A Fusing Apparatus for Toner Development and Quality Control

Ming-Kai Tse, Francis Y. Wong, and David J. Forrest
QEA, Inc.
755 Middlesex Turnpike, Unit 3, Billerica MA 01821 USA
Tel: (978) 528-2034 · Fax: (978) 528-2033
e-mail: info@qea.com
URL: www.qea.com

Paper presented at the IS&T's NIP13
International Conference on Digital Printing Technologies
Nov 2-7, 1997, Seattle, Washington

A Fusing Apparatus for Toner Development and Quality Control

Ming-Kai Tse, Francis Y. Wong, and David J. Forrest
Quality Engineering Associates, Inc.
Burlington, Massachusetts, USA

Abstract

Toner fusing is a critical step in determining print quality in electrophotography. In the fusing process, the toner is melted and bonded to the media by the combined influences of heat, pressure, and time. Not surprisingly, the process is complex, and its success depends not only on the melting and viscous flow characteristics of the toner, but also on a wide range of variables such as machine design, roller lubrication, and media characteristics. Because of its complexity, it is generally impossible to predict how successful the process will be if traditional laboratory measurements, such as melt flow indices, alone are used. Instead, the quality of a print from a given fusing system can best be evaluated in the printer itself, or, better yet, in a test apparatus that closely simulates the printer but places the process conditions under user control.

The apparatus described here provides just such an environment. It is a computer-controlled hot-roll fusing apparatus that provides a flexible, general-purpose test bed designed to accept a wide variety of fuser roller types and sizes. It is suitable for testing a wide range of toners and substrates, including black and color toners and papers of different basis weights and surface coatings, as well as transparencies. It allows the user to vary each of the process conditions independently, including roll temperature, contact pressure, process speed, roller lubrication, and media type, and thus determine the fusing latitude of a given toner under different conditions or the range of a process variable within which fusing quality is acceptable for a particular application.

Given the rapid evolution of printing technology and the growing demand for high-performance color toners, quantitative fusing measurement is becoming more and more important. The toner fusing system described here can be used in conjunction with other measurement tools, such as an automated image analysis system for quantitative print quality evaluation and a spectrophotometer for measuring both transmitted and reflected light quality, for the highest level of toner fusing quantification. The toner fusing apparatus is a powerful tool both for toner, media, and fusing system development and for quality control.

This paper discusses the design requirements, key design considerations, test results obtained in evaluating the prototype, and the experience gained in the process.

Introduction

Successful toner development requires an understanding of the critical properties that contribute to image quality. Theoretical models of the fusing process can help identify important factors; but such models must be validated and refined by experiment, and this requires appropriate test equipment. The ideal test apparatus duplicates field conditions, behaving just like the fusing system in a printer or copier but providing independent control over each process variable to facilitate experimentation and simulate extreme conditions for quality control.

In printers and copiers that employ dry powder imaging, the toner is fixed, or fused, to the substrate. Fixing the toner powder involves liquification, coalescence or sintering, spreading, penetration into capillaries, and resolidification (see Figure 1).[1, 2] In hot-roll fusing, the image is fixed by the combined effects of time, temperature, and pressure.

The fixing temperature "window" is bounded above by hot offset (manifested by adhesion of the toner to the hot-roll surface) and below by cold offset (manifested by the transfer of unfused toner to the hot roll). Toner designers aim to maximize the fusing latitude – that is, the temperature range between hot offset and the minimum fix temperature – so that desirable fixing quality can consistently be achieved (see Figure 2). The apparatus described here was developed to advance this goal.

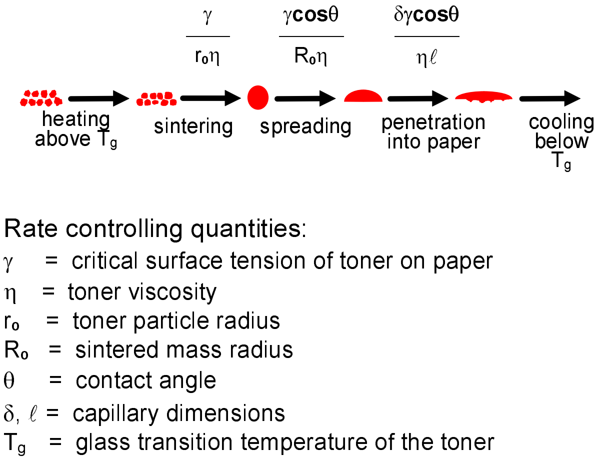

Figure 1: Processes involved in toner fusing on paper (after Lee[3] and Prime[1])

