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Comparative Assessment of Various Toner Types and Its Impact on Print-Edge Quality in Electrophotographic Printing Presses

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Abstract

Print-Edge sharpness is one of the most important parameters for evaluating print quality in electrophotographic printing because it directly influences image clarity, text readability and the overall visual appearance of printed products. The present study investigates the influence of toner technology and paper substrate on Print-Edge sharpness through a comparative assessment of three commercially available toner types, namely Emulsion Aggregation (EA) toner, Polymerized toner and Pulverized toner. The study was conducted using four commonly used printing substrates: Silk Coated paper, Textured paper, Uncoated paper and NTR paper. Test prints were printed under controlled electrophotographic printing conditions to ensure consistency in machine settings and environmental parameters.

Print-Edge sharpness was evaluated and quantified using standard human observer method by measuring the edge definition of printed characters and graphical elements. The comparative analysis examined the interaction between toner characteristics and substrate surface properties, including coating, roughness and absorbency and their influence on edge reproduction. EA toner and Polymerized toner generally produced sharper and more well-defined print edges than Pulverized toner, particularly on coated paper such as Silk Coated Paper. In contrast, textured and uncoated substrates exhibited relatively lower edge sharpness because of their higher surface roughness and greater toner spread. NTR paper showed intermediate performance depending on the toner formulation employed.

The findings indicate that both toner technology and substrate characteristics play a critical role in determining Print-Edge sharpness in electrophotographic printing. The study provides valuable insights for selecting suitable toner–paper combinations to optimize print quality and enhance image fidelity in commercial digital printing applications. The outcomes contribute to the understanding of material interactions in electrophotographic printing and provide a scientific basis for improving print quality through appropriate toner and substrate selection.

Keywords; Electrophotographic Printing, Silk Coated Paper, NTR Paper, Uncoated Paper, Textured Paper, EA Toner, Emulsion Aggregation (EA) Toner, Polymerized Toner, Pulverized Toner, Print-Edge Sharpness.

INTRODUCTION

Electrophotographic (EP) printing has become one of the most widely adopted digital printing technologies for commercial, transactional, packaging and short-run printing applications because of its ability to produce high-quality prints with rapid turnaround times, variable data capability and cost-effective production. Unlike conventional printing technologies, electrophotographic printing relies on electrostatic image formation followed by the transfer and thermal fusing of toner particles onto the printing substrate. Consequently, the quality of the final printed image is significantly influenced by the physicochemical properties of the toner, the surface characteristics of the paper substrate and the interaction between them during the imaging and fusing processes (Schein, 1996; Kipphan, 2001; Sonmez et al., 2024).

In the recent years, continuous developments in toner manufacturing technologies have led to the introduction of chemically prepared toners, such as Emulsion Aggregation (EA) and Polymerized toners, in addition to conventional Pulverized toners. These toner technologies differ considerably in particle morphology, particle size distribution, shape uniformity, surface chemistry, melting characteristics and fusing behaviour (Babaie et al., 2024; Schein, 1996).

Print quality is a multidimensional concept comprising optical density, colour reproduction, gloss, image uniformity, edge sharpness, line quality and toner adhesion. Among these parameters, Print-Edge sharpness is considered one of the most sensitive indicators of image fidelity because it determines the clarity of character boundaries, graphical elements and fine line reproduction. Poor edge definition results in blurred images, feathering and reduced readability, thereby affecting both the aesthetic appearance and functional performance of printed products. International standards for hard-copy image quality also recognize edge sharpness as an essential parameter for evaluating digital print quality (ISO 13660, 2001; Bijender et al., 2026).

Although several studies have investigated the influence of paper properties or printing systems on electrophotographic print quality, comparatively fewer investigations have systematically evaluated the combined influence of different toner technologies and commercially used paper substrates on Print-Edge sharpness. Most previous studies have focused on colour difference, optical density, gloss or tone value increase, while limited attention has been devoted to quantitative comparison of edge sharpness produced by modern EA, Polymerized and Pulverized toners across different grades of printing papers (Sonmez et al., 2024; Kumar & Kumar, 2024). Considering the increasing demand for premium digital print quality in publishing, packaging, commercial printing and personalized printing applications, understanding these interactions has become increasingly important for both researchers and the printing industry.

