Toner Fix Analysis Using Numerical Simulation Techniques

Takuma Onishi[1], Kyohei Kato[1], Masaki Kouno[1], Hiroki Eguchi[2], Yasunari Kobaru[2], Yasuo Yoda[2]; *1 Analysis Technology Center, Canon Inc., Tokyo, Japan*2 Peripherals Development Center, Shizuoka, Japan

Abstract

Numerical simulation method is proposed to predict fix strength on a destruction test of fixed image on a xerography fusing system. The 2-Dimensional ALE (Arbitrary Lagrangian-Eulerian) fluid and non-isothermal simulation can solve toners transitional deforming on a fuser nip and calculate a contact area between the toner and a paper, which takes into account involved factors: viscoelasticity of the toner and its temperature dependence, thermophysical properties of the toner and a fusing material, loading conditions, and fusing temperature etc. In addition, the structural simulation is applied to clarify how a fusing material fit the roughness on the paper structure and is combined with the fluid simulation. The combined method can calculate the contact area on images of both high and low density, which agrees with experiments of that when the type of toner is changed. Additionally, the results show that roughness on a paper structure affects the fix strength which strongly depends on the contact area. This method can be used to design fusing systems and toner properties.

Introduction

In xerography fusing systems, toners electrically transferred from a photoconductive drum to a paper are fixed by heating and pressurizing to maintain the quality of image. The fix strength is important part of the quality, which is measured and evaluated by a destruction test like abrasion test to a fixed image. Analytical predicting of the fix strength will be conductive to more efficient design and to better performance on fusing systems.

Some institutes have been researched the predicting methods of image fix on xerography fusing systems. In the reference [1], an analysis model has been proposed to predict the fix strength on a belt fusing system. Theoretical and basic principles about toner flow and toner penetration into pore of paper introduces the equation on analysis model of that, and the flow equations based on viscosity flow of a toner used in the target fusing system. In another reference [2], it has shown that the viscoelasticity of toner affects the toners deformation. This method is a numerical method by discretization of the 2-Dimensional viscoelastic flow equation, and takes into account the expansion of a toner particle and the combine between toners transitional deforming by solving the physical values such as velocity, pressure and stress tensor of Euler grid. The toners deform in a fuser nip and coagulated after the nip. The toner viscoelasticity and some fusing conditions like nip load affect those processes. In this reference [2], the nip load and number of peak of that brings the difference of state of sticking between toners and paper, and it shows that the viscoelastic properties affects the adhesion of those relates with fix strength. For predicting of fix strength, it is important to consider the viscoelastic property of toners.

No researchers quantitatively discussed fix strength on the real conditions like roughness on paper structure with considering viscoelasticity of toner. This paper has shown the numerical simulation techniques and the results on the real fusing conditions. The techniques can be useful for predicting the fix strength on a xerography fusing system.

Structural Simulation for Paper Roughness

The surface of a paper has the roughness shown in Figure 1 (a) because the fibers gather and it overlaps. Especially, results of the destructive test for low density image depend on roughness of the paper structure. A fusing material fits the upper surface of the toner on surface of paper because the material has elastic property. However, a part of toner isn't pressurized and extends only with increasing in temperature.

The structural simulation is applied to solve fitness between the fusing material and paper. Figure 2 shows a structural analysis model, which is made with considering the rough surface outline (shown in Figure 1 (b)) of the paper to express the difference of the depth of the paper. This simulation also takes into account the elasticity of the fusing material, and boundary condition decided by the nip load. Figure 3 (a) and (b) respectively show the simulation results and pressurized region calculated from the simulation applying to the paper roughness shown in Figure 1 (a). The result has shown that many of toners in the concave portion of paper are not pressurized according to this calculation.

