Optimizing Developer Roll Design for Increased Component Life

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Abstract

Developer roll design variables including roll compliance, coating hardness, and topography were evaluated relative to toner filming and photoconductor (OPC) wear; two common end of life failure modes in contact development laser printer systems. It was found that reduced coating hardness offered the greatest potential for minimizing toner filming. With respect to OPC wear, trends indicate that both overall developer roll compliance and topography can influence the usable life of the photoconductor; with softer rolls and a peaked topography preferred.

Introduction

Trends towards increased page yields and reduced cost per page in the laser printer marketplace have driven a shift from cartridge-based architectures towards printers with semi-permanent developer units. As a result, it has become increasingly important to extend the usable life of electrophotographic (EP) components such as the photoconductor (OPC), doctor blade, and developer roll. In contact development systems, the primary end of life failure modes for these components include OPC wear and toner filming, both of which can be strongly correlated to developer roll design. Yet it remains unclear exactly which factors in roll construction have the greatest impact on failure. In this work, overall developer roll compliance, surface (coating) hardness, and topography were considered; examining the influence of each independently on toner filming and OPC wear in an effort to improve our understanding of optimal developer roll design.

For the purposes of this study, 2-layer developer rolls were examined in non-magnetic single-component laser printer systems. They were comprised of thick (4-6mm) semi-conductive (10^4-10^8 Ω-cm) elastomeric cores molded onto conductive metal shafts. To the surface of each core, a thin (50-100 μm) elastomeric coating of higher resistivity (10^{10}-10^{12} Ω-cm) was applied.

As the thickest layer, core compliance is a primary factor in determining the overall hardness of the finished developer roll. To create rolls of varying hardness, three different core resins with durometer hardness ranging from 40 to 70 Shore A were used (**Table 1**). Although the chemical composition of each core was quite different, the impact of those differences on toner filming or OPC wear should be minimal because, after coating, the core does not interact directly with the toner or other printer components.

Table 1: Core Selection

Core Designation	Hardness (Shore A)
1	66
2	46
3	41

The same cannot be said, however, for the developer roll coating. Material-based properties such as surface tack, coefficient of friction, and abrasiveness can significantly alter roll function as it relates to toner filming and/or OPC wear. In an effort to isolate surface hardness as a test factor, it was therefore necessary to create coatings of varying hardness while maintaining a consistent chemical composition. This was accomplished using a mixture of branched and linear curatives in a polyester-based polyurethane coating. By varying the ratio of branched:linear materials it was possible to vary the cross-link density of the elastomer and, thus, its hardness with minimal alteration of the overall chemical composition of the coating. The hardness of each coating was estimated using independently prepared thin-film samples and a Shore M durometer. The results are listed in **Table 2** for reference.

Table 2: Coating Hardness

Coating Designation	Hardness (Shore M)
A	77
B	71
C	69
D	65

Surface texture is another key aspect in developer roll construction; most often used as a knob to control toner mass and charge. It is generally quantified in terms of roughness (Ra and/or Rz), but such numerical specifications do not offer a complete description of roll topography. It is possible to create rolls of similar roughness using different combinations of fillers, molding, or grinding techniques affording very different landscapes on the surface of a developer roll. **Figure 1** shows SEM images of three developer roll surfaces with different topographies commonly found in commercial systems today; namely grooved (X), pitted (Y), and peaked (Z). All three textures were examined in relation to this study.

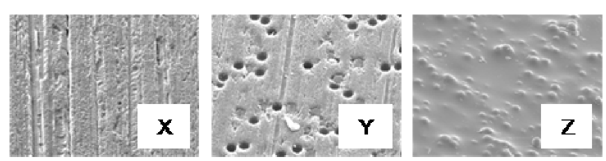

***Figure 1**. SEM images of typical developer roll topographies; (X) Grooved; (Y) Pitted; (Z) Peaked.*

In all, eight developer roll configurations were created to isolate and vary three different test factors, roll compliance, surface hardness, and topography to examine their impact on toner filming and OPC wear. Each roll type was given a unique ID reflecting its core, coating, and texture components which are summarized in **Table 3**. In one case, C2X, data from the same set of rolls was used in the analysis of multiple test factors.

