Investigation into the Cause of Print Mottle in Halftone Dots of Coated Paper: Effect of Optical Dot Gain Non-uniformity

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ABSTRACT

One of the printing troubles on print quality is non-uniformity of printing density called print mottle. The causes of print mottle are various. As far as paper, it has been thought that surface roughness of paper, absorption of ink and fountain solution cause non-uniformity of ink transfer. As the results of evaluation on commercial coated paper, print mottle did not occur in solid area and non-uniformity of ink transfer also did not arise. But print mottle occurred in halftone dots, and it was thought another factor except ink transfer affect print mottle in halftone dots. This was confirmed because print mottle was also observed in halftone dots which shape and density were quite even on the paper (chemical proof). The purpose of this research is to clarify the cause affecting print mottle in halftone dots.

It is known that apparent dot gain (optical dot gain) arises in halftone dots due to lateral light scattering of printing medium, and optical dot gain affects printing density. We set up a hypothesis that non-uniformity of optical dot gain causes print mottle in halftone dots. Therefore, we investigated the non-uniformity of lateral light scattering of paper that was thought to bring about the non-uniformity of optical dot gain.

In the past researches to measure the lateral light scattering, ruled-lines were formed on the paper, the modulation arisen in amplitude of microdensity profile of ruled-lines due to light scattering, and light intensity distribution against distance was calculated from the modulation. We measured the modulation using printed ruled-lines on paper. Non-uniformity of light scattering was found, and it was thought that this was caused by coating amount variation and so on from microscopic observation. From these results, non-uniformity of optical dot gain was thought to be one of the important factors affecting print mottle in halftone dots.

INTRODUCTION

Non-uniformity of printing density called print mottle is one of the printing troubles concerning print quality. The causes of print mottle are various, for example printing pressure, printing speed and so on as printing conditions, rubber blanket, ink etc. as printing materials. As far as paper, the effects of surface roughness of paper, absorption of ink and fountain solution were reported, it has been thought that non-uniformity of ink transfer is the main cause of print mottle. As results of printing evaluation on commercial coated paper, print mottle did not observed in solid area and non-uniformity of ink transfer also did not occur. On the other hand, print mottle arose in halftone dots, and there was difference between samples. This was thought that another factor different from ink transfer affected print mottle in halftone dots. This was confirmed due to the result that print mottle was also occurred in halftone dots which both shape and density were extremely even on paper (chemical proof). The purpose of this research was to clarify the cause of print mottle in halftone dots.

In halftone dots, “Dot Gain” is known as a phenomenon that influences on printing density, and is classified into optical dot gain and mechanical dot gain. “Optical Dot Gain” is an apparent phenomenon and is different from ink transfer. In the past researches, it was reported that the mean value of optical dot gain was discussed up to the present, and optical dot gain was affected by lateral light scattering of printing medium. We we build up
a hypothesis that print mottle in halftone dots was derived from non-uniformity of optical dot gain. Therefore we investigated into the non-uniformity of lateral light scattering.

In the past researches to measure the lateral light scattering, ruled-lines were formed on the paper, the light intensity distribution against distance was calculated from the modulation arisen in amplitude of microdensity profile of ruled-lines due to light scattering$^{2,5}$. We applied this method using printed ruled-lines on paper.

As the finding of this research, we concluded that non-uniformity of optical dot gain was thought to be one of the important factors affecting print mottle in halftone dots. We report the results in this paper.

**EXPERIMENTAL**

**Paper**

Paper samples tested were commercial coated paper of A2 gloss grade which base paper was wood-free paper, total coat weight of both sides was about 20 g/m$^2$. Gloss of white paper was approximately over 70% at 75 degree, and each 13 kinds of papers which basis weight was 84.9 and 127.9 g/m$^2$ respectively, made by Japanese paper making manufactures and mills were examined.

