Characteristics of Two Component Magnetic Brush Development

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Abstract

Measurements of two component development using a magnetic brush with a rotating magnetic core, polymeric toner, and insulative, magnetically hard carrier are compared to the behavior of conventional two component development using a magnetic brush with a fixed magnetic core and insulative carrier. Significant differences are observed in the characteristics of the two technologies.

For rotating magnetic brush development, the mass area density for deposition of toner onto a conductive substrate has exponential time dependence, similar to the charging of a capacitor. The Equilibrium Theory for conventional development predicts mass area densities proportional to the ratio of roller speed to substrate speed. The difference in behavior can be attributed to the agitation of the developer nap produced by the rotating magnetic core development system.

Introduction

All high-speed dry electrographic processes use variants of magnetic brush technology. In electrophotographic applications, particle coverage ranges from approximately 5% of the image area to 100%, with mass area densities of approximately 10 g/m2. Process speeds of approximately 0.25 to 0.75 m/s are used for typical office applications.

Several distinct types of magnetic brush technology have been commercialized using either conductive or insulative carrier and applicator rollers with internal, stationary magnetic cores or with rotating magnetic cores.[1] These systems include conductive magnetic brush with a fixed magnetic core, insulative magnetic brush with a fixed magnetic core, and insulative magnetic brush with a rotating magnetic core. This is also described as the rotating magnetic brush development system, and is shown in Fig. 1a. Most magnetic brush systems have a fixed magnetic core that does not rotate, as shown in Fig. 1b. This is commonly called the conventional development system.

Almost all magnetic brush systems used today use insulative carrier particles. The carrier can be made of a magnetic, conductive material such as iron particles with an insulative coating, or the carrier particles can be made of an intrinsically non-conductive material, such as a magnetic ferrite with a high dielectric constant. Rotating magnetic brush development uses non-conductive, magnetic ferrite carrier. Conventional systems typically use conductive carrier particles with an insulative polymer coating. Polymeric toner particles typically have diameter ≥ 9 μm.

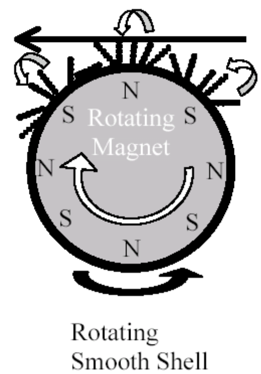

Figure 1a. Rotating magnetic brush development. The toning shell rotates cocurrent with the direction of travel of the receiver. The magnetic core rotates countercurrent to the receiver. The developer mix of magnetic carrier particles and polymeric toner particles is agitated by the rotating magnetic core.

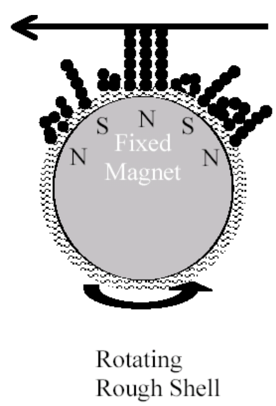

Figure 1b. Conventional development. The developer mix is moved only by the rotating shell.

In the usual applications of rotating magnetic brush development, the magnetic roller has a cylindrical, conductive shell and a magnetic core that contains bar magnets with alternating north and south poles facing the receiver. The magnetic carrier particles on the roller form chains in the magnetic field of the roller core. This is called the developer nap. When adjacent to a north pole or to a south pole, the carrier chains are perpendicular to the toning shell. Between north and south poles, the magnetic field of the core is parallel to the toning shell and the carrier chains are approximately parallel to the toning shell. The outer surface of the roller, or the toning shell, rotates cocurrent with the direction of motion of the receiver. The core rotates countercurrent to the receiver. As the core rotates, the carrier chains flip in the direction of motion of the receiver.

