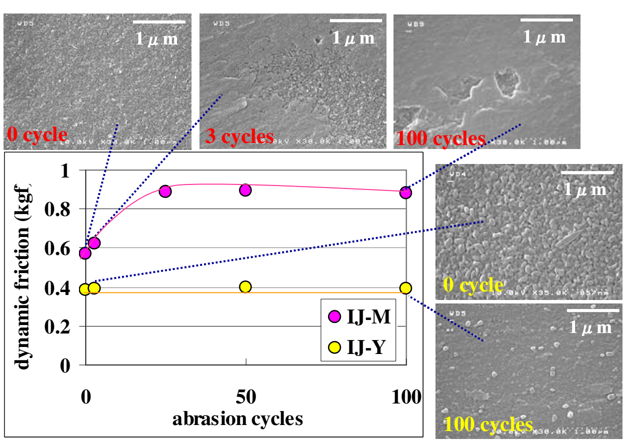

Figure 7. *Dynamic surface friction of IJ-M and IJ-Y prints at several abrasion cycles.*

The surface of IJ-M is smoothed and their surface friction increases as abraded times increase, while there are not major changes on surfaces of IJ-Y. Judging from the result that pigments on the IJ-M print gradually came off from the top as shown in SEM images of Figure 7, it is concluded that the major factor in abrasion resistance on coated paper is cohesive strength of ink layer, while adhesion to the substrate is a less important factor. The illustration of estimated abrasion mechanism is shown in Figure 8.

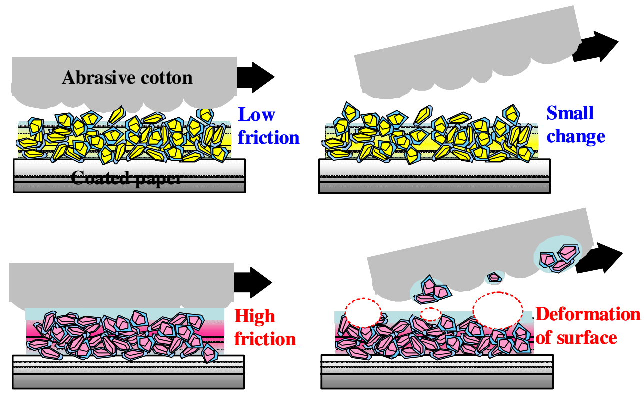

Figure 8. *Estimated abrasion mechanism of IJ-inks on coated paper (upper : IJ-Y shows good abrasion performance. under : IJ-M shows bad abrasion performance.).*

To make the ink layer stronger for abrasion resistance, strength of ink layer should be examined from a rheological view point as a pigment-polymer complex film. The major factors affecting it are proposed to be strength, glass transition temperature (of polymer), hardness, density, particle shape (of pigment), surface effect, void effect, critical pigment volume effect and pigment dispersibility (of pigment polymer complex) [3,4,5,6]. The reason why 4 colors of IJ prints showed different abrasion performances in spite of containing the same components except for pigments in Figure 4 is considered that these factors affected the strength of each ink film. In this study, we optimized these factors for encapsulated dispersions to make their ink layer stronger and the results of abrasion resistance performance are shown in Figure 9.

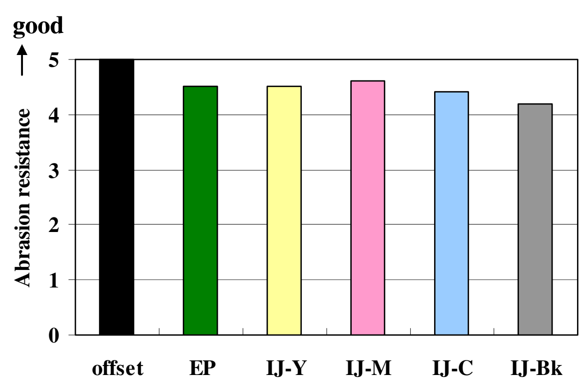

Figure 9. *Comparison of abrasion resistance performances of offset,EP and improved IJ(Y,M,C,Bk) prints.*

The results show that we could impressively improve abrasion resistance performance (after drying) of all colors of IJ inks on coated paper to the level comparable to EP. It is also noted that the improved encapsulated IJ inks don't need to contain any kinds of emulsion, although emulsions are commonly used to improve abrasion resistance of IJ ink.

Conclusions

The performance and mechanism of abrasion resistance of aqueous pigmented inkjet inks (after drying) on coated paper were investigated in terms of surface friction, strength of ink layer and adhesion to substrate. In the comparison of IJ ink on plain paper, coated IJ paper and coated paper, coated paper showed the worst performance because pigments are completely filtered on the paper and its ink layer is directly exposed to external forces. In the comparison of offset, EP and IJ (Y, M, C and Bk) prints using coated paper, the performance of IJ prints was worse than those of offset and EP, and 4 IJ colors showed different levels of performance.

The cohesive strength of the ink layer was found to be the major factor in the mechanism for abrasion resistance on coated paper, while adhesion of the ink layer to the substrate was found to be less important. The strength of the ink layer was considered to depend on surface friction properties. By controlling the strength of the ink layer from a rheological view point, we could impressively improve abrasion resistance performance of all colors of IJ inks to the level comparable to EP without adding any kinds of emulsion and any heating procedures.

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Author Biography

Tetsuya Eguchi received his B.S. and M.S. in physical chemistry from Kyushu University in 2006 and 2008 respectively. In 2008, he joined Kao Corporation and has been engaged in research and development of performance chemicals for inkjet printing.

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