Estimation of the Fusing Quality Based on Simple Toner Deformation Model

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Abstract

For developing fusing system in electrophotography, estimation of fusing quality such as minimum fusing temperature and gloss becomes difficult in case that fusing conditions (pressure, temperature, dwell time) and toner property change. In this study, simple analytical model has developed based on toner deformation considering viscoelastic properties of temperature and frequency to investigate mechanism of fusing performance. Consequently, the index:ε, the quantity of toner viscoelastic deformation, well estimates the fusing qualities for various parameter set under the same paper roughness and same toner mass per area condition.

Introduction

This report concerns about the estimating method for fusing quality such as minimum fusing temperature (MFT) and image gloss in electorophotography.For developing the fusing system, estimation of fusing qualities is important for optimizing design parameters according to target print speed and paper types.

Fusing parameters which control fusing qualities are generally known as temperature, nip pressure and dwell time. These parameters are related to amount of toner deformation in the nip region. If a pressure profile and dwell time are fixed, gloss will be easily estimated by fusing temperature. However estimation becomes difficult in case that various combination of fusing parameters exists. Because fusing quality is determined by mutual complement of fusing parameters.

Other factors which contribute to the fusing quality are considered as pre-nip (transferred fluctuation of toner) and post-nip (stripping or cooling) region, paper roughness and toner viscoelastic property.

In present study, we focused on nip region and proposed new model for estimating fusing quality based on toner viscoelastic strain, where frequency property of toner viscoelasticity is considered. Consequently, we clarified that new model has quantitatively good agreement with the fusing quality for various fusing conditions. Moreover, we demonstrated that image structure of toner is almost same among same gloss samples with different fusing parameters by spatial frequency analysis.

Simulation Model

In the nip region, toner deforms by heat and pressure and fills in the gap between toners, which enhances the contact area between toners and a paper. This result in increase of bonding performance and image gloss.

Therefore there was a consideration based on viscous strain to express fusing performance.

Conventional viscous strain model is as follows;

$$\varepsilon_{vis} = \int_0^{t_{Dwell}} \frac{P(t)}{\eta(T(t))} dt \quad (1)$$

Here, t is time, $P(t)$ is nip pressure at time t, η $(T(t))$ is viscous coefficient at $T(t)$ and subscript 'Dwell' means dwell time .

New model is formulated by equation (2). Basic concept of new model is toner strain considering viscoelastic properties of temperature and frequency. Especially, we intended to express the effects of dwell time and pressure profile on frequency property of viscoelasticity.

$$\varepsilon_{ve} = \int_0^{t_{Dwell}} \frac{P(t)}{G^*(\omega, T(t))} dt \quad (2)$$

Here, G^* is complex viscoelastic modulus, ω is frequency determined by the dwell time and the rate of pressure change.

Figure 1 shows the simulation flow to calculate the index: ε_{ve} by equation (2). Here, A, B and C in Fig.1 represents fusing condition. A is fast speed and middle temperature, B is middle speed and middle temperature, C is slow speed and low temperature. Now index becomes large in case-B. Time change of toner temperature is previously calculated considering layer structure of the nip.

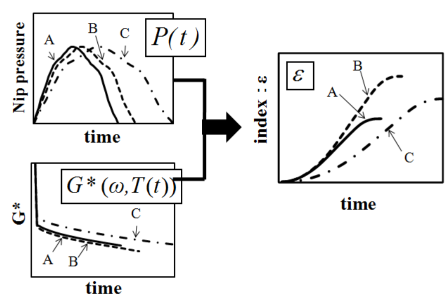


Figure 1*.Simulation flow*

Experiment

Experimental Condition

Fusing experiments were implemented using off-line fusing system bench. Fusing parameters are temperature, nip pressure profile and dwell time. The experimental conditions are listed in Table 1. Nip pressure profile is shown in Fig.2. We measured MFT and image gloss (60 degree). Here, MFT is judged by cold offset limit and image gloss is averaged by three different points of processed color.