In contrast, for conventional development systems shown in Fig. 1b having a fixed magnetic core, the developer nap on the magnetic brush is static. For conventional development, higher process speeds require more rollers. For rotating magnetic brush development, higher process speeds require faster core speeds and may require more rollers.

Theoretical Analysis of Development

The Equilibrium Theory is widely accepted as the mechanism of particle deposition with insulative magnetic brush development.[1] Polymeric toner particles are bound to the carrier particles by electrostatic forces and also by surface forces. In the Equilibrium Theory, toner is freed from the carrier and deposited on the substrate only in three-body contact events in which, for electrophotography, the toner simultaneously contacts both the carrier and the substrate. During this contact event, surface forces between the polymeric toner particle and the substrate counteract surface forces holding the toner particle to the carrier, and the particle is deposited on the substrate by electrostatic forces.

Rotating magnetic brush development is not described by the Equilibrium Theory. Deposition rates for rotating magnetic brush development typically exceed predictions of the Equilibrium Theory, which does not take into account the significant effect of brush agitation produced by the rotating magnetic core.

In the Equilibrium Theory, mass per unit area for particle deposition on a substrate is given by (Schein, 1996 Eq. 6.56)

$$\frac{M}{A} = \frac{\varepsilon_0 V}{Q/M}\frac{\nu}{\Lambda} \tag{1}$$

where M/A is mass per unit area in g/cm2, Q/M is the charge-to-mass ratio for the polymeric particle in units of μC/g, ε_0 is the permittivity of free space in F/cm, V is the voltage between the substrate and the toning shell, ν is the ratio of the velocity of the development roller to the velocity of the substrate, and Λ is the dielectric distance from the applicator roller electrode to the carrier charge in cm. The parameter Λ is usually fitted to experimental data.

Experimental Results

Toner was bias developed with a rotating magnetic brush directly onto an aluminum substrate on a web press using commercially available materials and leveraged hardware manufactured by NexPress.

A black commercial styrene butylacrylate toner (D1; NexPress, Rochester, NY) was used. The extruded blend is pulverized to powder form and classified to yield a volume mean of 11.5 microns by Coulter Counter. A developer was prepared with this toner at a concentration of 15 weight percent with a strontium ferrite hard magnet core powder (Powdertech Corporation, Valparaiso, In) coated with 0.3 pph of charge agent. The developer was prepared by agitating on a paint shaker for 1 minute.

Results for D1 toner are shown in Fig. 2a and Fig. 2b.

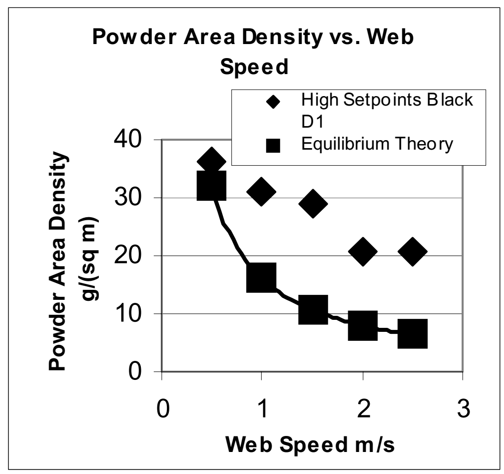

Figure 2a. Powder area density for D1 toner as a function of web speed. Greater area densities are obtained at high web speed than are predicted by the Equilibrium Theory.

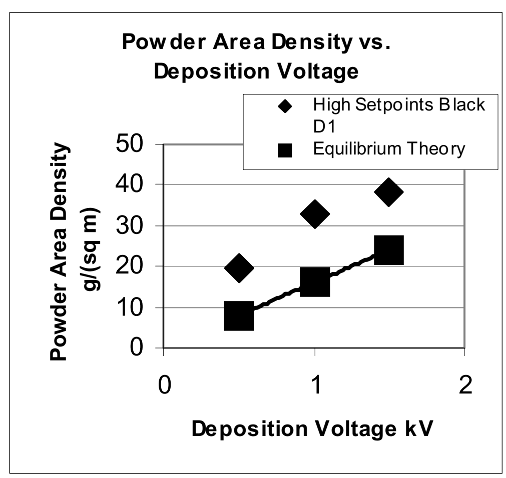

Figure 2b. Powder area density for D1 toner as a function of the bias voltage used for powder deposition. Greater area densities are obtained at high deposition voltages than are predicted by the Equilibrium Theory. Web velocity = 1 m/s.