**Printing**

Printing was done with a commercial four-color sheet-fed offset press (ROLAND 304, MAN Roland). A typical ink for sheet-fed offset press (Hy-Ecoo, Toyo Ink Mfg. Co., Ltd.) was used in this study. The test pattern contained both solid area and halftone dots (tone value 50%).

**Chemical Proof**

Chemical proof is one of the offpress proofs which are used to check a character, color reproduction, layout and etc. before running-on. Chemical proof is made of photosensitive materials like diazo compound and photopolymer. Image of these photosensitive materials are formed by light exposure and chemical development, then it is transferred onto paper. As one of the characteristics of chemical proof, shape and printing density of each halftone dots are extremely uniform compared with printed dots by press.

**THEORY**

**Optical Dot Gain**

Dot gain is a phenomenon that dots size of printed matter by press is larger compared with that of press plate. The larger the dot gain is, the higher the printing density is. The dot gain is classified into optical dot gain and mechanical dot gain due to the mechanism. Optical dot gain is an apparent phenomenon derived from the light which passes through halftone dots, then scatters laterally under the dots within paper, and subsequently emerges back from non-image part at periphery of the dots as shown in Figure 1. The larger lateral light scattering within paper is, the larger optical dot gain amount becomes. Mechanical dot gain arises from actual spreading of ink, in case excess pressure between blanket and press plate, excessive amount of ink used and so on.

![Fig. 1. Light path at periphery of halftone dot](image-url)
RESULTS AND DISCUSSION

Print mottle of commercial coated paper was evaluated by visual ranking method. The print mottle in solid area of each sample did not occur, and non-uniformity of ink transfer which had been thought to be the main cause also did not arise. Nevertheless, the print mottle was observed in halftone dots (50% tone value) as shown in Figure 2. This was considered that another factor which was different from ink transfer affected.

Printed samples of halftone dots were classified into 5 ranks, and named rank A-E from good to bad as results of perceptive evaluation by several testees. To investigate the relationship between ink transfer in halftone dots and the print mottle, approximate quantification of ink transfer was conducted. We thought that non-uniformity of ink transfer was approximately expressed by difference of tone values of dark part and light part of the print mottle, and calculated the tone values by means of binary treatment on microscopic image in halftone dots. The characteristic results were shown in Table 1. The tone value difference of sample Rank D was smaller than those of Rank A and Rank E, it result was thought to support the idea that another factor different from ink transfer affect the print mottle in halftone dots.

![Poor](image1.png) ![Excellent](image2.png)

Fig. 2. Print mottle in halftone dots (50% tone value, 50×50mm)

<table>
<thead>
<tr>
<th>Visual ranking</th>
<th>Rank A (good)</th>
<th>Rank D (bad)</th>
<th>Rank E (bad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>light part</td>
<td>53.3</td>
<td>57.0</td>
<td>54.6</td>
</tr>
<tr>
<td>dark part</td>
<td>55.0</td>
<td>57.6</td>
<td>57.0</td>
</tr>
<tr>
<td>difference</td>
<td>1.7</td>
<td>0.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 1. Tone value at light and dark part of print mottle

To confirm this idea by precise method, we examined if the print mottle occurred in halftone dots that was free from non-uniformity of ink transfer. On the coated paper that the print mottle appeared, halftone dots of extreme uniform shape and density were reproduced by means of chemical proof as shown in Figure 3. As a result, the print mottle also arose as shown in Figure 4, and difference of print mottle level between samples was observed, though level of the print mottle was less than that of printed matter. It seemed reasonable to suppose that another factor except ink transfer existed.
In order to make clear the phenomenon happened in halftone dots, we investigated the difference between dark part and light part of the print mottle by microscopic observation respectively. In dark part, the contour of pulp fiber of base paper in the coating layer was observed, and it was seldom observed in light part as shown in Figure 5. This feature was commonly observed both in offset printed matter and chemical proof as shown in Figure 6.
In halftone dots, dot gain is known as a phenomenon affecting printing density, and it is classified into optical dot gain and mechanical dot gain. Optical dot gain is a phenomenon that dots gain apparently and is different from ink transfer. In the past researches, the mean value of optical dot gain were discussed, we paid attention to its uniformity, and set up a hypothesis that non-uniformity of optical dot gain caused the print mottle in halftone dots. Also it was reported that optical dot gain is influenced by the lateral light scattering of printing medium, key factor was though to be non-uniformity of lateral light scattering within paper, we presumed the relationship between covering state of base paper by coating color and the print mottle as follows.

