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Investigation of the Effects of Additive-Blending Conditions on Toner Characteristics and Performances

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Abstract. *External additive blending is one of the most important processes in toner manufacturing. It determines the electrostatic properties, powder properties, and physical properties of the toner, and therefore the xerographic performance of the toner. Additive-blending conditions, as well as additive compositions, have huge effects on several important toner properties such as the triboelectric charge level, charging rate, free flow, cohesiveness, and powder density. Understanding the additive-blending process and its effects on toner performance is of practical use in designing additive-blending processes and choosing optimal blending conditions. The effects of additive-blending conditions, such as blending intensity and blending temperature, have been studied, and their effects on toner properties and image quality have been tested. The temperature dependency of the blending process and hence the resulting properties and performances of the toner have not been studied extensively before, and this forms the purpose of this report. In most cases, the blending temperature during the additive-blending process is maintained at a fixed temperature, usually atmospheric temperature, or below, to remove the heat generated during high-speed blending. The blending temperature has an effect on additive adhesion, which indicates how effectively additives adhere to the toner surface after mechanical stress, which toner experiences in a cartridge during life.* *©2012 Society for Imaging Science and Technology.*

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INTRODUCTION

Electrophotography, also known as xerography, is the key technology behind laser printers and photocopiers. Electrophotography is a series of processes, consisting of forming latent images by optical exposure, developing the latent images with toner, and then fixing the developed images onto a printable medium. Image development in xerography makes use of electrostatic force to attach colored and charged toner particles onto the latent image on a photoreceptor. The developed image is then transferred and fixed on the printable medium. Toner plays a critical role in high-resolution image printing. The effort to improve image quality has been a main research topic for a high-performance toner.

During the xerographic processes, toner passes through various parts of the printing device, including agitators in the toner hopper, supply roller, development roller, doctor blade, organic photoconductor (OPC), transfer roller, and fusing roller. The main transfer mechanism is electrostatic force, and high-quality images can be produced with carefully controlled toner properties. Typical properties of toner include triboelectric charge, particle shape, particle size and distribution, density, free flow, and fusing properties.

Over the years, toner design has been much studied, and a two-part design, in which a toner particle is segmented by an inner core and outer external additives, is generally accepted.[1] Core toner is usually a mixture of binder resin, coloring material, charging control agent (CCA), and wax. External additives are attached to the surface of the core toner, and they have a role in enhancing toner performance. External additives are responsible for image density, uniform color reproducibility, print yield, toner usage, and high resolution, in addition to powder properties. Mechanical stress during the movement of toner within the printing system can lead to toner particle rupture and deformation, and these are also prevented by using an optimal blending of additives.[2–4]

External additives are often composed of ceramic particles, such as SiO_2, TiO_2, Al_2O_3, and $SrTiO_3$, and non-ceramic materials.[3] Hundreds of different external additives for use in toner preparation are commercially available. The varieties are differentiated by primary particle size, crystalline structure, aggregation properties, and manufacturing methods such as sol–gel or fumed. Primary particle sizes range from a few nanometers to hundreds of nanometers. For toner manufacturing purposes, the additives are surface treated with derivatives of silane or silicone oil such as polydimethylsiloxane (PDMS) and hexamethyldisiloxane (HMDS) for enhanced environmental stability. Among the aforementioned additives, SiO_2 is known to provide large triboelectric charge and free flow, while TiO_2 yields environmental stability and Al_2O_3 improves cleaning of residual toner from the OPC. However, it is common to incorporate several different materials, and the final toner performance is fine tuned with the correct combination of grades, dosage, and blending conditions.[2,3]

Normally, external additives are attached on the toner surface by blending the core toner and external additives together in a high-speed powder mixer. During the additive-blending process, agglomerated additives are broken down to smaller aggregates or even to primary particles, and the additives are evenly distributed on the toner surface.[5] It is widely accepted that the additives adhere to the toner surface due to both mechanical impaction and electrostatic attraction.[6–8]

In this study, we tested blending conditions such as blending time, blending rpm, blending temperature, and

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Table I. Toner particle characteristics.

$D_{50}(v)$	$GSD_p = \sqrt{D_{84,N}/D_{16,N}}$	$GSD_v = \sqrt{D_{84,V}/D_{16,V}}$	$>10\ \mu m$	Circularity
6.175 μm	1.26	1.24	0%	0.99

Table II. Additive characteristics.

External additive	Size (nm)	BET (m^2/g)	Density (g/l)	Surface treatment
A	7	210	40	HMDS
B	12	140	40	HMDS
C	16	110	50	DDS
D	40	35	170	HMDS
E	50	50	180	DMDES
F	14	120	60	DMDES
G	40	30	130	PDMS
H	16	110	40	Alkylsilane
I	15	75	40	Alkylsilane

Table III. Additive-blending conditions for intensity and time test.

Test ID	Additive	Amount (pht)*	RPM	Time (min)
A1	A	1	4000	2
A2	A	1	4000	5
A3	A	1	4000	10
A4	A	1	4000	15
A5	A	1	8000	2
A6	A	1	8000	5
A7	A	1	8000	10
A8	A	1	8000	15
A9	A	1	12,000	2
A10	A	1	12,000	5
A11	A	1	12,000	10
A12	A	1	12,000	15

*pht : parts per hundred toner.

post-blending cooling, and observed their effects on toner properties and image quality.