All measurements were made with the same core speed and shell speed, which were increased from typical electrophotographic setpoints. Predictions of the Equilibrium Theory are also plotted.

Powder area density for rotating magnetic brush is much greater than predicted by the Equilibrium Theory. For comparison with the Equilibrium Theory, Λ was determined by measuring mass area density with the magnetic core stationary, and was found to be approximately 41 to 44 microns.

For fixed shell speed, core speed, and bias voltage, the mass area density decreases approximately exponentially with substrate speed. This is shown in Fig. 3, in which the data from Fig. 2a is replotted with area densities obtained with slower core speed and shell speed.

Further analysis based on the transit time through the magnetic brush shows that deposition depends on the amount of available powder and has time dependence similar to a capacitor during charging. Higher powder concentrations in the magnetic brush, higher core speeds, and higher bias voltages, for example, will increase mass area density within limits. With D1, 40 g/m2 has been obtained at 2 m/s web speed.

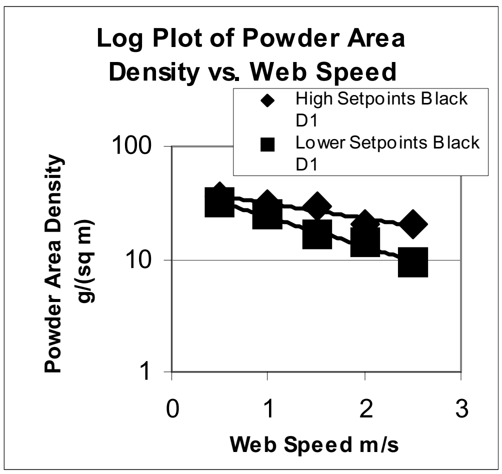

Figure 3. Powder area density for D1 toner at two magnetic brush setpoints, showing exponential behavior. Bias voltage = 1000 V.

Conclusion

Rotating magnetic brush development has been used with bias development to produce mass area densities of 30 g/m2 and greater at substrate speeds of 2 m/s. Exponential dependence on substrate speed was observed. The Equilibrium Theory predicts that mass area density is proportional to the ratio of roller speed to substrate speed. The difference is probably due to increased agitation in the developer nap for the rotating magnetic brush compared to conventional development systems with fixed magnetic cores.

The hardware setpoints used in these experiments were optimized to maximize mass area density and process speed, and are modified from setpoints typically used in electrophotography. Imaging systems have additional requirements for uniform development of large black areas of an image and uniform width for lines, independent of the direction of the line with respect to the process direction. The maximum number of toner particles in the background areas of the image, or in the white areas of the image, must also be tightly controlled.

Relaxing the requirements for variable images allows magnetic brush development, and particularly rotating magnetic brush development, to operate at much higher speeds than are typically used for imaging systems, and to produce much larger mass area densities. Also, a much wider range of mass area density can be obtained than is needed for images.

Acknowledgements

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References

1. L. B. Shein: Electrophotography and Development Physics, revised 2nd ed. (Electrostatic Applications, Morgan Hill, CA 1996).

Biography

Dr. Eric Stelter works on electrographic development and related technology at NexPress Digital LLC, where he is a Senior Scientist in the Materials and Advanced Technology group. He has been granted more than 25 patents in this field. He began his career at Eastman Kodak after receiving his Ph.D. in physics from the University of Illinois in 1985. He is an active member of IS&T, the American Physical Society and the American Association for the Advancement of Science.