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A Study on the Development of Coupling Simulation Technique for Predicting Toner Particle Leakage

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Abstract

The distribution environment of printer products creates a lot of shocks. The shock causes a variety of malfunctions in the printer. Among them, toner leakage problem is the most difficult problem to solve. Multiple drop tests were conducted to find some causes of toner leakage. However, there are many limitations because toner particle size is too small.

In this study, to overcome these limitations and inefficiency of development process, the new simulation method is introduced. This method is developed for predicting toner leakage, and 1-way coupling analysis technology is used between structural analysis solver(LS-DYNA) and particle analysis solver (Metariver DEM) to make a toner leakage phenomenon visible.

Introduction

It is difficult to analyze the cause of toner leakage. Because the toner particles are very small(5~10um), and a toner leakage phenomenon happens very quickly. Once a leak occurs, the area around the development unit is contaminated with toner as shown Fig 1. This makes it difficult to analyze a mechanism where toner leaks. Simulation technology is required to determine the cause of this problem.

The purpose of this study is to predict toner leaks by visualizing the behavior of toner particles using the computer simulation technology. Visualization techniques through the computer simulation make it easier to analyze the cause of toner leakage. In addition, the effectiveness verification of improvement measures is quantitatively comparable. This technology enables developers to get accurate improvement solutions, not estimates. As a result, it can make the cost and time savings of the development phase. However, it is difficult to predict the toner particles behavior and leakage of toner particles through analysis. Prediction and visualization requires new, merged simulation technology between particles and structures.

This paper proposed a new simulation technique for predicting toner particle leakage. The proposed simulation techniques included verification by quantitative comparison with tests.

Figure 1. Toner leakage at development unit

Structure of Developer Unit

The mono color developer structure which selected as a reference model is shown in Fig 2. Most of the space in developer unit is the space where Toner is stored. The auger transfers the Toner to the space where the roller is located. The transferred toner is passed to the developer roller(DR) via the supply roller(SR). The developer roller(DR) passes the Toner to OPC. The SUS Blade ensures that a certain amount of Toner is applied to the developer roller(DR). When these structures are struck by a momentary impact, relative movements between them create a momentary gap. And then, through that gap, toner leaks. Toner leakage depend on parameters such as structure type, stiffness, amount of toner, and press force of roller and blade.

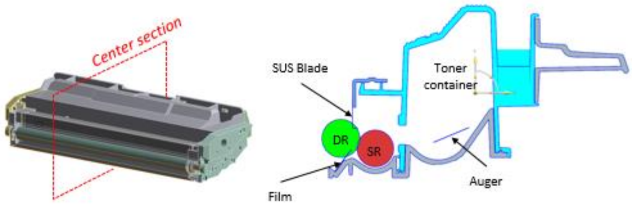


Figure 2. Structure of mono color development unit

Development of Structural Analysis Model

Material Test

Prior to the construction of the analytical model, a test was conducted on the materials that comprise the main parts. In this paper, the physical properties of a total of 26 major parts were measured, estimated and applied. The main parts are made up of plastic, steel, rubber, sponge, and film. Among them, Rubber and Sponge played an important role in toner leakage and required more precise measurements. For Sponge, the Strain-Stress Curve was measured for compression using a 50mm cube sample as shown in Fig3.

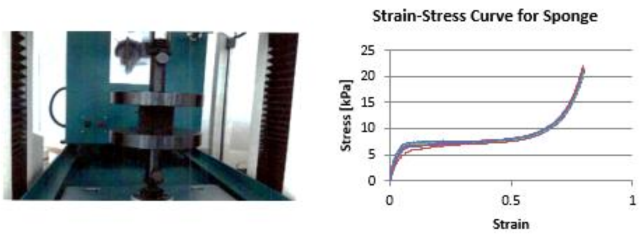


Figure 3. Material Property Test of Sponge

In the case of Rubber, the elasticity factor has been predicted through hardness and used in the analytical model. The equation below is the relative equation between the commonly used rubber hardness and the elastic factor [3].