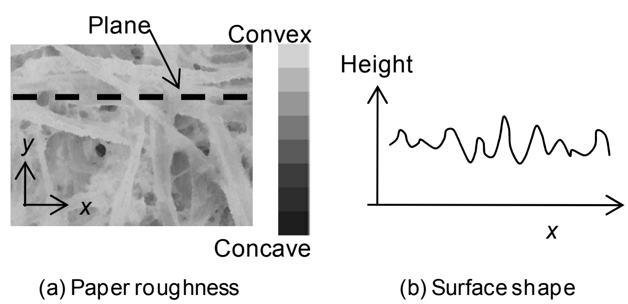

Figure 1. *Paper roughness*

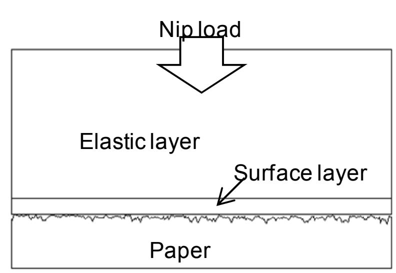

Figure 2. *Structural analysis model*

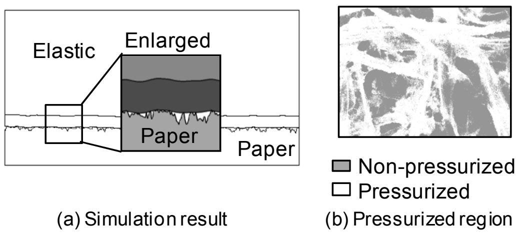

***Figure 3.** Simulation result*

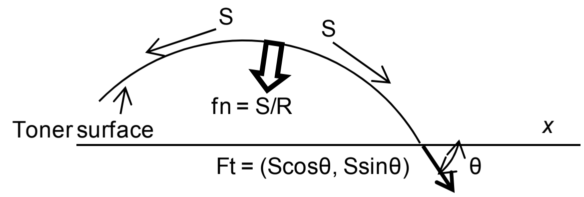

***Figure 4.** Wetting angle and surface tension*

Fluid Simulation for Non-Pressurized Toner

Equations of 2-Dimensional incompressible fluid consist of the conservation of mass, the momentum conservation, and the constitutive equation, which are solved by an ALE-FEM (Arbitrary Lagrangian-Eulerian Finite Element Method).

$$\nabla \cdot \boldsymbol{v} = 0 \tag{1}$$

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{f} = \rho \boldsymbol{a} \tag{2}$$

$$\boldsymbol{\sigma} = -p\mathbf{I} + \boldsymbol{\sigma}' \tag{3}$$

$\boldsymbol{v}$, σ, $\boldsymbol{f}$, ρ, $\boldsymbol{a}$, p, and σ' are velocity, stress, volume force, density, acceleration, pressure and extra tensor, respectively. σ' is described by Equation (4):

$$\boldsymbol{\sigma}' = 2\eta(\dot{\gamma})\boldsymbol{D} \tag{4}$$

$\boldsymbol{D}$ and η are deformation rate tensor and shear rate dependent viscosity, respectively. Shear rate dependent viscosity η is based on the Carreau-Yasuda law shown in Equation (5), and is applied to shift factor $H(T)$ described by WLF (Williams Landel Ferry) law shown in Equation (6).

$$\eta(\dot{\gamma}) = \eta_\infty + (\eta_0 - \eta_\infty) \cdot (1 + (\lambda \dot{\gamma})^a)^{(n-1)/a} \tag{5}$$

$$\ln H(T) = -\frac{\mathrm{C}_1(T - \mathrm{T_a})}{\mathrm{C}_2 + T - \mathrm{T_a}} \tag{6}$$

$\mathrm{T_a}$ is the reference temperature. Others are determined by fitting it to the measurement value of shear rate and temperature dependent viscosity measured by a rheometer.

Figure 4 shows the relation of involved physical factors: wetting angle θ between the toner and a paper, surface tension S. The toner shape of the transition is decided by hanging these factors. The effect of the boundary tension is considered by giving $\mathrm{F_t}$ obtained from hanging forces to act on the interface each other to an interfacial node. The normal forces $\mathrm{f_n}$ described from the surface tension S and the curvature R are added on the free surface.

Calculating the transitional expansion of a toner on a simple system which one toner on a glass plate deform in the isothermal condition was tested. Figure 5 shows a mesh model used to this axisymmetric simulation. The simulation results of contact area between the toner and the glass compared to the experiments which were plotted from transitional interface images captured by a high speed camera in the temperature condition of 100degC and 150degC, as shown in Figure 6. This result means that this simulation method has described the toner expansion in non-pressurized well.