Table 1. Experimental condition

Temperature	110 – 170degC
Dwell time	40 – 110msec
Nip Pressure	High(0.5MPa) ,Low(0.1MPa)
TMA	Processed color
Paper	Coated paper

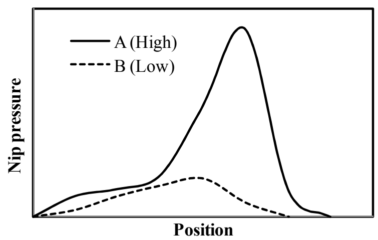


***Figure 2**. Nip pressure profiles*

Experimental Result

Figure 3 indicates the relationship between dwell time and MFT for nip pressure A and B. From Fig.3, we can see that MFT has different value depending on both dwell time and nip pressure.

In Figure.4, the relationship between heat roller temperature and image gloss (60 degree) are plotted for different combination of dwell time and pressure. Figure 4 shows that there exists some combinations of fusing parameters to get same image gloss.

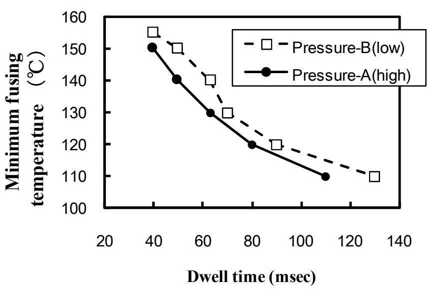


***Figure 3**. Experimental result: relationship between fusing parameters and minimum fusing temperature*

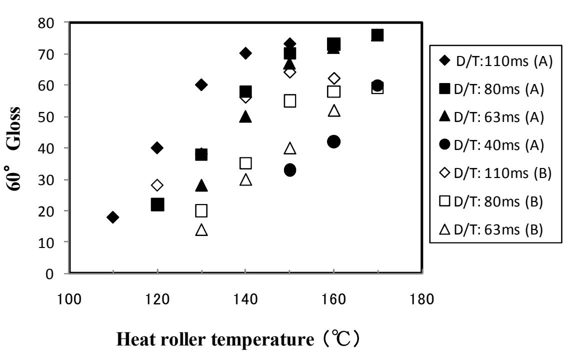


***Figure 4**. Experimental result: relationship between gloss and fusing parameters*

Consideration for MFT

Which index can well estimate the fixing limit (cold offset) or gloss in case that the fusing conditions are different?

So, we select the indices to judge fusing performance (cold offset) as follows;

1. Toner-paper interface (TPI) temperature after the time duration (dwell time)
2. Storage modulus(G'): toner viscoelastic property after the time duration (dwell time)
3. Viscous strain of toner
4. New model : viscoelastic strain of toner

Here we set the MFT as fusing temperature, dwell time and nip pressure in Fig.3, and calculate above indices. Then we evaluate if above four indices can judge the fixing limit (cold offset) in uniform value.

Figure 5 shows the TPI temperature and G' after the time duration. From Fig.5, the TPI temperature and G' have different values against each fusing condition.

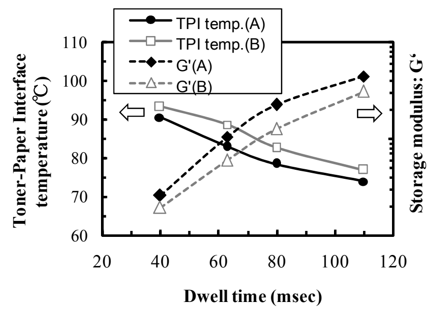


***Figure 5**. Evaluation of the Indices of fixing quality:toner-paper interface temperature and storage modulus*

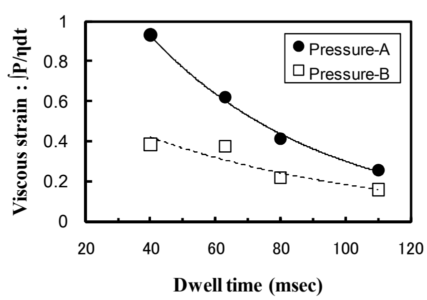


***Figure 6**. Evaluation of the index of fixing quality: viscous strain*

Figure 6 shows the viscous strain of toner against each fusing condition. From Fig.6, viscous strain also has different value against each fusing condition. Therefore these conventional indices are not proper to judge fixing limit.