$$\log_{10} E = 0.0235S - 0.6403$$

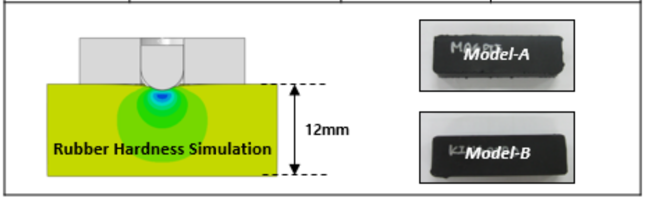
$$S = \begin{cases} S_A \ (for\ 20 < S_A < 80, \\ S_D + 50 \ (for\ 30 < S_D < 85, \end{cases}$$

Where, S_A is the ASTM D2240 type A, S_D is the ASTM D2240 type D

However, the estimated elastic modulus was found to be somewhat different from the actual value. The table(Table1) below shows the comparison results between test and simulation. Errors tend to increase with higher hardness.

Table 1 : Hardness Comparison Result

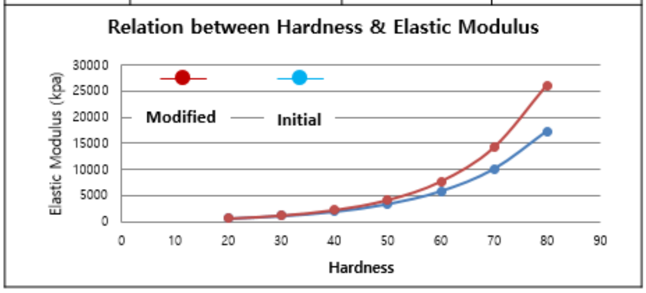
Comparison Result		Model-A	Model-B
Elastic modulus [kPa]		2223	2476
Hardness [Asker-C]	Physical Test Result [Avg.]	66.3	69
	Simulation Result	65.5	66.8
	Accuracy [%]	98.8%	96.8%



In order to correct the error, simulation was used to adjust the elastic modulus to obtain the value most similar to the experiment. The corrected results are shown in the table below and have been identified to be somewhat different from the previously proposed method of relationship between rubber hardness and elastic modulus.

Table 2 : Hardness Comparison Result (After Correlation)

Comparison Result		Model-A	Model-B
Elastic modulus [kPa]		2500	3000
Hardness	Physical Test Result [Avg.]	66.3	69
	Simulation Result	66.8	70.0
	Accuracy [%]	100.7%	101.4%



Most of the remaining plastic and steel types are assumed to be elastic. The reason is that no deformation beyond the elastic zone occurs.

Validation of Natural Frequency Result at Single Part Level

The structural analysis model has been developed as a prior step in predicting toner leakage. Accuracy of simulation model, excluding toner, has been verified through structural analysis in part level. Modal frequency response has been validated for accuracy in the vibration characteristics of the structure. Among the seven main parts, the six parts show more than 10% error in natural frequency.

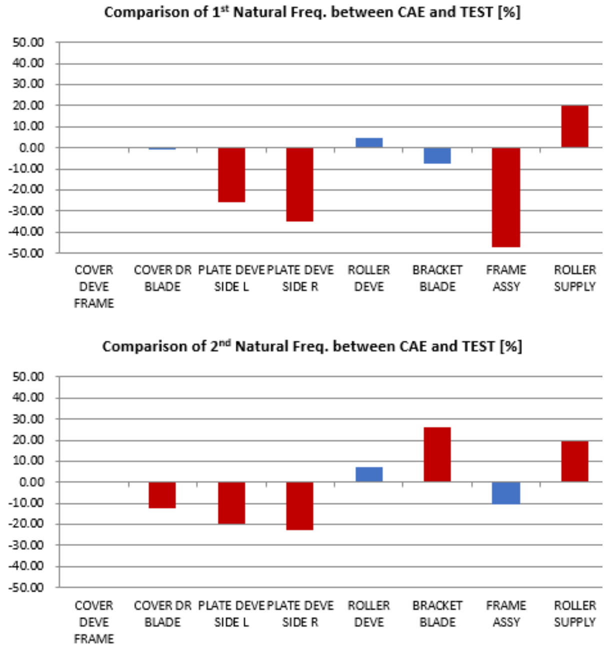


Figure 4. Comparison of Natural Freq. between Simulation and TEST

To compensate for the error, a frequency response curve was compared through modal frequency response analysis. The simulation results were calibrated with a goal of less than 10 % in natural frequency and 20 % in amplitude of natural frequency. (log scale.) The compensation parameters used the elastic modulus, the damping ratio, and the modelling conditions. Fig 5. [4] shows the result of the frequency response curve before and after calibration of the SR Roller and Side Cover. The red line is the physical test result, the blue line is the simulation result before calibration, and the green is the result of the simulation after calibration.