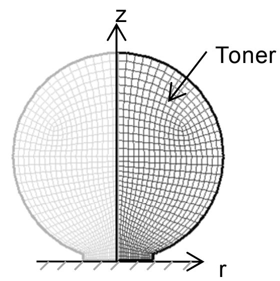

***Figure 5.** Mesh model in case of non-pressurized toner deform*

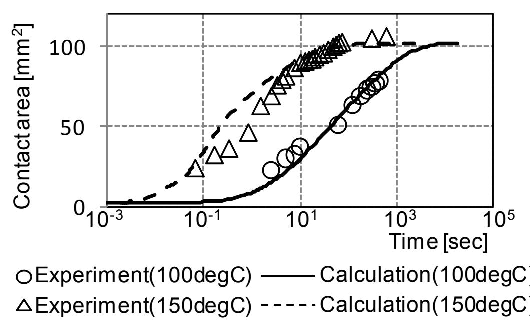

***Figure 6.** Comparison of contact area between calculations and experiments*

Fluid Simulation for Pressurized Toner

When toners are piled up enough on the paper, that is the case of the high image density, these deform are less affected by the paper roughness because toners are uniformly pressurized. Assumption that the surfaces of the paper are flat will be set up in the uniform pressure condition. The fix strength relates to the contact area between the toners and the paper, and the area is decided by action of involved factors: the viscoelasticity of the toner and its temperature dependence, thermophysical properties of the toner and the fusing material, the welding force, and the fusing temperature etc.

The ALE-FEM method is effectively used also for this problem because it can clearly show the shape of toners surface with a comparatively small number of finite elements because of a non-structural mesh and not considering air regions between toners. The model of a basic fluid follows the case with non-pressurized, different models are the following: the constitutive equation is based on the viscoelasticity model, and the wetting phenomenon isn't considered by the boundary condition.

The Giesekus model [3] which enhanced of Maxwell model to non linear model is selected to be the constitutive equation, and the expression is as Equation (7).

$$\left[\mathbf{I} + \frac{\alpha_i \lambda_i}{\eta_i} \boldsymbol{\sigma}_i^{'}\right] \boldsymbol{\sigma}_i^{'} + \lambda_i \overset{\nabla}{\boldsymbol{\sigma}_i^{'}} = 2\eta_i \boldsymbol{D} \quad (7)$$

Affixing character "i" shows the mode and takes the value from 1 to 6. η_i, λ_i and α_i are viscosity, relaxation time and non linear parameter, respectively. The coefficient of each mode is decided by fitting to the measurement of frequency dependent viscoelastisity. The shift factor $H(T)$ applied to viscosity and relaxation time.

The walls, the paper and the fusing material as rigid body, move at the velocity that is to pressurize the toner according to the pressure distribution of the fusing nip. The motion of the interface between the toner and the walls synchronizes by applying the boundary condition shown in Equations (8) to normal force on the surface of toner in the interface.

$$f_{\mathrm{s,n}} = -\mathrm{k}(\boldsymbol{v}_{\mathrm{s}} - \boldsymbol{v}_{\mathrm{w}}) \cdot \mathbf{n} \quad (8)$$

$\boldsymbol{v}_{\mathrm{w}}$, $\boldsymbol{v}_{\mathrm{s}}$ and k are wall velocity, fluid surface velocity on the contact region and penalty coefficient, respectively. The tangential component of interfacial force depends on the material and the normal stress to accurately calculate the effect of toners slipping to the wall.

$$f_{\mathrm{s,s}} = -\mu \mathrm{P_s} \quad (9)$$

μ and $\mathrm{P_s}$ are friction coefficient to a wall (paper or fusing material) and normal stress, respectively.

Fusing System and Boundary Conditions

Figure 7(a) shows the on-demand fuser frequently used in Canon. The fusing material is used the film composed of surface layer, elastic layer, and the base layer, and it is heated by the heater. The fusing nip is made in the area placed with the heater and the pressurizing roller. The paper to which the toner is transferred passes the nip at a process speed. Figure 7(b) shows the pressure distribution in the nip which pressurizes the toners. Figure 8 shows the temperature distribution calculated from the equation of transitional heat conduction on the x-y plane by solving the 2-Dimensional finite element method with considering the material properties, the paper passing and heat radiation to air. The temperature distribution from calculation results on the reverse of the paper and the film was used to the boundary condition of the fluid simulation for the pressurized toner fix.