Table 3: Experimental Developer Roll Configurations

Roll ID	Coating (ShoreM)	Core (ShoreA)	Topography	Test Factor
A2X	77	46	Grooved	Surface Hardness
B2X	71	46	Grooved	Surface Hardness
C2X	69	46	Grooved	Surface Hardness
D2X	65	46	Grooved	Surface Hardness
C1X	69	66	Grooved	Roll Compliance
C2X	69	46	Grooved	Roll Compliance
C3X	69	41	Grooved	Roll Compliance
C2X	69	46	Grooved	Topography
C2Y	69	46	Pitted	Topography
C2Z	69	46	Peaked	Topography

Experimental

Toner Filming

The effects of long term toner churn were replicated in an accelerated test using a specialized fixture designed to cycle the developer roll within a laser printer cartridge in the absence of a photoconductor, such that the undeveloped toner was constantly recycled within the cartridge. Low toner loading, 40 g, further stressed the system to hasten failure. Each experimental developer roll was built into a new, unused cartridge; then placed into the test fixture and cycled continuously for 1 hour. Print samples were generated at the end of the hour and evaluated for the presence of thin vertical white streaks indicative of toner filming of the doctor blade. The test was repeated for up to 35 hours or until print defects related to toner filming were observed at which point the roll was rated “fail” and removed from test. Results are quantified in terms of time to film (TTF) reflecting the number of hour-long cycles required to achieve failure. Each data point represents an average of three rolls per sample cell.

OPC Wear

Photoconductor wear was tested using a modified laser printer in which the cleaning and transfer systems had been removed to minimize non-developer roll contacts on the OPC. The photoconductors had a drum-based architecture comprised of OPC layers coated on an anodized aluminum core. Experimental developer rolls were built into cartridges and filled with 400 g of toner. Each roll/cartridge was paired with a new, unused photoconductor and charge roll; then cycled continuously for the equivalent of 25,000 pages under an applied white vector to prevent toner development. The test was paused approximately every 800 pages to refresh the toner in an effort to minimize filming. The average thickness of the OPC layers around the circumference of the drum and along the length of the paper path was measured for each pairing before and after test using an eddy-current tester. Reported wear values are a measure of the change in OPC thickness, and represent an average of 3-5 developer roll/OPC pairings per sample cell.

Results and Discussion

Toner Filming

Toner filming results when the toner is broken down due to the churning action of the development system and repeatedly passing through high pressure nips between the developer roll and other cartridge components such as the doctor blade. Over time extra particulate additives (EPAs) are lost from the surface of the toner altering its ability to flow and accept or hold a charge. At its worst, the exposed waxy surface of the toner smears across the surface of the developer roll forming a film or cakes onto the doctor blade inhibiting its ability to meter a uniform toner layer. From a customer perspective, toner filming is manifest in print defects such as thin vertical white streaks that result from the scraping action of agglomerated toner masses on the surface of the doctor blade.

In an effort to understand how developer rolls might be better designed to reduce the rate of toner breakdown and extend the usable life of cartridge components, three different aspects of roll construction were evaluated relative to toner filming. These included overall roll compliance, surface (coating) hardness, and topography. End of life failures were quantified in terms of time to film (TTF) which measures how long, in hours, the development system can withstand continuous toner churn before the first sign of print defects related to toner filming of the doctor blade. Each data point is an average of the results for three tests per cell and error bars represent $\pm 1\sigma$.

By far, the strongest correlation was observed for developer rolls with differing surface hardness (**Figure 2**). The hardest coatings (77 Shore M) afforded filming in under 4 hours while a steady increase in time to film was observed as coating hardness was decreased. The softest coatings (65 Shore M) yielded a seven-fold improvement with an average TTF of nearly 28 hours. This is consistent with the theory that the softer developer roll coatings act as a cushion for the toner particles as they pass through the doctor blade nip minimizing toner wear.

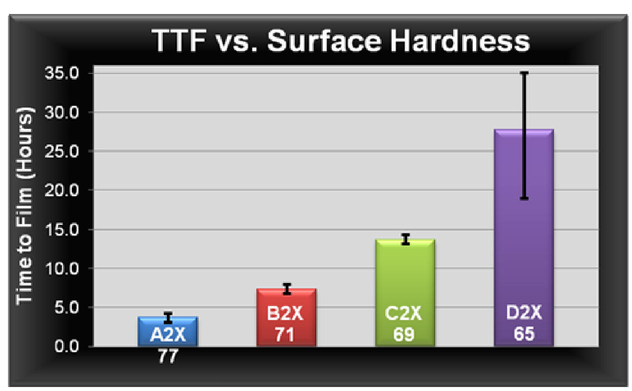

***Figure 2**. Time to film versus developer roll coating hardness: Each data point is an average of three tests per cell and error bars represent ±1σ. Column labels indicate the roll configuration ID and coating hardness in Shore M.*

Interestingly, we did not see a similarly strong correlation when the overall roll compliance was varied. Given the marked reduction in the rate of toner filming observed when decreasing the hardness of just the top 50-100 µm of the developer roll, one might expect an even greater response when the overall hardness of the roll was reduced. Instead, there was only a slight, statistically insignificant, trend towards increased TTF with significant decreases in roll hardness (**Figure 3**). This may reflect a competitive balance between the advantage of reduced nip pressure and the disadvantage of increased nip width relative to toner working when a softer developer roll is used. Given the relatively small size of the toner particles (5-10 µm), however, it is more likely that the 50-100 µm coating is more than sufficient to fully cushion the toner; making any additional compliance afforded by a softer core unnecessary.