Figure 7 shows the relationship between new viscoelastic strain and each fusing condition. Here, angular velocity ω in equation (2) is estimated by the rate of nip pressure change and dwell time.

As seen from Fig.7, new index indicates almost one value despite different fusing conditions.

Therefore this implies that frequency property of viscoelasticity : $G'(\omega)$ possibly affects on the toner deformation process which express the fusing performance.

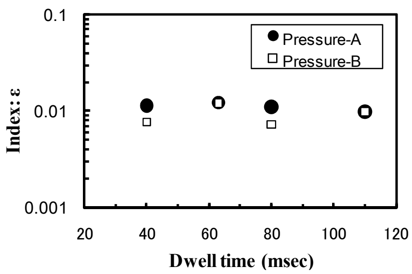


Figure 7. Evaluation of the index of fixing quality: quantity of viscoelastic deformation ε

Consideration for Gloss Mechanism

New Gloss Index

As shown in Fig.4, estimating image gloss becomes difficult against arbitral combination of fusing parameters.

Now, we verify the accuracy of conventional and new indices, viscous strain and new viscoelastic strain respectively, to estimate image gloss against each fusing condition using the experimental result in Fig.4.

Figure 8 demonstrates the relationship between the viscous strain and image gloss. Figure 9 indicates the case using viscoelastic strain. Here, image gloss plotted is measured value, and each index is calculated value.

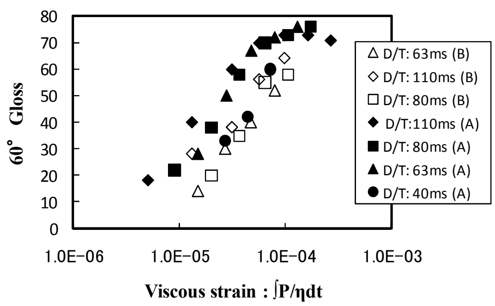


Figure 8. Relationship between the viscous strain and gloss

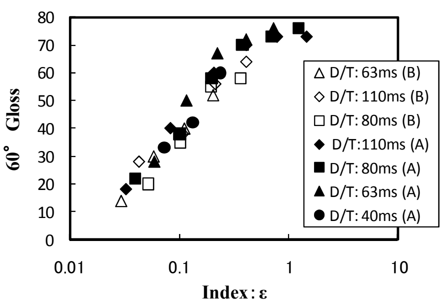


Figure 9. Relationship between index ε and gloss. ε has good correspondence with gloss value

In Fig.8, we can see that plots separate in two group by pressure A and pressure B. In contrast, in Fig.9, the new index: viscoelastic strain shows good correlation with image gloss despite different fusing condition (draw master curve).

Thus, these results imply that image gloss is determined by the amount of toner deformation under the condition of in-nip region, where paper type, toner mass per area and pre-nip/post nip conditions are regarded as same.

Surface Structure Analysis

Is surface structure of toner image same among same gloss samples even if fusing conditions are different? So, we implement frequency analysis of printed surface using RAPS (Radialy Averaged Power Spectrum)[1] which is kind of 2D FFT. RAPS means the degree of up-and-down of the surface against spatial frequency.

Example is shown in Fig.10, where samples with different gloss 34/53/72 are measured using RAPS. Changing point in RAPS near 160(1/mm) at gloss:34 is due to diameter of toner (6μm). This value decrease with gloss-up, which means gap between toner particles makes smooth by melt.

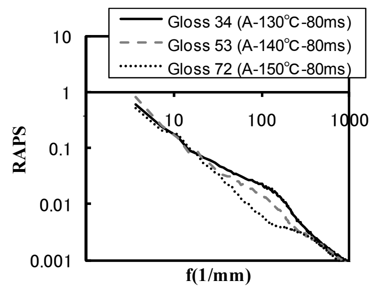


Figure 10. Comparison of RAPS with different gloss (Multi-color, pressure-A(high), dwell time:80ms, coated paper)

Figure 11 demonstrates RAPS around gloss:40 samples (processed color) with different fusing conditions. Here, A and B means high and low pressure condition respectively, and lines are drawn by dwell time.