EXPERIMENTS

Additive Blending

Core toner was blended with surface-treated additives using a custom-made high-speed powder mixer. Polyester-based chemical toner was used in this study; the production of polyester-based core toner has been described in various technical articles and patents.[9–12] Black core toner, additives, and a powder mixer were conditioned at 25°C and 50% relative humidity (RH) for more than 8 h before blending. Table I lists the core toner particle size and the size distribution measured using a Multisizer 3 Coulter Counter. Three blending conditions (blending intensity, blending time, and blending temperature) were tested in this study. To clearly observe the effects of blending conditions, only one additive was used in each test to avoid any possible interaction between different types of additive. Table II lists the properties of the additives used in this study. The additives were different in terms of core material, primary particle size, and surface treatment material. The primary particle sizes ranged from 7 to 50 nm, and the specific surface area ranged from 30 to 210 m^2/g. Polydimethylsiloxane (PDMS), hexamethyldisiloxane (HMDS) and dimethyldiethoxysilane (DMDES) were used as surface treatment materials by the manufacturers.

Table III gives a summary of the blending time and blending rpm values for this study. Sample A1 was prepared by blending 200 g of core toner with 2 g of additive A. The blending was done at 4000 rpm for 2 min. The temperature inside the blender chamber was maintained at 15°C, by using a water-jacketed vessel. Without temperature control, the temperature in the blender chamber increased as blending proceeded, especially at high blending intensity. The blended toner was then sieved using a 45 μm opening steel mesh to remove any large aggregates that may have formed during blending. Other samples were prepared by blending the same amount of toner and additives at 4000 rpm for either 5, 10, or 15 min. These samples were labeled A2, A3, and A4, respectively. The same sample preparation procedure was repeated at 8000 and 12,000 rpm, and the prepared samples were labeled A5–A8 and A9–A12, respectively. The 12 samples listed in Table III were prepared again using the same conditions as for samples A1–A12, but this time blending was done with additive B, additive C, and additive D. These samples were labeled B1–B12, C1–C12, and D1–D12, respectively. The surface area coverage (SAC) is calculated assuming that all toner particles are spherical in shape with the same diameter as $D_{50}(v)$ measured in the Coulter Counter, and additive particles are in primary particle form and evenly distributed on the toner surface. With additive amount of 2 g, the calculated SAC for samples A, B, C, and D was 113%, 66%, 50%, and 23%, respectively. The ratio of the highest SAC to the smallest SAC was about 4.9:1.

The effects of blending temperature were tested by blending 200 g of core toner with 2 g of additive E in a powder blender at 8000 rpm for 4 min. During blending, the temperature inside the blender chamber was maintained at either 15, 25, 35, 45, or 55°C using a water-jacketed vessel. After blending, the blended toner was moved into a metal container with a rapid cooling system using liquid nitrogen. The blended toner was stirred during the cooling process and the temperature of the toner reached the target temperature of 15° within 15 s. Then the toner was sieved and labeled E1–E5. Toner samples E6–E10 were prepared by the same procedures, but they were allowed to cool under N/N ambient conditions instead of being rapidly cooled. Table IV summarizes these blending conditions. Another set of ten samples was prepared using the same blending conditions

Table IV. Additive-blending condition for temperature test.

Test ID	Additive	Amount (pht)	Blending temp. (°)	Rapid cooling
E1	E	1	15	Yes
E2	E	1	25	Yes
E3	E	1	35	Yes
E4	E	1	45	Yes
E5	E	1	55	Yes
E6	E	1	15	No
E7	E	1	25	No
E8	E	1	35	No
E9	E	1	45	No
E10	E	1	55	No

and procedures, but this time the toner was blended with additive F. The resulting samples were labeled F1–F10.

To observe the effects of blending temperature on print image quality, toner was blended with a mixture of four different types of additive, and prepared for the image quality test. Blending was done using 200 g of core toner, 1.6 g of additive F, 3 g of additive G, 1.0 g of additive H, and 1.4 g of additive I. Table V lists the blending conditions. The blending rpm value was maintained at 1000 during the first 6 min, and increased to 10,000 for the last 2 min. The blending was done in a controlled environment, where the blending temperature was maintained at either 15, 35, or 55°C. Blended toner was cooled and sieved: rapidly cooled samples were labeled P1–P3, while samples cooled in ambient temperature were labeled P4–P6.

Print image test

To perform the print image quality test, 55 g of core toner was loaded in a toner cartridge whose reference yield was 2200 pages. A commercially available color laser printer with 12 ppm printing speed was used for the test. The ISO/IEC 24712 LSA chart pattern was used for toner consumption and cartridge yield test[13] and a PQ pattern, which is modified from the STMC pattern, was used to measure the image density. A QEA test target Rev. 4.0 and an ImageXpert print 600 dpi target version 5.1 were used for the quantitative print image test. 80 g/m^2 paper was used in all tests. All toner cartridges, the printer, and the paper were N/N conditioned for at least 8 h before printing.