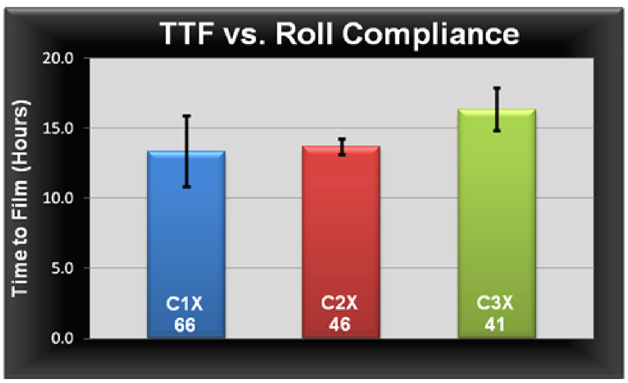

__Figure 3__. Time to film versus overall developer roll compliance: Each data point is an average of three tests per cell and error bars represent ±1σ. Column labels indicate the roll configuration ID and core hardness in Shore A.

Topography also had relatively little impact on time to film (**Figure 4**). Grooved and pitted surfaces were statistically equivalent. There was a decrease observed in TTF for samples with a peaked topography, but given the strong correlation of TTF with surface hardness it is difficult to say if this is actually the result of topography or localized areas of increased surface hardness due to the fillers required to create the surface texture.

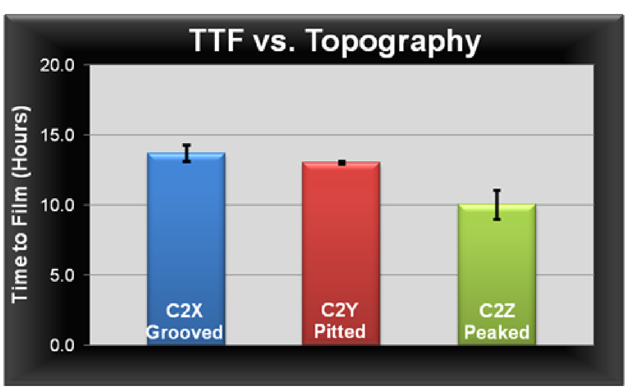

__Figure 4__. Time to film versus developer roll topography: Each data point is an average of three tests per cell and error bars represent ±1σ. Column labels indicate the roll configuration ID and topography.

OPC Wear

Throughout its life, the topmost organic layer of the photoconductor is worn by the constant abrasive action of components such as the cleaner blade, transfer system, developer roll, and toner. As this layer becomes thinner its ability to charge uniformly becomes compromised, ultimately resulting in areas of high background development affording unacceptable print quality.

Although the developer roll is certainly not a lone actor with respect to OPC wear, it can be a significant contributor and there exists an opportunity to improve system performance by better understanding how different aspects of developer roll construction impact wear. As above, roll compliance, surface (coating) hardness, and topography were considered, in this case relative to OPC wear. Reported wear values are a measure of the change in OPC thickness before and after test. Each data point is an average of 3-5 developer roll/OPC pairings per sample cell and error bars represent ± 1σ.

Unfortunately, the test method was found to be highly sensitive to the relative fixturing of the developer roll and OPC within the test apparatus affording a high degree of variability in measured wear among samples of the same type. In an effort to compensate, sample sizes were increased from three to five rolls per cell if the excess parts were available. Although the high level of variability precludes definitive statistical correlations, the observed trends may still offer some insight.

There was a trend towards reduced OPC wear as overall roll hardness was decreased (**Figure 5**). This is consistent with the idea that reduced nip pressure between the developer roll and OPC reduces the abrasive force of the developer roll, thus minimizing wear.

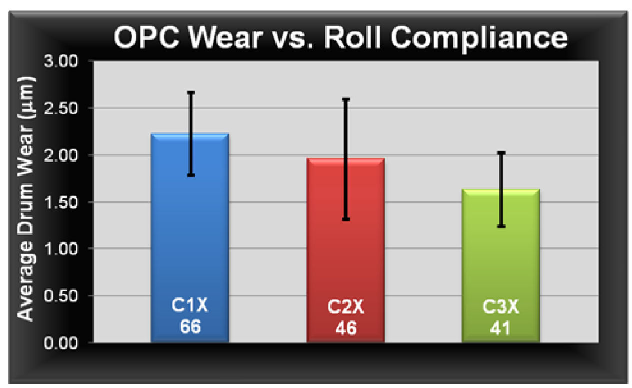

__Figure 5__. Change in OPC thickness versus developer roll compliance: Each data point is an average of 4-5 tests per cell and error bars represent ±1σ. Column labels indicate the roll configuration ID and core hardness in Shore A.