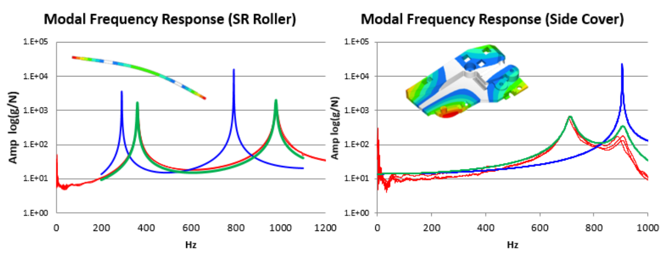


Figure 5. Correlation Result of Freq. Response Curve.

Validation of Shock Acceleration Result at Assembly Level

The current phase simulation model has been configured with a validated FE model in unit level. Impact acceleration verification was carried out to verify the reliability of the configured analytical model. A large impact tester was used to carry out the constant phase drop test at a height of 10, 20 and 30 cm. The acceleration sensors were installed in two places of developer unit to measure the impact acceleration. At the center of the impact tester, the input acceleration was measured with one acceleration sensor. The results below are a comparison of the simulation and experiment impact acceleration at each height. Similar results can be seen within 20 % of the error range based on the maximum impact acceleration. Fig 6.

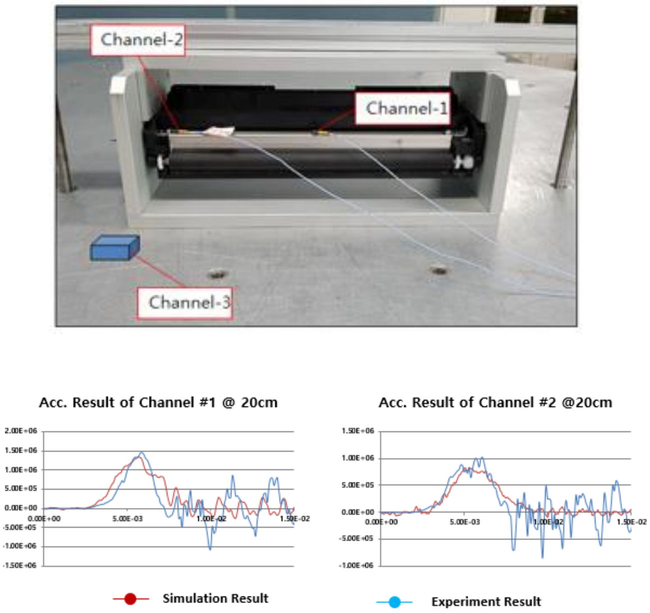


Figure 6. Comparison of acceleration curve between simulation and experiment at 20cm drop.

Table 3 : Total accuracy of acc. response

Accuracy	Channel #1	Channel #2
10cm Drop	89%	93%
20cm Drop	94%	85%
30cm Drop	87%	96%

Development of Toner Particle Model

To predict toner leakage, not only a structural analysis model but also a particle analysis model must be developed. This paper compared the characteristics of the Toner for the seven types of toners used in laser printers. In addition, three characteristics were assumed to affect the behavior of the Toner. Three characteristics are Toner diameter, roundness and cohesiveness. The Toner Drop test identified the main factors affecting the behavior of the Toner and constructed a particle analysis model to simulate the behavior of the toner according to the change in that factor.

Toner characteristics comparison

Prior to carrying out a test, investigated toner properties of seven toner types for toner drop test. The physical properties were compared using average value measured from production record over three years. Fig 7. is a comparison of toner diameter, cohesiveness, and roundness. It can be found that different values vary depending on the toner type.

