Xerographic Printing of Textiles

P. H. Pfromm, W. W. Carr, F. L. Cook, L. Wang, S. Shi, and H. Yan, H. Park*
School of Textile and Fiber Engineering, Georgia Institute of Technology
Atlanta, Georgia
**Institute of Paper Science and Technology*
Atlanta, Georgia

Abstract

Xerographic printing of a number of common fabrics was investigated. The role of the polymeric binder used for the formulation of the commercially available and custom-made toners was investigated. Fabric performance tests (crock-fastness), friction tests (not discussed here), and morpho-logical investigations were performed. The intricate relations of toner and fabric properties with the results of an important overall industrial performance test for fabrics (crockfastness) are discussed. Both cohesive and adhesive toner failure can be important. Improved toner performance was achieved with a thermoset polymer as the toner binder. However, curing times for the thermoset polymer used here are not sufficiently short for high-speed industrial printing.

Introduction

The textile industry has developed quick response systems to remove time from the textile-apparel supply pipeline; however, fabric printing is a bottleneck. Printing lag time prevents true manufacturing on demand. Some of the disadvantages of screen printing, the predominant method of printing textiles, are: 1) long changeover time for style and color changes, 2) screen production is time consuming and expensive, and 3) information is stored on screens requiring large storage space. In 1998, time from design to sample production is typically eight to ten weeks at a cost of about $6000-8000 per sample. It is widely accepted that screen printing will be unable to meet the requirements of demand activated manufacturing. Even with technologies such as computer-driven lasers to facilitate screen production, the time lag associated with screen printing is still too long. It is commonly believed that digital printing systems driven by computers storing information will replace screen printing. Some of the paper digital printing systems that may have potential for textile printing are xerography, ink jet, electrostatic, ion deposition, thermal transfer and TonerJet®. Polymeric materials are often used in these processes as binders to fix colorants to the fabric.

Textile digital printing research is being conducted at the Georgia Institute of Technology[1,2]. Xerography is one of the technologies that have been investigated. Technical barriers associated with xerographic textile are: 1) lack of textile-specific toners, 2) number of toner transfer steps, 3) low toner transfer efficiency to fabrics, and 4) unavailability of machinery specifically designed for textile printing. Thus, research is needed in several areas for xerography to become a large-scale commercial method of printing textiles. The research reported in this paper has focused primarily on developing polymer-based xerographic toners giving required printed fabric properties.

The xerographic process has been recognized as a revolutionary technology that could be used in many applications. In 1989, Carr et al.[3] investigated the use of xerography for textile printing. In textile applications, the toner must have properties compatible with xerography, and at the same time, must meet several textile requirements. Since no toner had been specifically designed for textile printing, fabrics were xerographically printed using toners made for paper printing. The binders for these paper toners were based on styrene-acrylic copolymers. The printed fabric had extremely poor textile properties, for example, rub fastness referred to as crockfastness by the textile industry.

Since the study reported by Carr et al.[3], color printers have reached the market place. The toners used for color printing are primarily based on polyester. In the study reported here, the performance of a typical polyester paper toner used for color printing was evaluated for printing fabric. The textile performance of the polyester toner, referred to as Colorocs in this paper, varied significantly with type of fabric used in the printing. In the rubbing test, dry crockfastness was usually acceptable; however, wet crockfastness ratings varied greatly with fiber and fabric and were usually lower than for dry crockfastness. Lower wet crockfastness ratings are also usually reported for screen printed fabrics. Little information is available in the literature concerning the mechanisms for color transfer during the rubbing (crocking) of fabrics. This paper discusses an investigation conducted in an effort to better understand the variation in the performance of the polyester toner on fabrics and to study the failure mechanisms occurring during crocking.

Experimental

A two component developer system (toner plus carrier) was used for making the xerographic prints on a Colorocs color printer. The magenta-colored Colorocs toner was selected for this study. It is a thermoplastic toner designed for xerographically printing on paper and consists of polyester

resin, styrene-acrylic resin, solvent dye, and polypropylene wax. The binder is a mixture of polyester and styrene-acrylic resins, and the polypropylene is used as internal lubricant and fuser release agent. A magenta solvent dye is used as the colorant. Colorocs carrier, normally used with the Colorocs printers, was used mixed with the toner to produce developer.

Cotton, polyester, nylon, and silk fabrics were used in this study. Descriptions of the fabrics are given in Table 1. Definitions of textiles specific terms can be found in the literature.

A model CP 4007 Colorocs color printer with a resolution of 300 dpi was used to produce the xerographic prints. The printer was designed so that the substrate, typically 0.21 m in width and approximately 0.28 m long, runs in a straight path through the machine. The curing unit was insufficient to properly cure the prints on the fabrics. The curing unit was removed, and the printed samples were cured in a convection oven. Most of the prints were cured for 3 minutes at an oven temperature of 200°C; however, in some cases, curing times of 5 and 10 minutes were used.