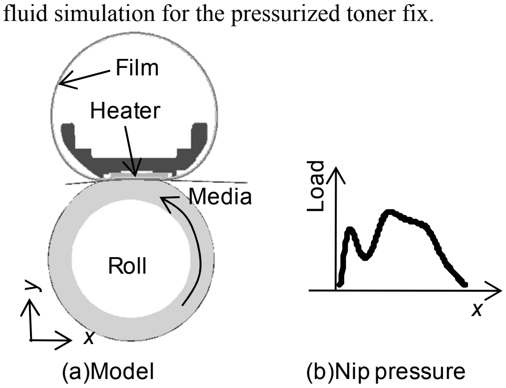

Figure 7. *On-demand fuser*

For non-pressurized toner fix analysis, the toners temperature was assumed to be a uniform distribution in volume of the toner, and to be the temperature on the surface of the paper. Figure 9 shows the heat transfer simulation model in y-z plane with considering the paper roughness, (a) and (b) are in and after the fusing nip, respectively. The finite element mesh in the nip consists of the paper, fusing material, and air between both. The mesh was made from adding the air mesh to result of the structural simulation. The boundary condition of the film reverse and the paper reverse was given by the heat transfer simulation result in the x-y plane. The model after the nip was based on the radiation to the air. Applying the heat transfer coefficient ($10\mathrm{W/m^2K}$) to the boundary condition of the paper surfaces brings that it can simulate with only the mesh of paper. It gave the temperature of the paper to the toner with depending on the depth of the paper. Concretely, the temperature of the toner in depth D of the paper was assumed to be the average value of the temperature of depth from (D-0.5ΔD) to (D+0.5ΔD). Here, the interval ΔD was 10μm.

Results and Discussion

Non-pressurized Toner Fix

Non-pressurized toner simulation was applied to the fix strength analysis on on-demand fuser. Figure 10 shows the conceptual diagram of this problem. Some of fixed toners on the paper are disappeared by destruction testing of the image. The probability of toners disappearance in depth D, the number of disappearance per that of toner before testing in the range of the depth, may be show the fix strength. Six cases were examined for three temperatures (135, 145, and 150degC) and for two depths (10 and 15 μm) in this analysis.

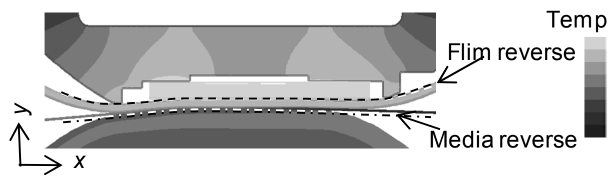

Figure 8. *Temperature distribution (computed by a heat transfer simulation)*

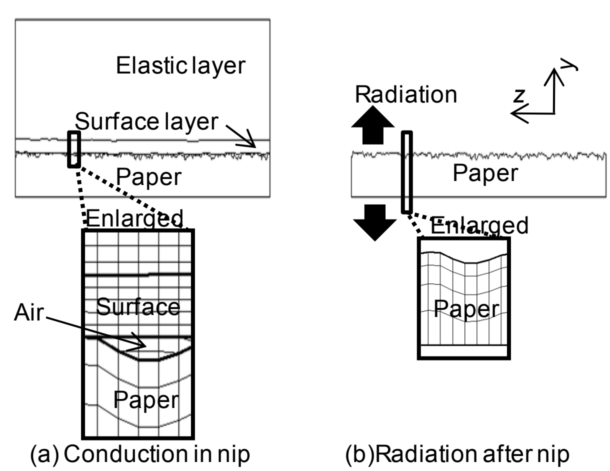

Figure 9. *Heat transfer model with considering paper roughness*

Figure 11 shows the transitional variable of the contact area between the toner and the paper computed by the fluid simulation with considering the boundaries conditions in the range of depth 10μm. The material properties of toner, wetting angle, surface tension, and viscosity were decided from the measurements. Figure 11 shows that the toner deforms spending the time of the order for a few seconds, and there aren't so many differences by the temperature in its contact area at the outlet of the fusing nip. Figure 12 shows the relation between the contact area calculated and the probability of toners disappearance measured from the observations in each depth. This result seems to be valid in terms of that the probability decreases proportionally for an increase in the contact area. Calculating the contact area in all rage of depth may bring that it can find the fix level in the paper.