The selection of an appropriate paper substrate is equally important because coated and uncoated papers exhibit substantial differences in their surface chemistry and microstructure, which directly influence toner anchorage and image formation. Silk Coated paper generally provide smoother surfaces with improved toner fixation, whereas Textured, Uncoated and NTR papers present different levels of roughness and absorbency that may alter toner distribution and consequently affect Print-Edge sharpness. Optimizing toner–substrate compatibility can therefore improve print clarity, reduce image defects and enhance overall print performance (Schleusener & Apel, 1997; Sonmez et al., 2024).

RESEARCH OBJECTIVES

The present study addresses this research gap by conducting a comparative assessment of three commercially available toner technologies i.e. Emulsion Aggregation (EA) toner, Polymerized toner and Pulverized toner printed on four different paper substrates, namely Silk Coated paper, Textured paper, Uncoated paper and NTR paper. Print-Edge sharpness was selected as the primary print quality parameter because of its direct relationship with image definition and visual perception. The study aims to evaluate the influence of toner technology and substrate characteristics on Print-Edge reproduction under the controlled electrophotographic printing conditions. The findings are expected to provide scientific evidence for selecting optimum toner–paper combinations to achieve superior print quality, thereby contributing to improvements in commercial electrophotographic printing and expanding the understanding of toner–substrate interactions in modern digital printing systems.

RESEARCH METHODOLOGY

The present research adopted an experimental comparative research design to evaluate the influence of toner technology and paper substrate on the Print-Edge sharpness of electrophotographic prints. The study was conducted under controlled laboratory conditions to ensure consistency in printing parameters and to minimize the influence of external variables. Three commercially available toner technologies, namely Emulsion Aggregation (EA) Toner, Polymerized Toner and Pulverized Toner, were selected as the independent variables because they represent the major toner manufacturing technologies currently used in electrophotographic printing systems. Four commonly used printing substrates, namely Silk Coated paper, Textured paper, Uncoated paper and NTR paper, were selected to investigate the influence of paper surface characteristics on Print-Edge sharpness. These substrates differ in terms of surface smoothness, coating composition, porosity and roughness, thereby providing a comprehensive basis for evaluating toner–paper interactions.

Before printing, all paper samples were conditioned under standard laboratory environmental conditions to minimize variations caused by temperature and relative humidity. Printing was performed using the same electrophotographic printing press throughout the study. All printing parameters, including print resolution, image coverage, fusing temperature, print speed, transfer voltage and environmental conditions, were maintained constant during the entire experimental process so that only toner technology and paper substrate influenced the experimental outcomes. A common digital test artwork was prepared to evaluate different print quality characteristics. The artwork consisted of solid colour patches, halftone patches, fine lines, positive and negative text, registration marks, grayscale elements and photographic images. The same digital file was printed on each electrophotographic printing system to maintain consistency throughout the study. The use of identical artwork ensured that any variation observed in print quality resulted from differences in the printing systems rather than differences in image content.

A total of twelve toner–substrate combinations were produced by printing each of the three toner technologies on each of the four paper substrates. Multiple print samples were generated for every combination to improve the reliability and repeatability of the experimental observations. All printed samples were visually inspected before measurement to eliminate any prints exhibiting machine-related defects or handling damage.

Print-Edge Sharpness was assessed by examining the reproduction of fine image details using digital microscopic imaging by standard human observers on the scale 1-10. Edge definition, transition smoothness and clarity of printed images were analysed to determine the sharpness characteristics of each printing system. Particular attention was given to the reproduction of fine image structures that are commonly encountered in commercial printing applications.

Line quality was evaluated by examining horizontal, vertical and diagonal lines of varying thickness incorporated into the test artwork. Measurements focused on line continuity, edge smoothness, line width variation and the presence of distortions or irregularities. Similarly, text quality was evaluated using printed characters of different font sizes and styles. The clarity of character edges, stroke uniformity, readability and reproduction of fine textual details were examined to compare the text rendering capabilities of the selected electrophotographic printing systems.

DATA COLLECTION AND ANALYSIS

The data for this study were collected through a controlled experimental investigation conducted using an electrophotographic printing system. Three commercially available toner technologies, namely Emulsion Aggregation (EA) Toner, Polymerized Toner and Pulverized Toner, were selected for comparative evaluation. Each toner was printed on four different paper substrates: Silk Coated Paper, Textured Paper, Uncoated Paper and NTR Paper. Standardized print test charts containing fine text, line patterns and graphic elements were printed under identical machine settings to ensure experimental consistency. The same is mentioned in the tables and figures below:

Table 1 Print-Edge Sharpness of EA Toner on Various Paper Grades

	Line Drawing Edges	Midtone Edges	Solid Edges
Silk Coated Paper	8.17	8.67	8.83
Textured Paper	7.95	8.15	8.22
Uncoated Paper	6.13	6.92	7.15
NTR Paper	5.07	6.23	6.31

Table 1, presents the print-edge sharpness values of Ink-I (EA Toner Ink) across different paper types, measured separately for line drawing edges, midtone edges, and solid edges. On silk coated paper, sharpness is highest—8.17 for line drawings, 8.67 for midtones, and 8.83 for solids—reflecting crisp edge reproduction due to the smooth, non-absorbent surface. Textured paper shows slightly lower values (7.95, 8.15, and 8.22), indicating mild edge diffusion. Uncoated paper reduces sharpness further, with 6.13 for line drawings, 6.92 for midtones, and 7.15 for solids, consistent with its porous nature. NTR paper records the lowest values overall 5.07 for line drawings, 6.23 for midtones, and 6.31 for solids demonstrating the strongest ink absorption and edge softening.

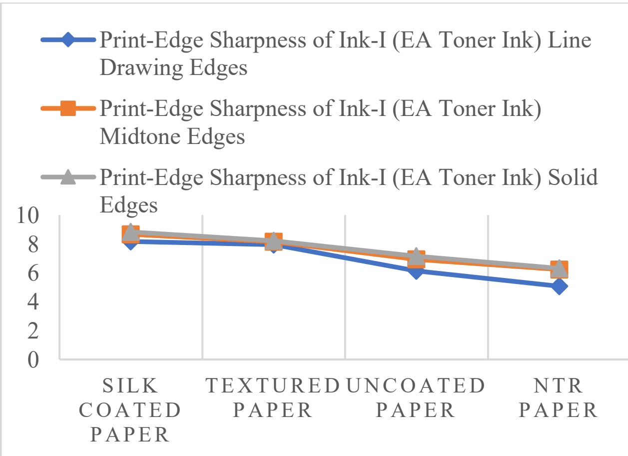

Figure 1 Print-Edge Sharpness of EA Toner on Various Paper Grades

These results confirm that coated papers provide superior edge definition across tonal ranges, while uncoated and absorbent substrates significantly diminish sharpness. The distinction between line, midtone, and solid edges highlights how substrate choice impacts not only fine detail but also tonal transitions, making coated papers essential for high-fidelity reproduction where clarity and contrast are critical.

Table 2 Print-Edge Sharpness of Polymerized Toner on Various Paper Grades

	Line Drawing Edges	Midtone Edges	Solid Edges
Silk Coated Paper	7.30	7.80	7.96
Textured Paper	7.08	7.28	7.35
Uncoated Paper	5.26	6.05	6.28
NTR Paper	4.20	5.36	5.44

Table 2, presents the print-edge sharpness values of Ink-II (Polymerized Toner Ink) across different paper types, measured separately for line drawing edges, midtone edges, and solid edges. On silk coated paper, sharpness is highest i.e. 7.30 for line drawings, 7.80 for midtones, and 7.96 for solids, reflecting crisp edge reproduction due to the smooth, non-absorbent surface. Textured paper shows moderately lower values (7.08, 7.28, and 7.35), indicating mild edge diffusion. Uncoated paper reduces sharpness further, with 5.26 for line drawings, 6.05 for midtones, and 6.28 for solids, consistent with its porous nature. NTR paper records the lowest values overall 4.20 for line drawings, 5.36 for midtones, and 5.44 for solids demonstrating the strongest ink absorption and edge softening.