Toner consumption per page was calculated by measuring the change in toner hopper weight as printing progressed. The cartridge was disassembled, and the toner hopper weight and waste chamber weight were measured after every 1000 prints of the LSA chart. The difference in toner hopper weight was divided by the number of printed pages to yield toner consumption per page. Also, after every 1000 prints, a PQ pattern was printed and the image density was measured using a GretagMacbeth spectrophotometer. Cartridge yield was tested as described in ISO/IEC 19798 with the exception that one printer was used in the yield test instead of three printers.[14] The resolutions of 2 pixel dots, 2 pixel vertical lines, and 2 pixel horizontal lines were measured with a QEA Personal IAS. A snapshot of the 2 pixel dots from the ImageXpert target was taken by the IAS and the diameters of three dots were measured. These measurements were repeated twice and the measurements were averaged. The width of 2 pixel lines was measured in a similar way.

Particle size distribution measurement

Particle size distribution of toner was measured using Multisizer3 Coulter Counter, Beckman Coulter Inc, which measured the number average and volume average particle diameters. In 20 ml of ISOTON II solution (Beckman Coulter Inc.), 15 mg of toner was dispersed with a small amount of surfactant. The toner dispersion was then sonicated in an ultra-sonic bath for 5 min. A few drops of the toner dispersion were added to 150 ml of electrolyte in the Multisizer3 container, until the total particle concentration reached 4%. The measurement continued until 30,000 particles were counted. The measurement window was set between 2 and 60 μm. The average size diameter and size distribution were automatically calculated by the Multisizer3.

Triboelectric charge measurement

Triboelectric charge was measured by the blow-off method using an Epping GMBH q/m-meter. A dual-component sample for q/m measurement was prepared by mixing toner with ceramic surface-treated ferrite carrier with an average diameter of 40 μm. The toner and carrier were agitated using a WAB Turbular Mixerat 96 rpm for either 0.5, 1, 3, 10, or 30 min. The average result of three repeated runs was used for reliability.

Cohesiveness measurement

Cohesiveness was used as a measure of free flow of toner.[15] It was measured using Hosokawa PT-S powder tester. A small amount of toner, normally 2 g, was allowed to pass through three sieves whose mesh sizes were 53, 45 and 38 μm in respective order by means of vibration and gravity. The sieves were vibrated for 40 s at level 3 vibration on the adjustable knob on the front of the device. Once complete, the amount of toner on each sieve was weighed to calculate the cohesiveness by the following relationship:

$$\text{Cohesion} = \frac{100 \cdot m_{53} + 60 \cdot m_{45} + 20 \cdot m_{38}}{\text{toner\_load\_weight}},$$

where m_{53}, m_{43}, and m_{38} were the weights of toner on each subscript corresponding sieve.

Additive adhesion measurement

Additive adhesion was determined by measuring the amount of additives on the toner surface before and after the toner was exposed to an ultra-sonic blast. The ultra-sonication simulates the mechanical stress toner experiences in a toner cartridge. Additive adhesion can quantify how effectively additives adhere to the toner by exposing the toner to intense sonic energy or stress.

Table V. Blending conditions for print image test.

Test ID	RPM #1	Time #1 (min)	RPM #2	Time #2 (min)	Blending temp. (°)	Rapid cooling
P1	1000	6	10,000	2	15	Yes
P2	1000	6	10,000	2	35	Yes
P3	1000	6	10,000	2	55	Yes
P4	1000	6	10,000	2	15	No
P5	1000	6	10,000	2	35	No
P6	1000	6	10,000	2	55	No

The toner, whose additive amount needed to be measured, was dispersed with a presence of surfactant and stirred while being sonicated in a custom-made multi-stirrer bath with ultra-sonic connection for 30 min. The sonicated toner was washed and filtered. The amount of additives was then measured using a Philips X-Ray Fluorescence (XRF) MagiX. A set of reference XRF intensities of Si and Ti was determined by measuring a set of reference toner samples, whose additive amounts were set to 0.5, 1.0, 1.5, 2.0, and 2.5 pht of SiO_2 and TiO_2. The amount of additive SiO_2 or TiO_2 could be determined by comparing the measured XRF intensity to reference intensities. The XRF was used to measure the additive amount of the initial and sonicated samples, and the ratio of additives before and after the sonication was calculated as additive adhesion value and was used to determine how strongly additives adhere to base toner.

RESULTS AND DISCUSSIONS

Triboelectric charge

Figure 1 shows the triboelectric charge of the toner blended at different conditions. The core toner has a baseline triboelectric charge of −16.6 μC/g. Fig. 1(a) shows that the triboelectric charge curves are rather horizontal, indicating that the triboelectric charge is independent of blending time and that the charge is strongly determined by additive type. An analysis of variance (ANOVA) test was performed to determine the triboelectric charge difference of toner blended for 2, 5, 10, and 15 min. The calculated p-value was 0.857, and it could be concluded that the triboelectric charges were not different for the toner samples blended for different times. Fig. 1(b) shows that the triboelectric charge dependency on blending rpm value varies for different types of additive. In the case of additive B, the charge value increases from −30 to −35 μC/g with blending intensity increase from 4000 to 8000 rpm, but no further increment is noticed above 8000 rpm. However, the toner with additive D shows a different trend. The charge remains constant at −37 μC/g from 4000 to 8000 rpm, but it decreases to −35 μC/g at 12,000 rpm. Fig. 1(c) shows that the blending temperature has no effect on the saturated triboelectric charge. The triboelectric charge does not change with blending temperature with or without the presence of rapid cooling. The ANOVA test was used again to determine the change in triboelectric charge with blending temperature. The calculated p-value was 0.583 and the blending temperature did not change the triboelectric charge of the toner samples. Fig. 1(d) shows the charge ramp up for five samples prepared with additive F blended at five different temperatures. The toner was mixed with carrier and charged for 0.5, 1, 2, 10, and 30 min, and the triboelectric charge of the toner was measured with the blow-off method. When the toner was mixed with carrier and charged for longer time, the triboelectric charge of the toner increased. This shows that the blending temperature has a noticeable effect on the charging rate, even though the saturation charges are the same for the five samples. The toner which was blended below 35°C has a similar charging rate. However, the charging rate is found to be slower when the blending temperature is higher than 35°C. At higher blending temperatures, the additives may be more likely to be partially embedded into the surface of the toner, degrading their ability to enhance the triboelectric charge. The charging rate is mainly a surface effect, and it may decrease with a reduction of effective surface area of embedded additives.