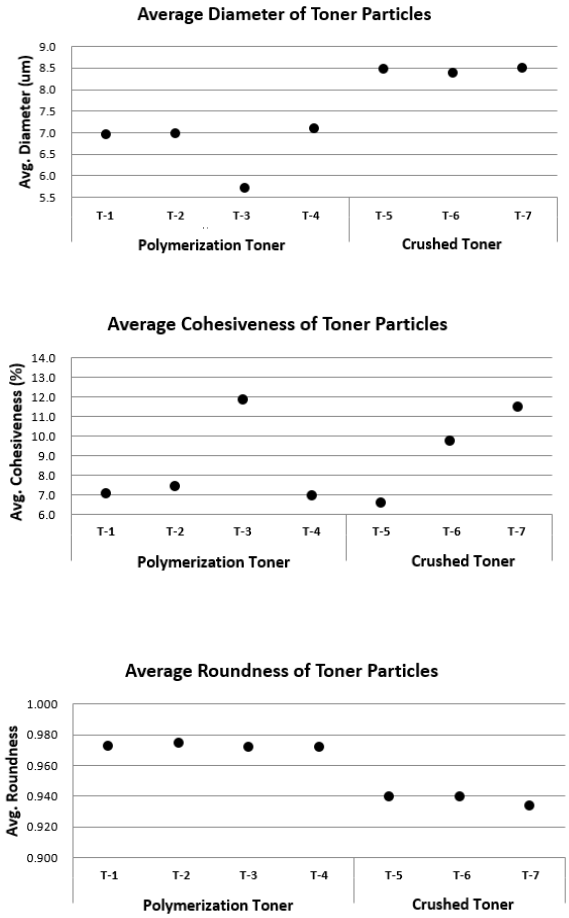


Figure 7. Comparison of toner properties

Toner Drop Test

Toner behavior caused by external impact may be affected by the properties of toner properties. To confirm this, we conducted Drop Test by type Toner. We measured a certain amount of the toner accumulated height and spread length as shown in the Fig 8. below. Measurements were made with a laser beam profiler.

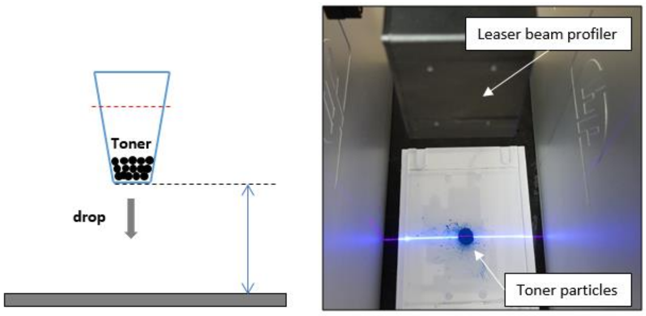


Figure 8. Toner drop test condition & measurement

As a result of the drop test, toner behavior was assessed to be highly correlated with cohesiveness. Fig 9 compares the height of toner accumulation with the characteristics of toner for each toner type. It can be found that trends in the results measured by the drop test are similar to those of the toner cohesiveness characteristics.

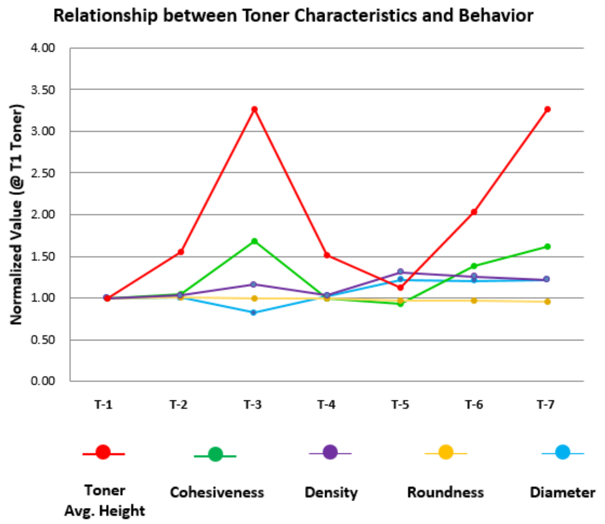


Figure 9. Relationship between toner characteristics and behavior

Validation of Toner Simulation Model

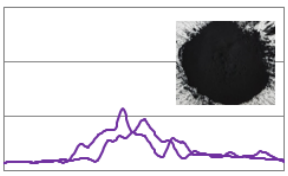
A particle analysis model was constructed and the simulation parameters were verified. The particle analysis model development and simulation utilized SAMAII DEM solver of Metariver Technology based on GPU computing. [5][6] To verify the parameters, the results of the toner drop test are utilized. In the particle analysis parameters, adhesion and friction parameters were used as alternatives to toner cohesiveness. Friction parameters used constant models and dynamic and rolling friction applied in the particle simulation model. Adhesion parameter consists of two different type. One is adhesion between particles and the other one is between particles and interface wall. Viscosity used a certain value and the Coulomb Force was omitted.

