Effect of Humidity on the Triboelectrification of Toner

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Abstract

The charging characteristics of toner are among the most important end-use properties within modern xerography. Toner charge stability is the ultimate design goal helping to make color printer more competitive in comparison to other printing technologies. In this study the tribocharge property of different color toner are compared. Particular emphasis was given to the humidity response of these composite materials. A standard test procedure has been developed.

The styrene-acrylic chemically prepared color toner analyzed here and most polyester toner show an unstable charging level with respect to humidity. In contrast, a stable humidity response was realized for toner based on cyclo-olefin copolymer binder resins. With these materials, consistent image print quality can be expected, which is unaffected by environmental conditions.

Introduction

In the first step of conventional xerography, the surface of a photoconductor is homogenously charged, typically by using a wire or grid biased to high voltage.[1,2] Subsequently, an electrostatic pattern is generated on the surface of the photoconductor by illuminating and consequently discharging or neutralizing the desired areas, whereby a so-called latent image is formed. In the third step, this latent image is developed by bringing it in close contact with toner of appropriate polarity.

At this point the toner is electrostatically transferred from the photoreceptor to a substrate, usually paper In the fifth step the image is fused by melting the toner onto a substrate surface, creating a permanent image. The energy needed to melt the toner can be supplied without contact to the toner, e.g. by radiation or light flashes or with contact by running the paper sheet between two rolls, of which at least one is heated.

In the final step, the photoconductor has to be cleaned of the remaining toner and its charge erased. This ensures that the photoconductor can be reused in its original condition.

As xerographic development on the photoconductor translates into a specific charge transfer, it is said to be an inverse function of toner charge level. From a toner viewpoint, the triboelectric charge is a critical property, and the creation and maintenance of a functional charge value is a major materials design challenge. In particular the following charging properties of toners are desired:

- Stable sign and value of toner charging providing consistent image quality under different workloads.
- Rapid charging of toner particles especially important for single-component development, where contact times of the toner between the charged donor roll and the metering blade is very short.
- Narrow charge distribution so that "wrong-sign" toner (and thus background development of white areas) are effectively avoided.
- Stable tribocharge level with respect to different environmental conditions to ensure that the image quality is independent of relative humidity.

Although variations in toner charge can be compensated for via closed-loop control of other factors, these control schemes, (including image density sensors, electrostatic voltage sensors, environmental temperature/RH sensors) add additional complexity and costs to the systems.[3] Thus inherent toner charge stability remains an important ultimate design goal.

Charge control agents are usually used in modern toner formulations to improve the level of the electrostatic charge and the charging kinetics.[4,5] Accurate toner and printer design is needed to minimize the amount of wrong-sign toner.[6] The hydrophilic / hydrophobic nature of toner raw material, esp. the employed polymer resins and external

additives, are claimed to be responsible for the relative humidity response.[3,7]

In color electrophotography two different charging and development processes are distinguished:

- Non-magnetic single component development: Toner is charged electrostatically as it passes through the voltage between the a so called metering blade and the supply roll. This development subsystem is simple but limited to speeds below 20 pages per minute, as every toner particle must have the chance to get charged by moving through the charging zone.
- Dual-component development: Charging is accomplished by rubbing toner against a metal oxide carrier of 50-100 micron size, so called tribocharging. High printing speeds can be achieved as, charging happens off-line in a separate, agitated container. This charging system is more expensive to build, as a separate container with controllable toner and carrier level is required.

This study compares the charging properties of several commercial color toners in a dual component development process, as this is easily simulated in off-line laboratory experiments. Particular emphasis was given to the relative humidity response of these materials.

Experimental

Several methods and apparatus to measure the amount of toner charge / mass (q/m) in dual component development systems are described in the literature. Often, large deviation of up to 200 – 300% for the charge value of one material is reported. Thus a standard test procedure for measuring q/m values is described, and a standard two-component developer was introduced.[8] The following important factors have to be considered:

- Toner equilibration at 50% RH at 20-25°C for at least 24 h.
- Toner concentration of between 3-5 wt%.
- Reproducible mixing conditions. Mixing by hand-shaking about 200 times with a speed of 2-3 cycles/s and a stroke of 0.3 m is proposed.
- Toner blow-off rates in excess of 90% to ensure that a representative sample is measured.