Nevertheless, the exact mechanism of triboelectric charge is still unknown, and in most industrial applications empirical data is used. The exact relationships between the charging rate, blending temperature, and the resulting toner properties still need further study.[16–18]

Cohesiveness

Figure 2 illustrates the effects of blending time, blending intensity, the specific surface area of additives, and blending temperature on toner cohesion. Fig. 2(a) shows that the cohesiveness of toner is strongly dependent on additive types, especially additive sizes. The cohesiveness of the toner blended with additive A is the lowest, and the toner blended with additive D shows the highest cohesiveness. The cohesiveness is rather independent of blending time at blending intensity of 4000 and 8000 rpm. The core toner has a very poor free flow, and very high cohesion value of 98. The existence of additives dramatically reduces cohesion and improves toner free flow. Fig. 2(b) shows the effect of blending rpm value on cohesiveness, and it strongly depends on additive types. The cohesiveness of toner blended with additive B is lower than that of toner with additive D. This confirms again that selecting the proper additive type is the main factor in designing toner cohesiveness. The cohesiveness of toner blended with additive D did

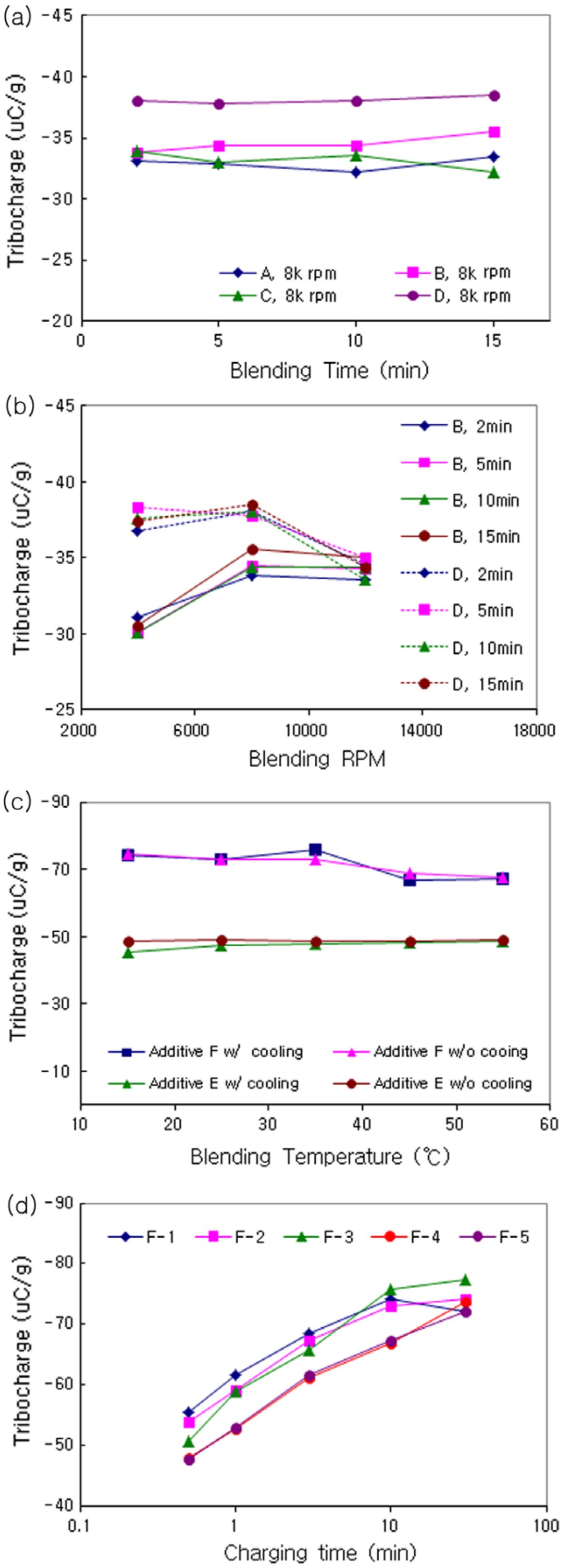

Figure 1. Triboelectric charge of toner blended under different conditions. (a) Tribocharge of toner blended for 1, 2, 10, and 15 min at 8k rpm. (b) Tribocharge of toner blended at 4k, 8k, and 12k rpm for 2, 5, 10, and 15 min. (c) Tribocharge of toner blended at 15, 25, 35, 45, and 55°C with or without rapid cooling. (d) Charging rate of toner samples F1–F5 blended at 15, 25, 35, 45, and 55°C.