A total of three case for the Analysis conducted verification of results. The dynamic fraction, rolling fraction, and adhesion parameters of the analytical models were adjusted to obtain experimental results and verified particle analysis models. Table 4.

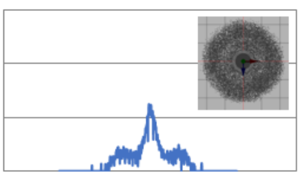
Table 4 : Validation result of toner drop simulation

Correlation Result (T-4)	Experiment	Simulation
Heaped Height [mm]	1.60	1.75
Spread Width [mm]	21.00	21.00

Experiment (T-4 Toner)

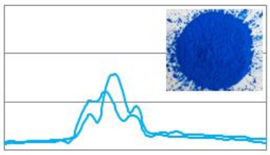


Simulation (T-4 Toner)

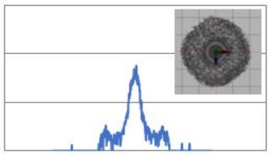


Correlation Result (T-5)	Experiment	Simulation
Heaped Height [mm]	1.05	1.09
Spread Width [mm]	23.75	23.00

Experiment (T-5 Toner)

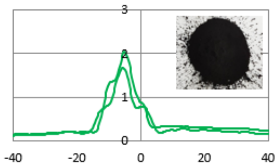


Simulation (T-5 Toner)

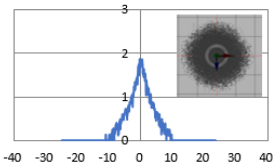


Correlation Result (T-6)	Experiment	Simulation
Heaped Height [mm]	2.02	1.86
Spread Width [mm]	19.9	19.4

Experiment (T-6 Toner)



Simulation (T-6 Toner)



Toner Leakage Test at Simple JIG Model

Before the simulation of toner leakage, a simple JIG was developed for verifying the results. To maintain constant and repeated test conditions, the JIG model is developed simply as much as possible. Fig10 shows the section diagram of the test JIG and test JIG mounted on the small impact testing machine.

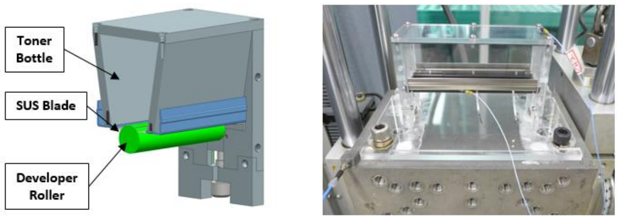


Figure 10. Simple JIG Model

There were three types of toners used in the test : T4, T4, and T4. The test was conducted at a height of 5 cm, 10 cm, and 15 cm. In order to compare the quantitative results of the physical test and the simulation, the leaked toner from the drop test was captured for white paper. The captured toner was converted to a leakage point using the concentration measurement program. The result converted to leakage point was a quantitative comparison for each case. Fig12 shows the relationship between toner diameter and cohesiveness by comparing the leak results.

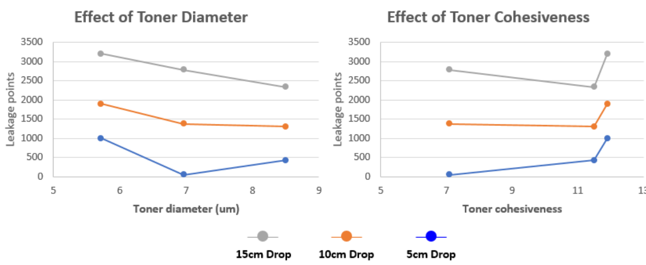


Figure 11. Leakage points in accordance with toner characteristics

Unlike the result of a toner drop test, there was a significant impact due to toner inlet. This shows that the size of toner has a greater impact on the momentary impact and the behavior of leakage through the gap than the cohesiveness of toner.