From the literature, it is well known that carbon black based black toner shows quite low charge values due to its electric conductivity, and tends to stabilize the charge by electronic conjunction.[9] Yellow toner are normally more negatively charged because of the diazo-type pigments that are typically used. In the present study, cyan toner pigmented with copper phthalocyanine, and magenta toner based on 2,9-dimethlyquinacridone or Carmine 6B colorants were used.

Standard Test Procedure

Prior to agitation, the toner samples are stored at 23°C and 50 RH for 48 h. Afterwards, 4 wt% of toner and 96 wt% of carrier are weighed into 50 ml glass vials with plastics caps. In order to avoid any interference from the plastic caps the inside of the cap is protected with aluminum foil.

The toner is then activated with a so-called roll mixer at 40 rpm. Note that these agitation conditions may be quite mild in comparison to the more aggressive mixing conditions in paint mixers.

The tribocharge level is measured with the q/m meter of Epping PES designed for dual component development. Around 2.5 g of the developer are weighed into the measurement cylinder, which is then closed with a 510 mesh sieve to allow only the toner and not the carrier to exit. The toner is then pulled off with a standard 1600 W aspirator for five minutes, and the remaining charge in the Faraday cage cylinder is recorded. Afterwards, the remaining mass in the cylinder is measured and q/m calculated by dividing the measured charge value q by the toner mass loss m. The toner weight loss also indicates if the toner is quantitatively removed. Typical removal rates are higher than 90%. A removal of <90% indicates that particles with a large q/m have been withheld by the carrier so that a wrong q/m value is obtained.

In order to study the influence of humidity on the tribocharge level, the toner is first activated against a carrier for a given time. Immediately after agitation a direct measurement is performed. In parallel, a sample of activated toner is stored for 24 h in aluminum pans at different conditions of controlled humidity. The following humidity conditions were tested:

- Low humidity by storing the activated toner at room temperature in a desiccator with silica gel drying agent. Control measurements indicate relative humidity levels of < 5% RH.
- Medium humidity level by storing the activated toner samples in a controlled humidity room of 23°C and 50% RH.
- High humidity by storing the activated toner sample at room temperature in a desiccators with a large water reservoir at the bottom. Control measurements indicate relative humidity levels of > 95% RH.

After 24 h of storing under controlled humidity, the remaining tribocharge level of the activated toner is measured and compared with the initial, unconditioned value. In all cases the reported values are the average of at least two individual measurements.

Results

A typical example of the toner charging as a function of agitation time and carrier composition is shown in Figure 1. Carrier 1 is a typical silicon coated Cu-Zn ferrite of approximately 80 μm size, while carrier 2 is an uncoated plate like iron oxide carrier of approximately 100 μm size.

As expected, the tribocharge value is different for the two carriers. For the further studies, carrier 1 was chosen as the reference material.

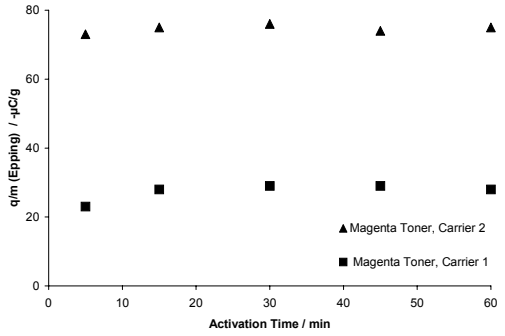

Figure 1. Triboelectrification of toner as function of mixing time.

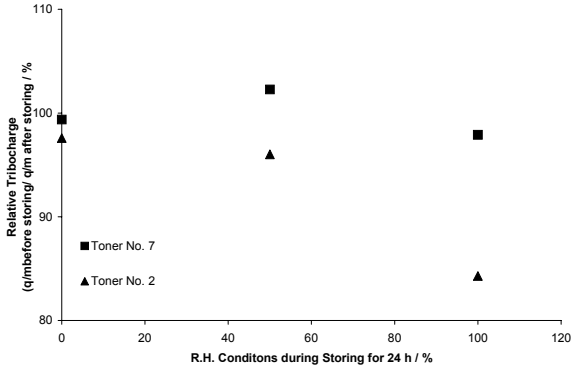

Figure 2. Relative Tribocharge as a function of RH during 24 h storing.

Table 1. Toners and Initial Tribocharge Value

No.	Resin	Preparation	Direct q/m - miroC/g
1	styrene-acrylic	chemical	40
2	polyester	milling	32
3	polyester	milling	10
4	polyester	milling	30
5	polyester	milling	20
6	polyester	chemical	8
7	COC	milling	30

Furthermore, it is seen from figure 1 that tribocharging for the toner studied here is quite fast, reaching a limiting value after ca. 15 minutes.