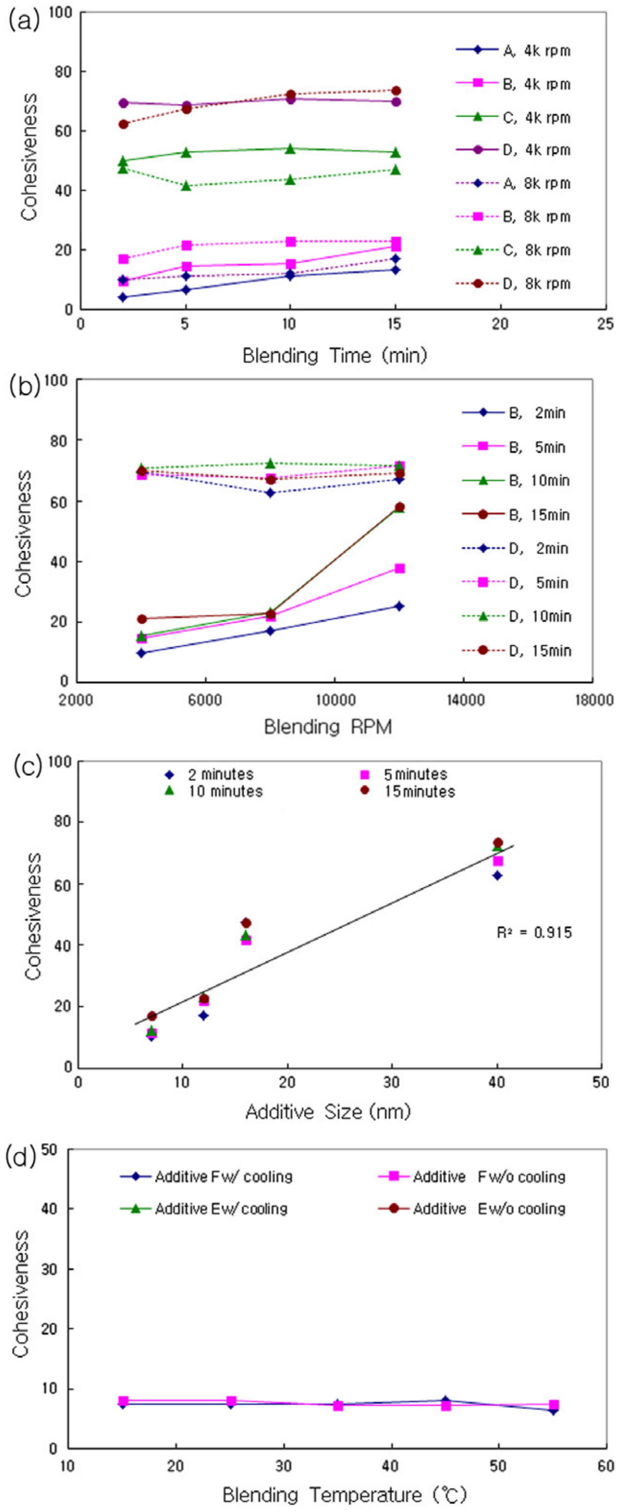

Figure 2. Cohesiveness of toner blended under different conditions. (a) Cohesiveness of toner blended for 1, 2, 10, and 15 min at 4k and 8k rpm. (b) Cohesiveness of toner blended at 4k, 8k, and 12k rpm for 2, 5, 10, and 15 min. (c) Cohesiveness of toner blended with different additive size of 7, 12, 16, and 40 nm. (d) Cohesiveness of toner samples E1–E5 and F1–F5 with or without rapid cooling.

not change much with blending rpm value, whereas the cohesiveness of toner blended with additive B changes with blending rpm value. Sample D shows a huge increase in cohesiveness when blended at 12,000 rpm. An explanation for this phenomenon is that, at higher blending intensity, the mechanical impaction pushes additives into the toner surface, and additives can be partially embedded in the toner surface. When additives are embedded in the toner surface, the function of reducing friction or interaction between toner particles is weakened and cohesiveness increases. It is more difficult to make the large additives embedded into the toner surface. Therefore, for the large additive D, the blending conditions have almost no effect on cohesiveness while the cohesiveness of toner blended with small additive B increases at higher blending intensities.

Fig. 2(c) shows the relationship between the additive size (primary particle size) and the cohesiveness. The cohesiveness increases with the additive size under every blending condition. The R^2-value was 0.915, and a strong relationship was found. Cohesiveness is a measure of toner free flow, in which friction or particle–particle interactions are the main factors. Cohesiveness was examined for toners blended with same weight of additives and the average number of additive particles per toner varied depending on the additive size and density. The specific surface area increases as the additive diameter decreases. Additives with high specific surface area dramatically reduce the particle–particle interaction, which hinders toner free flow, and they are very effective in improving toner free flow.