Toner Leakage simulation and Physical Test Validation

Toner leakage analysis was conducted using a previously verified structural analysis model and particle analysis model. The toner leakage analysis used LS-DYNA Solver and SAMADII DEM Solver. Use LS-DYNA Solver for structural analysis. To achieve the initial compression state of the rollers, use the Phase Change Analysis of the LS-DYNA. Phase change analysis here refers to the transition from static implicit to dynamic Explicit state. [4][5] Coupling analysis utilizes '1- way coupling analysis method' that calculates two solvers sequentially. The coupling analysis proceeds with the particle analysis when the results of the structural analysis are determined. Therefore, it is assumed that there are no structural deformation effects of the toner behavior. In this paper, tests were compared simultaneously to verify the accuracy of the analysis of toner leakage prediction.

Coupling analysis Between Structural and Toner Particles

Import the results of the drop impact analysis using the LS-DYNA Solver from the SAMADII DEM program. Where the LS-DYNA analysis results are the X, Y, and Z displacement results that occur during the impact time at each node point of the analytical model. Develop the 2D Section boundary model at the desired location of the imported model, such as Fig 12.

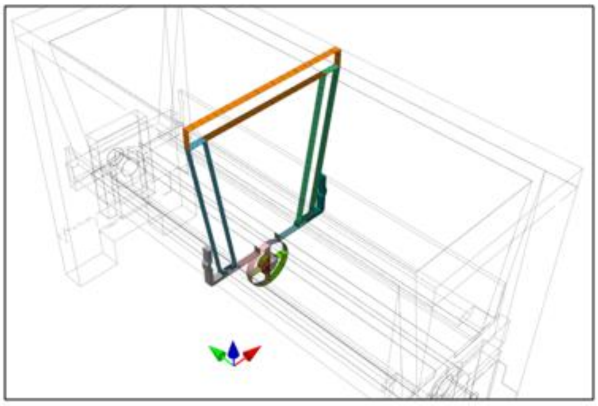


Figure 12. 2D section boundary model at SAMADII DEM program

2D analysis is necessary to reflect the actual toner size(5~10um) of the toner in particle analysis. However, to overcome these limitations, the structural analysis conducted in the LS-DYNA used a sufficiently validated 3D model. In addition, the SAMAII DEM program was customized to allow development of 2D section boundary models at any location. In this study, 2D section boundary model was constructed in the center of the most frequently leaking position current environment. Fill the 2D section boundary model with the previously validated toner model and perform particle analysis. Fig13 compared particle leakage analysis results conducted at different heights. Depending on the drop height, the difference in the amount of toner leakage can be checked visually and quantitatively.

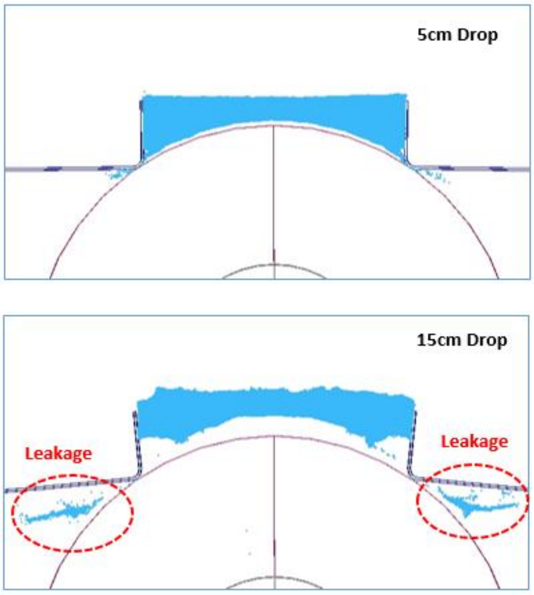


Figure 13. Toner leakage simulation with simple JIG

Validation of Toner leakage analysis

Simulation was performed on the simple JIG under the same conditions as the result of the test conducted according to the toner type and the drop height. Fig 14 is a graph comparing the results of an experiment and analysis for each condition. An experiment is a result of a concentration measurement to convert the leakage point. Analysis is the result of counting the number of leakage of the actual analytical particle. Generally, similar trends can be seen, and deviations from toner size can be seen through the analytical model.