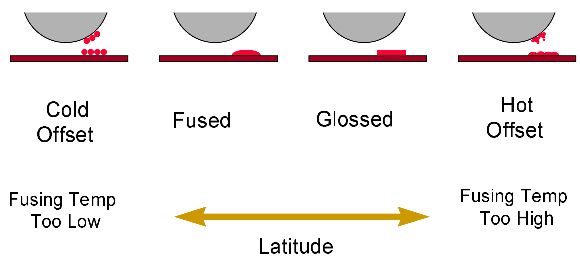

Figure 2: Schematic of fusing latitude.

Fusing Apparatus Design Requirements

Any test apparatus designed for controlled fusing experiments must possess certain features. It must be constructed to deliver unfused images on paper or other media to a fusing system. (The unfused images are typically generated by a printer with its fusing sub-system disabled.) The apparatus must have a complete fusing system in which roller speed, temperature, and pressure can be independently adjusted. It must offer the researcher control over both material and process variables. Fused output from the apparatus must be conveniently collected for evaluation by the investigators. Figure 3 shows a simple schematic of a toner fusing apparatus. The specific capabilities required of the apparatus are described below.

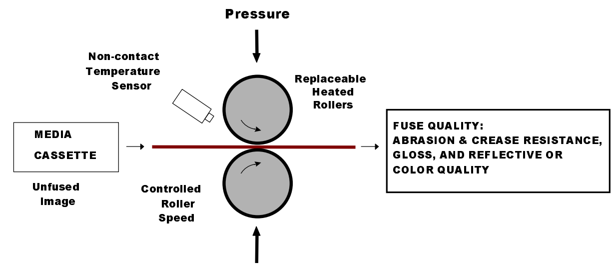

Figure 3: Schematic of test apparatus.

Material Variables

1. **Medium**. The apparatus must be designed to accept a range of media, including both papers of different sizes and basis weights and transparencies, without jamming.
2. **Toner**. Since an important application of the apparatus is to compare different toners, its operation must be independent of toner type.
3. **Rollers**. The apparatus must be designed for use with rollers of different sizes and materials, to mimic the wide variety of hardnesses and surface properties of fuser and pressure rollers found in printers and copiers. To facilitate experimentation, changing rollers must be made easy.
4. **Lubricant**. Many printer and copier fusing systems apply a lubricant to the fuser roller to prevent adhesion of toner to the roller. The test apparatus must be equipped to apply a lubricant selected by the operator.
5. **Pattern**. Since the experimenter may wish to test fusing quality with a wide variety of test patterns, the apparatus must be designed to maximize the printable area of the media and minimize any disturbance of the unfused image.

Process Variables

1. **Feed Sequence and Rate**. The apparatus must be designed for operator control over the rate at which unfused images are fed into the fuser, as well as the pause (if any) between images. Furthermore, since experiments may involve exact sequencing of different test patterns or intermittent blank pages, the apparatus must afford control over the fusing sequence.
2. **Fuser Roller Surface Speed**. Fundamental to fusing quality is the speed at which the medium travels through the nip between the rollers. Fusing “dwell time” is a function of nip width (itself a function of roller elasticity and pressure) and the surface speed of the roller. The apparatus must provide accurate control over roller surface speed to control dwell time.
3. **Surface Temperature**. Another fundamental parameter affecting fusing quality is temperature. The apparatus must provide precise control over the fuser roller surface temperature.
4. **Pressure**. Roller pressure is another critical variable affecting fusing quality, and the apparatus must

therefore afford control of the pressure between the rollers.

5. **Lubrication Rate**. The apparatus must be designed to apply lubricant to the fuser roller evenly and consistently, and the operator must be able to control the rate of application.