From Fig.11, we can see that the image structures are almost same among same gloss sample despite different fusing conditions because RAPS curves overlap each other.

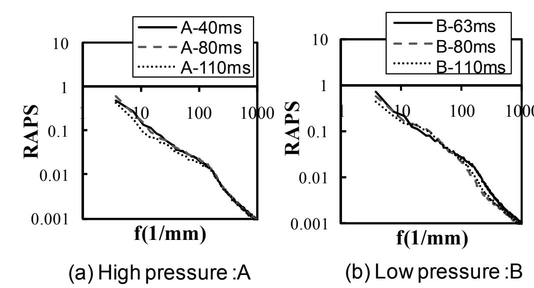
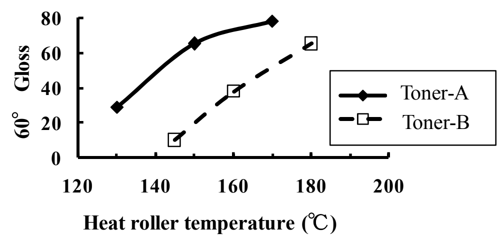


Figure 11. Comparison of RAPS with each dwell time for high and low peak pressure value (Multi-color, gloss coated paper)

Effects of Toner Viscoelasticity

Here we investigate the relationship between new index: viscoelastic strain and image gloss in case of different toner species with low and high viscoelastic properties.

Figure 12(a) depicts the gloss curve of low viscoelastic toner (Toner-A) and high viscoelastic toner (Toner-B), and Figure 12(b) shows the relationship between new index. From Fig.12(b), new index has good correlation with gloss even in case of different viscoelastic properties.



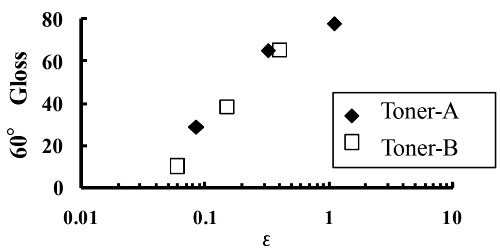


***Figure 12**. Relationship between index: ε and gloss (A: low viscoelastic toner, B:high viscoelastic toner).Above: temperature vs gloss, below: index vs gloss.*

Problems

Present study treats relatively smooth paper and small deviation of transferred toner to avoid noise except for nip parameter. In another study, we already have confirmed that the present model was valid for other toner mass (single color) condition and other paper (plain/matt/cast coated).

However it is difficult to estimate gloss uniformly across different toner mass and different paper roughness. For example, small amount of toner can't fill the gap where toners discretely exist. Thus gloss becomes low even the amount of toner deformation is large. On the other hand, paper roughness or noises except fusing parameters also effect on gloss.

Summary

- Proposed new model for estimating fusing quality based on toner viscoelastic strain, where frequency property of toner viscoelasticity is considered.
- Verified the accuracy of the new model. New index has had quantitatively good agreement with the fusing quality (MFT and image gloss) for various combination of fusing parameter.
- It was implied that frequency property of toner viscoelasticity possibly affects behavior of the toner deformation.
- Frequency analysis of printed image(RAPS) was implemented. Consequently, image structure of toner was almost same. among same gloss samples with different fusing parameters.
- In the future study, we are going to extend to further modeling considering factor of pre/post nip region such as toner mass, paper roughness and stripping to clarify the mechanism of image forming process.

References

[1] Y.Kitano, T.Enomae and A.Isogai, "Mechanism of Gloss Development with Matte-coated Paper in Electrophotography", NIHON GAZO GAKKAISHI, 45, 304-513 (2006) [in Japanese]

Author Biography

Satoshi Hasebe received his BS(1991) and PhD(1997) in mechanical engineering from Hokkaido University. Since then he has worked in the Research and Technology Division at Fuji Xerox. His work has focused on the development and application of the simulation techniques for marking process mainly in electrophotography and ink jet system. He is a member of Imaging Science of Japan and Japan Society of Mechanical Engineering.