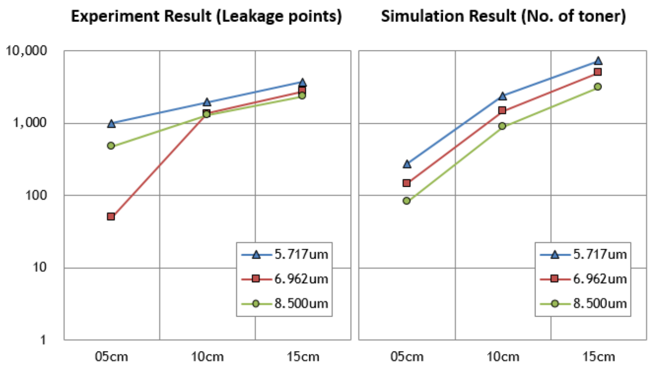


Figure 13. Comparison result of toner leakage (Experiment & Simulation)

Toner leakage simulation and physical test conducted on developer unit of production model also. Toner used the type T-4 toner. The test impact acceleration is applied with 40G, 60G and 80G. When the impact is generated, the leaked toner was captured same as simple JIG test. Fig 14

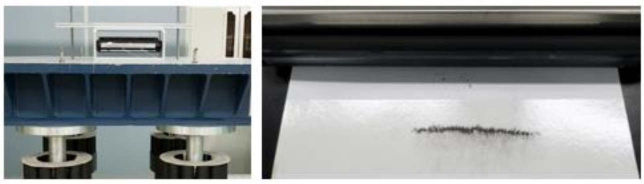
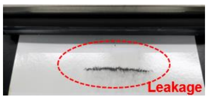


Figure 14. Shock test of developer unit & leaked toner captured

The results were compared with the analysis using the same conditions as the test. The Fig 15 and Tables 5 below show the results for each case. Both analyses and experiments have identified a tendency for toner leakage to occur at the same impact acceleration. The results of a relatively vulnerable toner leakage in Developer Roller and Film were also predicted.

Table 5 : Experiment result on developer unit

DR-SUS Blade		DR-Film	
40G	No leakage	40G	No leakage
60G		50G	
80G		60G	

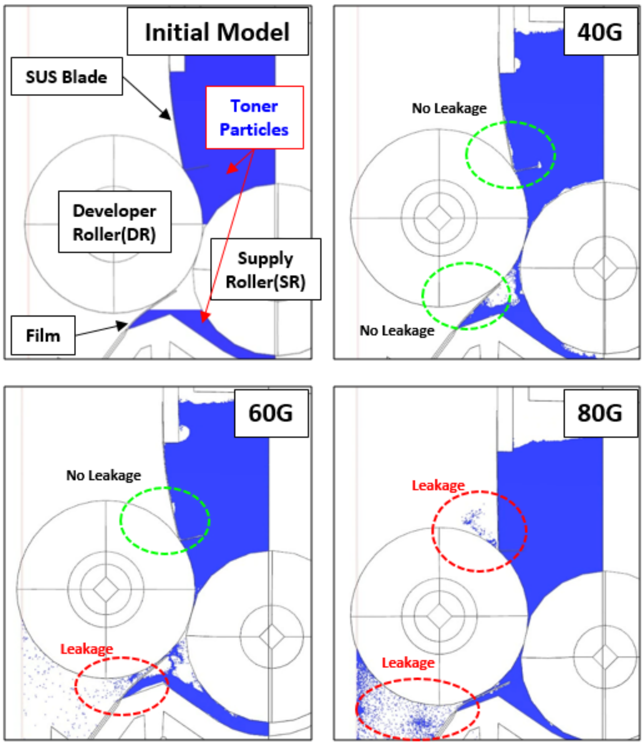


Figure 15. Toner leakage simulation result on developer unit

Conclusion

It is difficult to analyze causes of toner leakage through experiments. It is also difficult to analyze the effects of the improvement measures through experiments. This is because it is difficult to see toner behavior due to impact and it is difficult to determine quantitative effects of improvement. To overcome these difficulties, skills that can be reviewed in the preceding steps are needed. In this paper, new simulation methodology which predict particle leakage visually through coupling simulation between particles and structure was suggested. The accuracy of the simulation was demonstrated at the part level, unit level, and particle level by experiment with quantitative comparison. The proposed technique is expected to allow analysis of the root cause of leakage of toner particles in the preceding steps. It is also possible to determine the effects accurately by quantitatively comparing the effects of improvement measures. This can be expected to reduce development time and reduce costs.

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