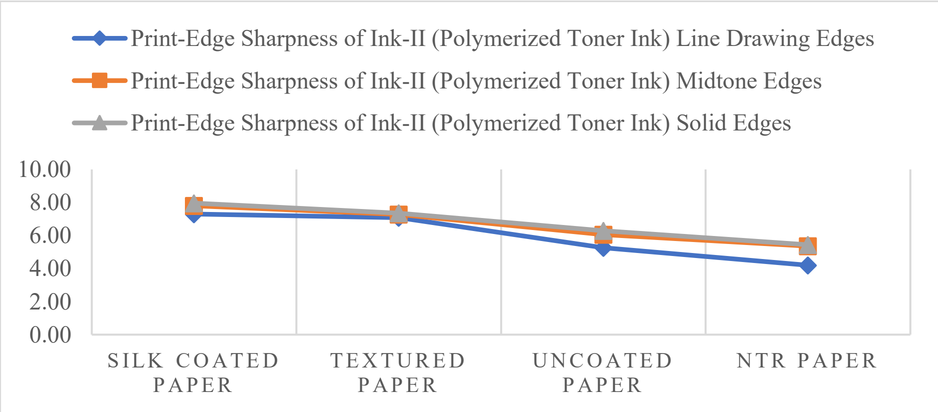

Figure 2 Print-Edge Sharpness of Polymerized Toner on Various Papers

These results show that coated papers provide superior edge definition across tonal ranges, while uncoated and absorbent substrates significantly diminish sharpness. Compared to Ink-I, Ink-II shows consistently lower sharpness values, suggesting that polymerized toner ink produces softer edges and less precise detail. This highlights the combined impact of ink formulation and substrate choice on achieving high-quality print reproduction, especially where clarity and tonal transitions are critical.

Table 3 Print-Edge Sharpness of Pulverized Toner on Various Papers

	Line Drawing Edges	Midtone Edges	Solid Edges
Silk Coated Paper	6.62	7.12	7.28
Textured Paper	6.40	6.60	6.67
Uncoated Paper	4.58	5.37	5.60
NTR Paper	3.52	4.68	4.76

Table 3, presents the print-edge sharpness values of Ink-III (Pulverized Toner Ink) across different paper types, measured separately for line drawing edges, midtone edges, and solid edges. On silk coated paper, sharpness is highest 6.62 for line drawings, 7.12 for midtones, and 7.28 for solids reflecting relatively crisp edge reproduction due to the smooth, non-absorbent surface. Textured paper shows moderately lower values (6.40, 6.60, and 6.67), indicating mild edge diffusion. Uncoated paper reduces sharpness further, with 4.58 for line drawings, 5.37 for midtones, and 5.60 for solids, consistent with its porous nature. NTR paper records the lowest values overall—3.52 for line drawings, 4.68 for midtones, and 4.76 for solids demonstrating the strongest ink absorption and edge softening.

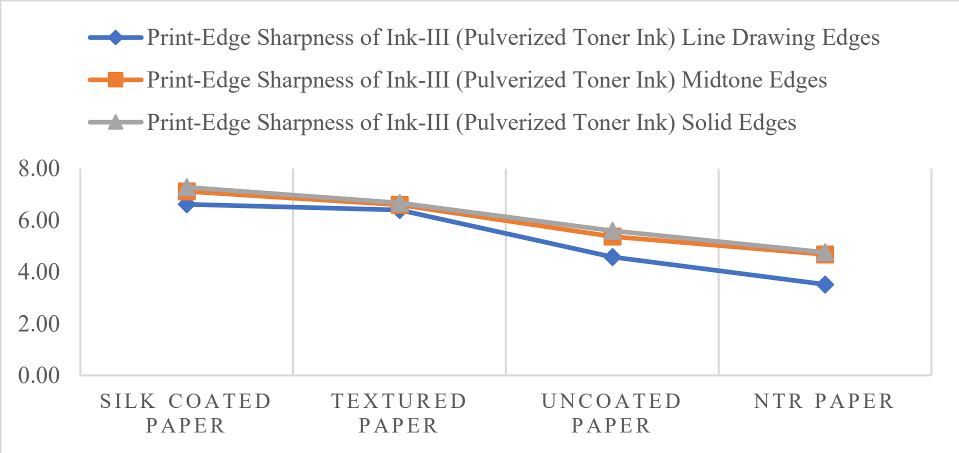

Figure 3 Print-Edge Sharpness of Pulverized Toner on Various Papers

These results confirm that coated papers provide superior edge definition across tonal ranges, while uncoated and absorbent substrates significantly diminish sharpness. Compared to Ink-I and Ink-II, Ink-III consistently produces the lowest sharpness values, showing that pulverized toner ink yields softer edges and less precise detail. This underscores the combined impact of ink formulation and substrate choice on achieving high-quality print reproduction, especially where fine detail and tonal clarity are critical.

RESULTS AND DISCUSSION

The Print-Edge sharpness results obtained for the three toner technologies on different paper substrates demonstrate that both toner formulation and substrate characteristics significantly influence the quality of edge reproduction in electrophotographic printing. Tables 1–3 and Figures 1–3 present the comparative performance of EA toner, Polymerized toner and Pulverized toner on Silk Coated, Textured, Uncoated and NTR papers. A consistent trend was observed across all toner types, indicating that coated papers produced substantially sharper print edges than uncoated and highly absorbent papers. This behaviour can be attributed to the smoother surface, lower porosity and reduced toner penetration of coated papers, which facilitate uniform toner deposition and effective fusing.