Changing the developer roll topography offered similar reductions in OPC wear (**Figure 6**). Pitted developer roll surfaces performed the worst. For this particular topography, the holes present on the surface of the developer roll create a multitude of rough edges that run perpendicular to the rotational direction of the developer roll and OPC like little scoops. It may be that these edges increased the abrasive action of the developer roll, thus, increasing OPC wear. A grooved surface texture is also comprised of numerous edge aspects, but due to the nature in which such surfaces were created for the purposes of this study, those edges lay nearly parallel to the rotational direction of the developer roll and OPC. As a result, this texture was slightly less abrasive and less OPC wear was observed. With a peaked surface, rough edges are eliminated and the contact area between the developer roll and OPC is minimized affording further wear reduction.

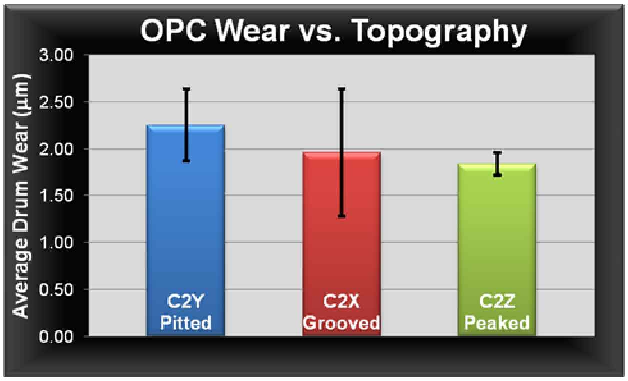

Figure 6*. Change in OPC thickness versus developer roll topography: Each data point is an average of five tests per cell and error bars represent ±1σ. Column labels indicate the roll configuration ID and topography.*

There does not appear to be a direct correlation between surface hardness and OPC wear (**Figure 7**). Although the data indicate a significant drop in OPC wear for the hardest coating, this may result from severe toner filming observed in the earliest stages of the test which most likely altered the developer roll surface and toner flow within the system. In the absence of toner filming, wear results for two softer coatings were statistically equivalent. Further testing in an un-toned system will be required for clarification.

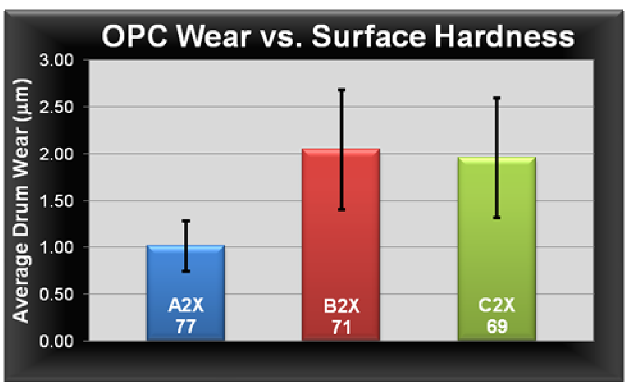

Figure 7*. Change in OPC thickness versus developer coating hardness: Each data point is an average of 3-5 tests per cell and error bars represent ±1σ. Column labels include roll configuration ID and coating hardness in Shore M.*

Summary and Conclusions

Developer roll design variables including roll compliance, coating hardness, and topography were evaluated relative to toner filming and OPC wear; two common end of life failure modes in laser printers with contact development systems. Of those factors tested, only developer roll coating hardness showed a significant correlation with toner filming. In an accelerated test, a seven fold increase in time to film was achieved with a moderate decrease in coating hardness from 77 to 65 Shore M. With respect to OPC wear, trends indicate that both overall roll compliance and topography can be used to reduce wear; with softer rolls and a peaked topography preferred.

According to these results an optimal developer roll design would be comprised of a compliant core and soft coating with peaked topography. Although there was some indication of increased toner filming with the peaked topography it should be possible to compensate with a softer coating that strikes the appropriate balance of properties. In the end, combining all three factors should significantly extend the usable life of the developer components affording consumers increased page yield with reduced interventions throughout the life of their printer.

Author Biography

Kelly A. Killeen received her BS in chemistry from the University of Rochester (1990) and her PhD in chemistry from the University of California, Irvine (1996). Following a post-doctoral appointment at the University of Southern California, she joined Lexmark in 1998 as an R&D chemist specializing in the development of novel materials for the printing industry. Since that time she has worked on a wide array of projects spanning both laser and inkjet printing technologies.