Fig. 2(d) shows that the cohesiveness remained at the same value when the blending temperature changed. In the ANOVA test, the calculated p-value was 0.413, and it could be concluded that the blending temperature had no effect on cohesiveness. The post-blending rapid cooling did not have any effect on the cohesiveness at all tested blending temperatures. This was confirmed in the ANOVA test, where the calculated p-value was 0.269. It is again shown that the additive type, especially the additive size, is the dominant factor in cohesiveness. The cohesiveness of toner with additive E is larger than that of toner with additive F at all blending temperatures. Additives E and F are made by a sol–gel method, have a perfect spherical shape, and exist in a primary particle form. These features of additives E and F reduce the cohesiveness compared to similar size fumed additives.

Toner particle size distribution

Figure 3(a) shows the average toner particle size, D_{50v}, of the toner samples blended with additive B. The toner particle size does not vary with blending time and blending intensity. The average diameter of all samples is 6.181 µm and the standard deviation is only 0.0359 µm. The diameter of blended toners is same as the diameter of core toner regardless of blending conditions. The difference in diameter between core toner and blended toner is 0.006 µm, and it is within margin of error. The diameters of toner blended with additives A, C, and D are the same. In the ANOVA test, the p-value was calculated as 1.00, and it was statistically confirmed that the toner size did not change with blending conditions. Fig. 3(b) shows the diameter of blended toner with additive E at different blending temperatures with and without rapid cooling after blending, and the particle size is the same regardless of the blending temperature and post-blending cooling rate.

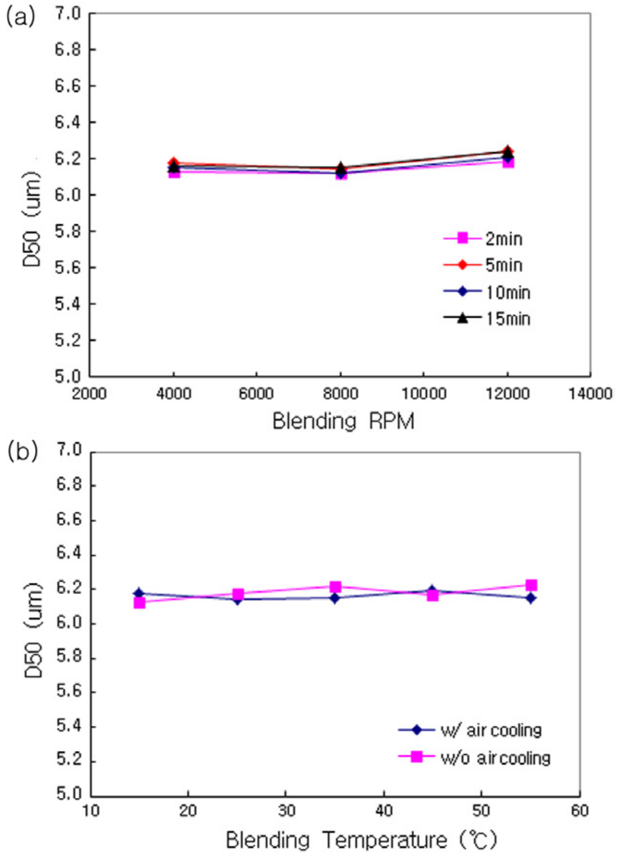

Figure 3. Average diameter of toner particle blended under different conditions. (a) Average volume diameter of toner particles blended at rpm of 4k, 8k, and 12k. (b) Average volume diameter of toner particles blended at 15, 25, 35, 45, and 55°C.

Toner surface morphology

Toner surface morphology is observed by using a scanning electron microscope (SEM). A high-resolution Jeol JSM-7400F was used, and the SEM images of the blended toners are shown in Figure 4. Fig. 4(a) is the SEM image of toner sample E6, which was blended at 15°C, and Fig. 4(b) is the SEM image of toner sample E10, which was blended at 55°C. No significant difference in toner surface morphology for different blending temperatures is observed. Even at 55°C, no sign of toner deformation, rupture, or agglomerates was observed. The toner particles are still spherical. The additives are uniformly distributed on the toner surface and do not form an aggregates.

Fig. 4(c) is the SEM image of toner E1, which was blended at 15°C with rapid cooling, and Fig. 4(d) is the image of toner E5, which was blended at 55°C without rapid cooling. It is observed that the blending temperature has almost no effect on toner surface morphology even with rapid cooling.

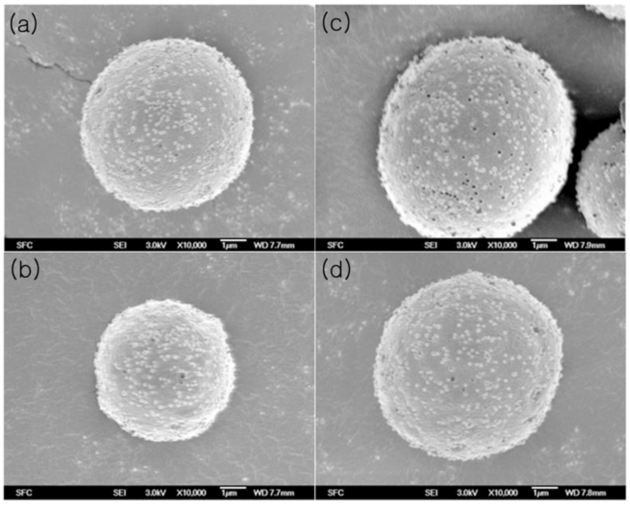

Figure 4. SEM images of Toner blended at different temperatures with or without rapid cooling. (a) SEM images of E6, blended at 15°C without rapid cooling. (b) SEM images of E10, blended at 55°C without rapid cooling. (c) SEM images of E1, blended at 15°C with rapid cooling. (d) SEM images of E5, blended at 55°C with rapid cooling.