Toner classification and initial tribocharge value after 30 minutes agitation time are shown in table 1.

As polyester based toners are widely used in the color toner market, several were included for comparison. These toners are prepared either by classical jetmilling and classifying or via the newer "chemical".

In addition, chemically prepared styrene-acrylic toner and a toner based on cyclo-olefin copolymer (COC, available from Ticona under the tradename Topas® COC) were investigated.

As toner is a complicated composite material carefully developed to deliver optimum performance within a particular printing process and engine, it is not surprising that the material studied here show largely different tribocharge properties against the reference carrier.

In order to compare the impact of relative humidity on the tribocharge value, the tribochage measured after storing for 24 h at controlled humidity is compared to the 100% value of the direct measurement.

A typical result of remaining tribocharge after storing, compared to the direct value as a function of relative humidity, is shown in figure 2.

As shown in figure 2 the relative remaining tribocharge of the activated toner decreases as a function of relative humidity during storage. The decrease in tribocharge is thus most pronounced at high relative humidity. The apparent increase of the relative tribocharge with toner 7 shows that the testing method has limited accuracy.

From Figure 2, we conclude that the toner studied here shows dramatically different humidity responses: Whereas the tribochage level of toner 2 drops to only 84% of its initial value after 24 h storage at high humidity, toner 7 is hardly influenced by the humidity, with the charge level retaining 97% of its direct value.

These differences can be explained by the underlying chemistry of the two toner resins. Polyester toner resins, especially with the high acid values necessary for quick charging and good fixing, are known to have a significant humidity response on charge retention.[7] In contrast, toner based on amorphous cyclo-olefin copolymers show stable humidity response of the tribocharge value. This may be explained by the unpolar chemical nature of the polymer, which results in extremely low water uptake. The remaining relative tribocharge level (RRTL) of the other toners after storing at 95%RH for 24 h is shown in table 2.

The most significant humidity response is observed with toner 1, which was prepared chemically prepared styrene acrylic. As these binder resins are normally known to be less sensitive to relative humidity, some of the ingredients, or perhaps surface additives, may be moisture sensitive.

Table 2. Remaining Relative Tribocharge Level

No.	Resin	Preparation	RRTL /%
1	styrene-acrylic	chemical	72
2	polyester	milling	74
3	polyester	milling	70
4	polyester	milling	89
5	polyester	milling	99
6	polyester	chemical	95
7	COC	milling	97

The humidity response of toner based on polyester binder resins give rise to quite different humidity responses:

For toners 2-4, strong change of the tribocharge level with respect to relative humidity is observed, whereas toner 5 and 6 show quite high charge retention. Although it appears that some polyester toners are sensitive to environmental conditions, this effect can be masked by proper choice of the toner ingredients, e.g. polyester toner with low acid value, CCA concentration and selection, and special surface additives like hydrophobic titiania with low humidity response.

Toner 7, based on cyclo-olefin copolymer, shows very low sensitivity with respect to humidity during storing. This stable tribocharge level is apparently linked to the hydrocarbon nature of these materials. It is concluded that charging characteristics of cyclic olefins are more robust in varying humidity environments, thus requiring less development effort for humidity stabilization. Easier and thus less expensive design of color toner and printers can thus be achieved.

Conclusion

The triboelectric charging of several color toners has been measured under equivalent conditions. Particular emphasis was given to the relative humidity response. Styrene-acrylic chemically prepared toner and most polyester toners show an unstable humidity response, whereas cyclo-olefin copolymer binder resins exhibit relatively stable tribocharge retention across a range of humidity conditions.

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Biography

Klaus Berger received his Ph.D. in Physical Chemistry from the university of Paderborn, Germany, in 1995. He then worked on biodegradable polymers at the Federal Institute for Cereal, Potato and Starch Research in Detmold, Germany and on the rheological properties of associating polymer solutions at the Laboratory for Ultrasounds and the Dynamics of Complex Fluids in Strasbourg, France. In 1997 he joined the research and development group of Topas® COC within Hoechst and later Celanese/Ticona. He is currently working on Topas® COC toner binder resins for high quality printing in a fully equipped state-of-the-art polymer and toner lab. He I s a member of IS&T.