In the bad covering state part by coating color, light that passed the dots and reached to pulp fibers of base paper, the propagated along the fibers and scattered further in-plane direction as shown in Figure 7. This led to large amount of optical dot gain and printing density was high. On the other hand, in the good covering state part, light passed the dots and reflected upward, and did not scatter widely in-plane direction. The amount of optical dot gain was small and the printing density was not so high.

To verify this hypothesis, we examined the difference of lateral light scattering due to covering state by coating color.
In the past researches to measure the lateral light scattering, ruled-lines were formed on paper, the light intensity distribution against distance was calculated from the modulation arisen in amplitude of microdensity profile due to light scattering. We applied this method. Ruled-lines were printed by press on coated paper, and microdensity profile was measured across the lines using microdensitometer. In case the distance between lines was enough wide like 5mm, the density between lines was the same as white paper in Figure 8. But in case the distance between lines was enough narrow like 50 µm, the density between lines was higher than white paper slightly as shown in Figure 9. It was though that the colored light which passed the lines emerged back between the lines due to the lateral light scattering and affected density (See Figure 1).
Lateral Light scattering of “uncoated paper” as a model of bad covering state with coating color and “coated paper” as that of good covering state were compared. The white papers of same density were selected to ease the comparison of each white paper. The density of non-image area between lines of uncoated paper was higher than that of coated paper as shown in Figure 9. This result was thought to show that lateral light scattering of bad covering state of base paper was higher than that of good covering state.

To examine the non-uniformity of lateral light scattering within the same paper, ruled-lines were printed on coated paper that the print mottle appeared in halftone dots, and microdensity profile was measured on its dark part and light part in the same way. Density at ruled lines of both parts were almost the same level, however density between lines of dark part was slightly higher than that of light part as shown in Figure 10. It was thought that this difference showed the existence of non-uniformity of lateral light scattering.

By microscopic observation on the dark part, pulp fibers were perceived near the surface in coating layer. On the other hand, fibers were not perceived in light part. The tendency was the same as the observation with print mottle in halftone dots. This difference of covering state of base paper was thought to bring about the non-uniformity of lateral light scattering.
CONCLUSION

Print mottle in solid area of commercial coated paper and non-uniformity of ink transfer did not occur, but print mottle appeared in halftone dots and it was thought that another factor excluding ink transfer related. This was confirmed because print mottle was also observed in halftone dots which shape and density were quite even on the paper (chemical proof). Therefore we investigated to clarify another factor affecting the print mottle in halftone dots.

We set up a hypothesis that the non-uniformity of optical dot gain was the cause of print mottle in halftone dots. Optical dot gain was known to be affected by lateral light scattering. We investigated the non-uniformity of lateral light scattering in paper as a cause of non-uniformity of optical dot gain.

According to the investigation of microdensity profile of printed ruled-lines, non-uniformity of lateral light scattering on paper surface was found. From these results, we concluded that non-uniformity of optical dot gain was one of the important main causes affecting print mottle in halftone dots, and this was thought to be affected by covering state of base paper by coating color. It is expected that further depression of print mottle by controlling both ink transfer and optical dot gain.