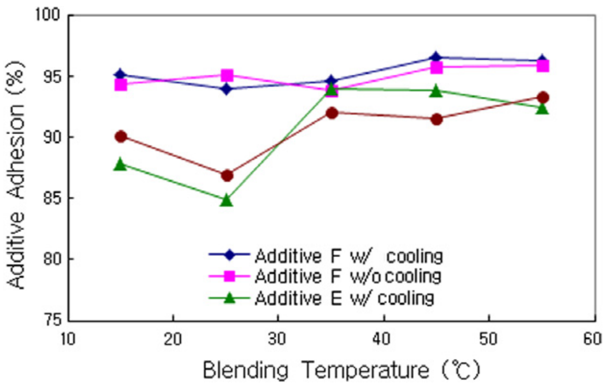

Figure 5. Additive adhesion of E1–E10 and F1–F10.

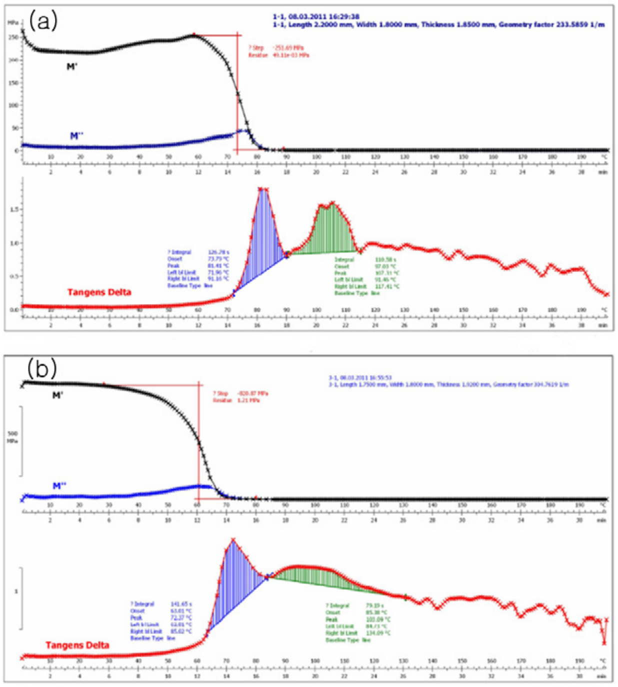

Figure 6. Dynamic mechanical analysis spectra. (a) Storage modulus, Loss modulus, and tangent delta measurement of the core toner. (b) Storage modulus, Loss modulus, and tangent delta measurement of the blended toner.

Additive adhesion

Figure 5 illustrates the additive adhesion of samples E1–E10 and F1–F10. The additive adhesion of sample F is higher than that of sample E at all tested blending conditions with or without the presence of rapid cooling. It is known that the attraction or adhesion between toner and additives becomes more significant for smaller additives and it was empirically confirmed that smaller additives F are attached to the toner surface more strongly than larger additive E. The additive adhesion of sample E is below 90% when the blending temperature is below 35°C, but it increases above 90% when the blending temperature is higher than 35°C. Additive adhesion becomes greater when the toner is rapidly cooled above the blending temperature of 35°C. However, additive adhesion is greater without rapid cooling when blended below 35°C. In sample F, additive adhesion does not change with blending temperature as much as in sample E. It still shows a greater value for blending temperatures above 35°C. Rapidly cooled toner shows higher additive adhesion, even though the change is smaller in sample E. In the ANOVA test, the calculated p-value was 0.013, and it could be concluded that the additive adhesion was different at different blending temperatures. To see the effects of rapid cooling, another ANOVA test was carried out and the p-value was calculated as 0.924. It was found that the rapid cooling after blending did not change the additive adhesion.

It is noticed that when the blending temperature is higher (above 35°C) and the sample is rapidly cooled, the additives are more strongly attracted to the toner surface, and more additives can remain on the toner surface after ultrasonic exposure, which simulates mechanical stress in the toner cartridge. The cause of this phenomenon is not clearly understood. However, dynamic mechanical analysis (DMA) of the core toner and blended toner provides a clue. As seen in Figure 6, the DMA spectra of the core toner and the blended toner show different storage modulus and tangent delta values. A small amount of external additives on the toner surface changed not only the electric and toner free flow properties, but also the thermo-mechanical properties. The storage modulus of the core toner increases with temperature up to 60°C, then decreases with temperature above 60°C. The storage modulus of the blended toner monotonically decreases starting at 28°C. Also the temperature at which the storage modulus reaches the residue modulus value is different for the core toner and the blended toner. The core toner reached a residue level at 88°C, while the blended toner reached a residue level at 72°C. However, the residue level for the blended toner is higher than that of core toner. The two peaks in the tangent delta graph occurred at 81°C and 107°C for the core toner, and the peaks were shifted to 72°C

Table VI. Image density and resolution of print tests.