The toner fusing apparatus is designed to meet these requirements. Placing all of the process variables under user control, the apparatus makes it possible to change any one variable or any combination of them while keeping the others unchanged. The system provides computer control over the page feed rate, roller surface speed, and roller temperature. Enhancing the system's utility for both research and quality control, the software also automatically logs fusing temperature statistics for each page.[4]

System Evaluation

The toner fusing apparatus was evaluated by examining the full range of performance of each of its sub-systems. For example, the system was tested at page feed rates between 1 page per minute (ppm) and 60 ppm, using a variety of media. Similarly, performance was tested at roller surface speeds between 4 ppm and 60 ppm. Temperature control was verified from 30°C to 200°C with 1°C resolution. The system's ability to fulfill each of the other design requirements was likewise verified.

After the requirements were individually checked, a more practical evaluation was performed by running a series of toner fusing experiments. The experiments were designed to determine the fusing latitude of four different toners at various speeds using two different types of media (white paper and clear transparency). The range of speeds, temperatures, media, and toner were selected to test the versatility and ease of use of the apparatus.

Analysis and Quantification of Experimental Results

Experiments conducted with a toner fusing apparatus are only useful if the fixing quality of its fused output can be quantified. In this study, three methods were used to determine fixing quality.

The first method was qualitative visual inspection. Visual inspection is very effective for identifying clearly unacceptable fixing quality. If the test print is properly designed, one can easily detect severe cold offset and hot offset without the aid of instrumentation. In addition, a piece of clear adhesive tape was used to test for poorly fixed toner – when the fixing quality is good, almost no toner will be lifted off by the tape.

Although visual inspection is an important tool, especially for identifying unusual phenomena and extreme conditions, its utility is limited since it is subjective and qualitative. To analyze the subtle effects of small changes in process parameters, quantitative measurement techniques are required, such as the second and third methods used in this study.

The second method of quality evaluation, the "crease test," was performed on images fixed onto paper. The paper was folded across a solid fill area of the image and controlled pressure was applied to form a crease. The paper was then unfolded, and a clean cotton swab was used to wipe away loose toner along the crease. Finally, the optical density in an area encompassing the crease was measured using an automated image analysis system.[5] The poorer the fusing quality of the image, the more toner was removed by the cotton swab and the lower the measured optical density.

The third method of quality evaluation, called the transmission test, was performed on images fixed onto transparencies. The fixed images were backlit with broadband (white) light, and the light energy transmitted was measured using a spectrophotometer.[6] This technique is especially effective for color toners, which transmit less light when poorly fixed.

The toner fusing apparatus performed very well in these experiments. No paper jamming occurred, regardless of media type or speed. Execution of the test plan was simple and efficient, as the system proved to be very easy to use.

Results

A representative sample of the results from the crease tests, shown in Figure 4, demonstrates the effectiveness of the apparatus in toner studies.

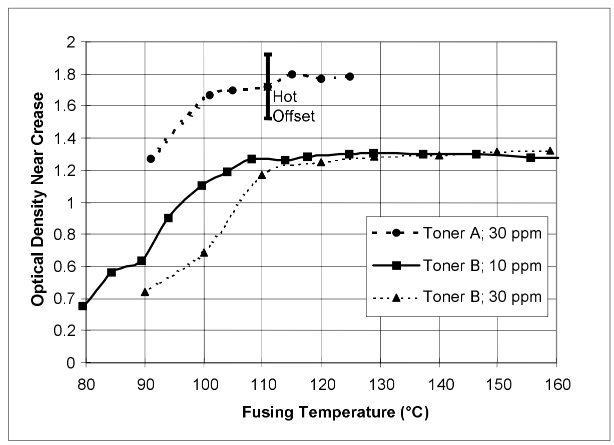

Figure 4: Representative crease test results. Visual inspection indicates that the hot offset temperature of toner A is 111°C at 30 ppm. No hot offset was observed for toner B.

Note that although both toner A and toner B are black toners, toner A is darker. From Figure 4 we see that the fusing quality for toner A decreases rapidly below 100°C. Visual inspection indicates that above 111°C, toner A exhibits hot offset. Therefore, under the selected test conditions for paper, pressure, speed, lubrication, etc., the fusing latitude for toner A was found to be between 100° and 111°C – a very narrow range.

The fusing latitude for toner B was shown to be much greater. Above 110°C, fusing quality was quite stable, and no hot offset was observed. The study shows that better fusing quality was achieved at lower temperatures when the paper speed was reduced, thereby increasing the dwell time of the page in the nip of the rollers.

A representative sample of the transmission test results is shown in Figure 5.