Among the three toner technologies, EA toner exhibited the highest Print-Edge sharpness on all paper substrates. On Silk Coated paper, the highest sharpness values were recorded, with Yellow achieving 8.83, followed by Magenta 8.67, while Cyan and Black each measured 8.17. The superior performance of EA toner is primarily associated with its chemically produced, highly spherical and uniform particle morphology, which enables precise electrostatic transfer and controlled toner fusion. On Textured paper, edge sharpness decreased slightly because of increased surface roughness, although relatively high values were maintained for all process colours. A more pronounced reduction was observed on Uncoated paper, where toner penetration into the fibrous structure reduced edge definition. NTR paper produced the lowest sharpness values, with Cyan and Black recording only 5.07, indicating significant edge diffusion caused by high substrate absorbency and irregular surface characteristics.

Polymerized toner demonstrated similar trends but produced consistently lower sharpness values than EA toner on every substrate. The highest values were again observed on Silk Coated paper, where Yellow reached 7.96 and Magenta recorded 7.80. Edge sharpness gradually decreased on Textured, Uncoated and NTR papers, following the same substrate-dependent pattern observed for EA toner. Although polymerized toner possesses relatively uniform particle characteristics, its slightly lower transfer efficiency and fusion behaviour resulted in reduced edge precision compared with EA toner. The difference was particularly evident on porous substrates, where toner spreading increased and image boundaries became less distinct.

Pulverized toner exhibited the lowest Print-Edge sharpness across all experimental conditions. On Silk Coated paper, the maximum value obtained was 7.28 for Yellow, whereas Cyan and Black recorded only 6.62. Performance deteriorated further on Textured and Uncoated papers and reached the lowest values on NTR paper, where Cyan and Black measured only 3.52. The comparatively poor performance of pulverized toner can be attributed to its mechanically ground particles, which possess irregular shapes and broader particle-size distributions. These characteristics reduce transfer uniformity, increase toner scatter and produce wider edge transition zones during the fusing process. Consequently, printed images appear softer with lower edge definition and reduced image fidelity.

A comparison among the four process colours revealed that Yellow consistently produced the highest Print-Edge sharpness, followed by Magenta, whereas Cyan and Black exhibited comparatively lower values across all toner technologies and substrates. This trend may be associated with differences in pigment composition, toner optical characteristics and fusion behaviour. The results further indicate that the influence of paper substrate remained consistent regardless of toner technology. Silk Coated paper produced the best edge definition because of its smooth and coated surface, followed by Textured paper. Uncoated and NTR papers exhibited greater toner penetration and lateral spread, resulting in reduced Print-Edge sharpness. Overall, the experimental findings clearly establish that print quality is governed by the combined interaction of toner formulation and substrate properties. The superior performance of EA toner on coated papers demonstrates its suitability for high-quality commercial printing applications requiring precise image reproduction, fine text and sharp graphical elements.

CONCLUSION

The present investigation demonstrates that toner technology and paper substrate significantly affect Print-Edge sharpness in electrophotographic printing systems. Among the three toner technologies evaluated, EA toner consistently produced the highest Print-Edge sharpness on all paper grades, followed by Polymerized toner, while Pulverized toner exhibited the lowest performance. The superior results obtained with EA toner are attributed to its uniform particle morphology, improved electrostatic transfer characteristics and efficient fusing behaviour, which collectively enhance edge definition and image clarity.

The study further confirms that paper substrate plays an equally important role in determining print quality. Silk Coated paper provided the highest Print-Edge sharpness because of its smooth, coated and less absorbent surface, whereas NTR paper exhibited the poorest performance owing to its higher porosity and greater toner absorption. Textured paper and Uncoated paper demonstrated intermediate performance, reflecting the influence of surface roughness and absorbency on toner spreading. Across all toner technologies, Yellow consistently achieved the highest edge sharpness values, followed by Magenta, while Cyan and Black produced comparatively lower values.

Overall, the findings highlight that optimum Print-Edge sharpness can be achieved through the appropriate selection of both toner technology and printing substrate. EA toner combined with coated paper offers the most effective solution for producing high-resolution prints with superior edge definition, making it particularly suitable for premium commercial printing, packaging and graphic reproduction applications. The results of this study provide valuable guidance for printing professionals and manufacturers in selecting toner–substrate combinations that maximize print quality and image fidelity in modern electrophotographic printing systems.

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