References
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Print mottle

- Print mottle;
  - Non-uniformity of printing density at solid area and halftone dots
  - Mainly occurs in coated paper of offset printing and deteriorates print quality

Causes of print mottle;

- Non-uniformity of fountain solution absorption
- Non-uniformity of ink absorption
- Paper surface roughness
  - Non-uniformity of ink transfer
  - Non-uniformity of printing density
Causes of non-uniformity of absorption

Base paper

- High basis weight of base paper
- Low basis weight of base paper
- Concave of base paper
- Large coating amount
- Much binder migration to the coating layer surface at drying process
- Less pore in coating layer surface
- Lowering absorption of ink and fountain solution during printing
Printing

Sample:
- Grade: commercial coated paper of A2 gloss grade
  (Japanese paper making manufactures and mills)
- Basis weight: 84.9g/m², 127.9g/m² 13kinds of paper respectively
- Base paper: wood free paper
- Total coat weight: about 20g/m²
- Gloss (75°): over 70%

Printing:
- Press: commercial four-color sheet-fed offset press (ROLAND 304, MAN Roland)
- Ink: typical ink for sheet-fed offset press (Hyecoo, Toyo Ink Mfg. Co., Ltd.)
- Test pattern:
Print mottle

Solid area

Visual evaluation: Excellent

Harftone dots

Visual evaluation: Poor

Visual evaluation: Excellent

(50 × 50mm)
Analysis of tone value

Evaluation method:
1) Microscopic image (monochrome) of halftone dots was captured
2) Binary treatment
3) Tone value (%) was calculated
4) Measurement was done at light and dark part of print mottle respectively
Print mottle and tone value (area)

Print mottle was not explained only by difference of tone value (area)
Print mottle and printing density of halftone dots

- It is hard to measure printing density of each halftone dots
- It is possible to reproduce uniform dots by chemical proof

**Chemical proof**

- One of the offpress proof
- Made of photosensitive materials

![Chemical proof process](image)

- **Exposure**
  - Film
  - Photosensitive material

- **Development**

- **Transferred onto paper**
  - Printed matter
  - Chemical proof

- **Paper**
Print mottle occurred even when shape and printing density of halftone dots were uniform.
Microscopic observation of print mottle

Printed matter

Chemical proof

Dark part

Light part

100 μm
Coat weight difference by burn-out treatment

White paper

Burn-out treated paper

Corresponding to dark part of print mottle

Corresponding to light part

100 μm
Mechanism of Optical Dot Gain

Light passes through halftone dots, scatters laterally within paper, then emerges back from periphery of the dots

Optical dot gain
(Apparent dot gain)
Non-uniformity of Optical Dot Gain

Non-uniformity of optical dot gain within paper due to coat weight variation was suggested to lead to print mottle at halftone dots.
Comparison of lateral light scattering

Microdensitometer

- Microdensity profile is measured
- Ruled lines are used to obtain stable result

Measured slit size
length, width
$1\mu m$ – $1mm$

Incident light

Ruled line

Photomultiplier tube

Slit

Paper
Microdensity profile-1

In case space width was enough large

5mm

Density of white paper
Microdensity profile-2

In case space width was enough narrow

Slit width 15µm  Space width 50µm  Line width 80µm

Density of white paper
Microdensity profile-3

Uncoated paper

Coated paper
Cause of density difference in space

- Printing density between ruled lines of uncoated paper is higher than that of coated paper
- Lateral light scattering of pulp fiber is larger than that of coating pigment

Lateral light scattering was suggested to be influenced by coverage state of coating color
Microdensity profile-5

The coated paper that print mottle occurred in halftone dots

Print mottle observed in ruled-lines

Dark part

Light part
Difference of dark and light part was observed at spaces
Conclusions

Print mottle in solid area of commercial coated paper and non-uniformity of ink transfer did not occur, but print mottle appeared in halftone dots and it was thought that another factor excluding ink transfer related.

This was confirmed because print mottle was also observed in halftone dots which shape and density were quite uniform (chemical proof).

By microdensity profile of printed ruled-lines, non-uniformity of lateral light scattering on paper surface was found, and suggested to lead to non-uniformity of optical dot gain.

We concluded that non-uniformity of optical dot gain was one of the important causes affecting print mottle in halftone dots, and optical dot gain was thought to be affected by covering state of base paper by coating color.