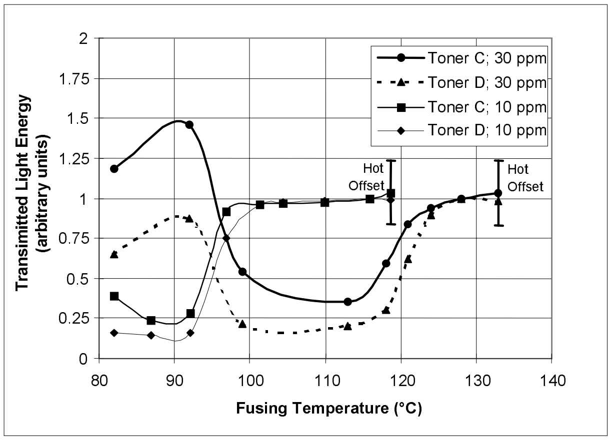

Figure 5: Representative transmission test results. Visual inspection indicates that the hot offset temperature of both toners is 119°C at 30 ppm. At 10 ppm, the hot offset temperature is 133°C for both toners.

Toners C and D are both color toners, and both behaved very similarly in light energy transmission tests. With the fusing speed at 30 ppm, both toners exhibited cold offset below 100°C. Since cold offset removes some of the deposited toner, the transmission energy was relatively high below the cold offset temperature, even though the fixing quality was very poor. From 100°C to 120°C, at 30 ppm the fixing quality of both toners was still very poor, as evidenced by the low level of transmitted light energy. If a transparency fused in this temperature range were projected on a screen, the colors would appear very dull, or the transparency might even appear black. From 124°C to 133°C, at 30 ppm, both of these toners fixed well, although hot offset was reached above 133°C, meaning that at 30 ppm the fusing latitude for these toners is quite narrow between 124°C and 133°C. At 10 ppm the fusing latitude was much better. At this speed, good fixing quality was achieved at 100°C for both toners, and hot offset was reached at 119°C.

For the given rollers, pressure, and lubrication, all of which remained constant throughout the experiments, the following fusing latitudes were identified:

Toner	Medium	Speed (ppm)	Minimum Temp. (°C)	Maximum Temp. (°C)
A	paper	30	100	111
B	paper	10	110	160
B	paper	30	110	160
C	transp.	10	100	119
C	transp.	30	124	133
D	transp.	10	100	119
D	transp.	30	124	133

Clearly, toner B has the best fusing latitude, fixing well between 110°C and 160°C with almost no sensitivity to speed. The color toners C and D exhibit much better fusing latitude at lower speeds.

Discussion

Analysis and quantification of fixing quality is a crucial aspect of any fusing study. The three techniques employed here for analyzing fused output reveal only some of the many contributors to fixing quality. Other factors, including gloss and resistance to abrasion, are also important determinants of quality. The most dependable conclusions will be achieved when experimenters employ a variety of analytical techniques in assessing toner studies.

The experiments summarized here were very easy to conduct with the toner fusing apparatus. Only four variables (toner, media type, speed, and temperature) were adjusted in these experiments, but the system provides a simple means for controlling the six others (test pattern, roller type, lubricant, lubrication rate, pressure, and page feed rate). This flexibility makes the toner fusing apparatus a powerful tool for a wide range of fusing studies.

Conclusions

1. Using the toner fusing apparatus, the fusing latitude of a variety of toners under user-controlled conditions was easily determined. The apparatus is able to demonstrate clear differences between toners under different process conditions.
2. The apparatus is a precise quantitative tool suitable for use in a wide range of toner studies. Applications include both development and manufacturing quality control.
3. The highest standards of quantification can be achieved when the toner fusing apparatus is used in conjunction with other specialized measurement tools such as an image analysis system and spectrophotometer.

References

1. R. Bruce Prime, Electrophotography Fourth International Conference, pp. 357-372, 1981.
2. Edgar M. Williams, The Physics and Technology of Xerographic Processes, pp. 245-259, John Wiley & Sons, 1984.
3. L. H. Lee, Adhesion Science and Technology, L. H. Lee, ed., pp. 831-852, Plenum Press, 1975.
4. Quality Engineering Associates, Inc., TFS-1000 Toner Fusing System
5. Quality Engineering Associates, Inc., IAS-1000 Automated Image Analysis System
6. Quality Engineering Associates, Inc., SPM-100 Spectro-photometer