Pressurized Toner Fix

Figure 13 shows the simulation model for the pressurized toner fix analysis. The toner was piled up to three layers. The contact areas calculated in the deference conditions which was three toners and from three to five temperatures were compared with the experiments in the same condition as calculation to valid the simulation method with viscoelasticity. The cellulose sheet is flat and transparency, which was used instead of the roughness paper for this analysis. The contact area between the toner and the sheet can be observed the back side of the sheet because of its permeability. Figure 14 shows the comparison of the temperature dependent contact area between the computed results and the experiment. The computed result has agreed with the experiments in three toners. The result has shown that this simulation can predict the fix strength to quantitatively calculate the contact area.

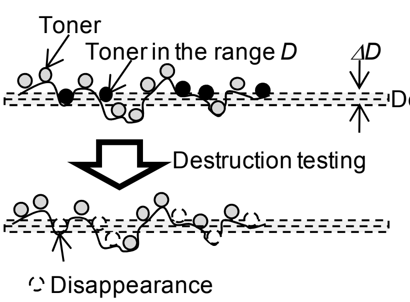

Figure 10. *Conceptual diagram*

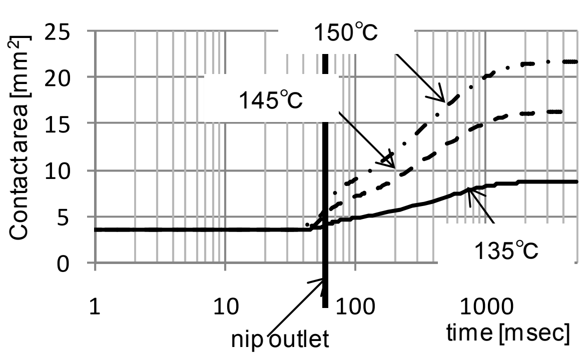

Figure 11. *Simulation result of toner non-pressurized expansion*

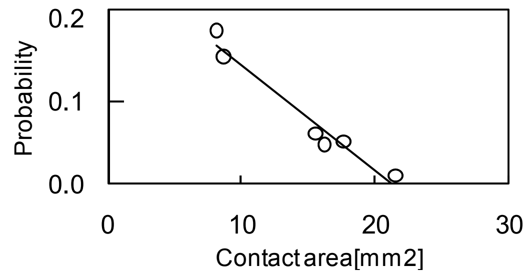

Figure 12. *Relation contact area with fix strength*

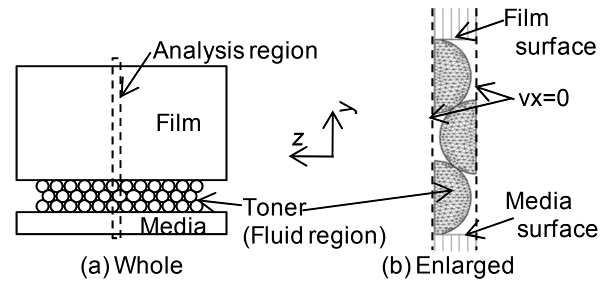

Figure 13. *Simulation mesh for pressurized toner fix*

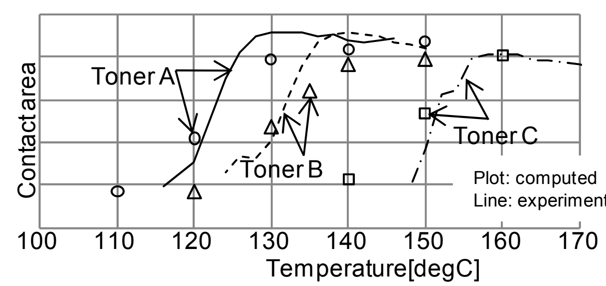

Figure 14. *Comparison of contact area*

Conclusion

The simulation method with considering the viscoelasticity and the paper roughness to fix analysis has been proposed.

References

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Author Biography

Takuma Onishi received his M.S. degrees in electrical and electronic engineering from Okayama University, Japan in 2002. He joined Canon Inc. in 2002 and has been engaged in the development of electro-photography by using numerical simulation.