Sample ID	Image density	2 pixel dot diameter (μm)	2 pixel vertical-line width (μm)	2 pixel horizontal-line width (μm)
P1	1.474	96.91	91.61	94.73
P2	1.546	102.88	96.81	101.80
P3	1.522	101.81	92.73	96.56
P4	1.476	100.68	96.57	102.63
P5	1.568	165.44	99.69	103.15
P6	1.558	110.99	100.73	104.70

and 103°C for the blended toner. The temperature at which the storage modulus of blended toner decreases is similar to the blending temperature, where additive adhesion becomes stronger. However, no direct relationship has yet been found, and this area needs further study.

Print image quality

The print image quality measurements of toner samples P1–P6 are listed in Table VI. The toner blended at 15°C has the lowest image density and the toner blended at 35°C has the highest image density with or without the presence of rapid cooling. Also, the toner blended at 15°C has the lowest toner consumption per page than other samples blended at 35 and 55°C. The toner blended at 15°C has the higher yield and it is similar to the reference toner yield, which was blended under N/N conditions. The other two toner samples have a lower yield than the reference yield. This is mainly because the additive composition and blending conditions are originally selected based on the test of samples blended under N/N conditions. Toners blended at a different temperature may require a modified additive composition and different blending conditions for optimal performance. The toners with rapid cooling exhibited lower image density compared to naturally cooled toners at all three different blending temperatures tested in this study. However, the toner consumption per page and cartridge yield do not show significant changes with rapid cooling. The reference blending condition was selected based on the test results without rapid cooling.

Figure 7 shows the snap shots of ImageXpert target printouts of P-1 and P-6. Differences in diameter and resolution can be clearly noticed. Table VI shows the diameter of a 2 pixel dot, the width of a 2 pixel vertical line and the width of a 2 pixel horizontal line, and they have the same trend as the image density. The toner blended at 15°C gives smaller dots and lines than the other two samples. The dots and lines become smaller when the toner is air cooled. Hence, rapid cooling after blending is found to enhance resolution for sharp images.

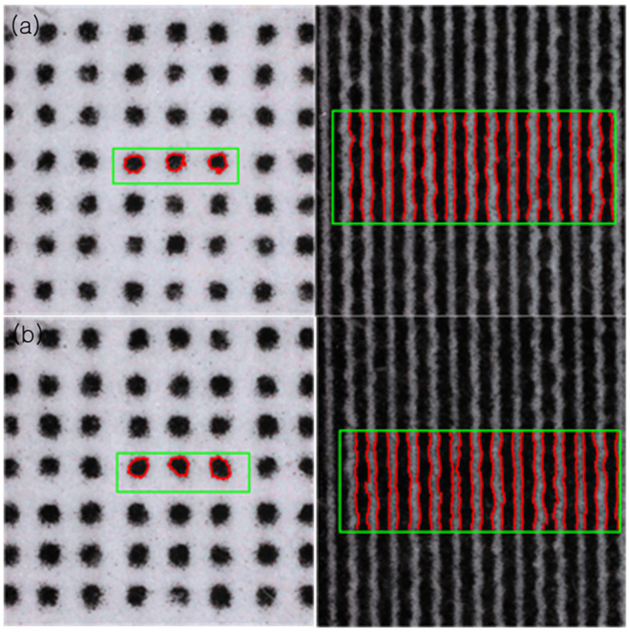

Figure 7. Print Image Resolution. (a) 2 pixel dot image and 2 pixel line image of P1 from ImageXpert target. (b) 2 pixel dot image and 2 pixel line image of P6 from ImageXpert target.

CONCLUSION AND FUTURE WORK

The additive-blending conditions, blending intensity, blending time, blending temperature, and cooling rate are studied and their effects on toner properties and actual image quality are reported.

We tested the effects of blending time and blending rpm values by blending toner with only one additive. The blending time has no effect on the triboelectric charge and cohesiveness. Both toner properties are more strongly dependent on additive types. The blending rpm value has an effect on triboelectric charge and cohesiveness, but its effect varies from sample to sample depending on the additive type blended with the core toner. The toner particle size and distribution do not change from those of the core toner for different blending times and rpm values.

The blending temperature has no effect on the saturation triboelectric charge and cohesiveness. The charging rate changes with blending temperature and becomes greater for the sample blended below 35°C. The high blending temperature does not deform an individual toner particle, as observed by SEM images. Additive adhesion becomes greater when toner is blended above 35°C with rapid air cooling. The print quality test is done by blending toner with a mixture of additives at three different temperatures. The blending temperature shows a change in image density and resolution. The post-blending cooling rate also has an effect on the print quality.

When toner experiences mechanical stress in a toner cartridge, additives may be embedded into the toner surface or detached from the toner surface. The additive loss can be characterized by measuring the additive amount on the toner surface before and after applying ultra-sonication, which simulates mechanical stress. However, the method of quantitatively analyzing additive embedment is not yet developed, but is still needed to characterize the performance of the blending process and its effects on print quality.

The effects of blending conditions were studied by blending one additive with the core toner, and the possible interactions between different types of additive were not studied. For industrial applications, it is important to know the relationships between the physical properties of additives and the toner characteristics and the relationships between the additive-blending conditions and the toner characteristics. We have tried to explain such relationships, though further study is required to verify whether they are universally applicable. However, the experimental results in this article provide various clues of the toner property analysis and will be useful in the toner industry.

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