Wang[4] investigated the effects of toner deposition on fabric properties and found that the amount of toner deposition on the fabric has a surprisingly small effect on crockfastness ratings within the range experienced in our work.

One of the important properties that a printed fabric must have is good rub fastness referred to as crockfastness. One standard crockfastness test (dry crockfastness) involves rubbing the print with a dry rubbing cloth. A second standard test (wet crockfastness) uses a wet rubbing cloth containing 65wt% water on a dry basis. These tests attempt to simulate the conditions of wearing and washing a fabric. Standard dry and wet crockfastness were measured using an American Association of Textile Chemists and Colorists (AATCC) test method (ratings are: 1: entirely unacceptable 2: unacceptable, 3: borderline acceptable, 4: good, 5: excellent (no color transfer)).

Table 1: Crockfastness data for a number of fabrics printed with Colorocs magenta xerographic toner (thermoplastic polymer vehicle). Also shown: tightly woven cotton printed with a thermoset resin based toner (HB Fuller, epoxy-based). Curing: 200°C, 3 minutes in air for all toners. (Crockfastness rating below 3 is unacceptable)

Toner	Fabric Type	ID#	Fabric weight [grams/ m^2]	Toner deposition [mg/cm^2]
Colorocs (polyester-based, thermo-plastic)	Cotton tightly woven	15	218	0.29
	Nylon 306a filament	107	59	-
	Silk	113	72	0.42
HB Fuller (epoxy-based, thermoset)	Cotton tightly woven **Thermoset-based toner**	58	218	-

Table 1, continued:

Toner	Dry crock-fastness	Wet crock-fastness (water)	Wet crock-fastness (hexadecane)
Colorocs (polyester-based, thermoplastic)	4-5 5 5	2-3 5 5	2-3 5 5
HB Fuller (epoxy-based, thermoset)	5	4-5	5

Three sets of crockfastness tests were carried out under conditions different from those in standard crockfastness tests. These tests were performed using the AATCC Crockmeter. In the first set of tests, the rubbing cloths were conditioned and wetted with water to amounts different from the standard wet crockfastness test (65wt% water pickup). Then these rubbing cloths were used to rub the printed fabrics.

In another set of tests, the normal pressure between the printed fabrics and the rubbing cloth was increased.

In the third set of special tests, organic liquids (hexadecane, decane, etc.) replaced water in the wet crockfastness test. The liquid pickup was kept at 65wt%.

Dry crocking ratings for the printed fabrics were equal to or superior to those for wet crocking. It was speculated that differences in crocking ratings were associated with differences in friction in the dry state versus the wet states. In an effort to better understand the crockfastness results, frictional measurements were conducted for dry and wet conditions.

Differential scanning calorimetry (DSC) was performed on a Seiko SII DSC 220C, and thermogravimetric analysis (TGA) was performed on a Seiko SII TG/DTA 320.

Surface morphology was observed under a Scanning Electron Microscope (SEM, Stereoscan 430, Leica Cambridge Ltd., 10kV, 2.39 A filament current, 200.0 nA probe current).

A polarized optical microscope (POM, Leitz Laborlux 12 POL, magnification 100X, with heating stage, manufactured by W. Nuhsbaum, Inc.) was used to study the wetting characteristics of the toner melt on single fibers, the melt flow behavior of the toners, and the wetting properties of toners on fabrics.

A DCA tensiometer and a FTA 200 contact angle measurement instrument were used to measure solid surface free energy on specimens of PET and cellulose acetate films (15mm x 20mm). The toner powder was applied to a glass slide and fused at 150~190C for 5 minutes.

Measurements of the tensile modulus were carried out on injection-molded specimens at room temperature using an Instron-5567 (2 in./min).

Results and Discussion

Table 1 gives an overview of the crockfastness data obtained in this work. Also shown are the fabric weight per

area and the toner deposition. The dry crockfastness test generally shows good results (4-5, good to excellent). However, wet crockfastness (to simulate washing) with water shows rather poor results (low crockfastness numbers), except for silk and filament nylon. Immediately the question arises why prints on silk (a natural polymeric fiber with high water sorption and an intricate fine structure) and nylon (an artificial polymeric fiber with low water sorption and no fine structure) both show very good performance when tested wet. Although cotton fabric is the focus of this paper, other fabrics were tested to obtain more information on the failure mechanisms of the prints.

It could be suspected that the wetting/spreading of the toner melt on the fabric material contributes to poor crockfastness. The toner might form small domains on the fabric, rather than spreading and providing a large amount of interfacial area for adhesion, and opportunities for geometric entrapment.

The surface energy of Colorocs toner was 20.8 dynes/cm . The spreading coefficient of Colorocs toner was 24.3 dynes/cm on a cellulose acetate film. This film was used to simulate cotton fibers. Therefore, wetting/spreading is not a likely cause for poor crockfastness of cotton fabrics.

An optical microscope equipped with a hot stage was used. Toner particles that adhered to single fibers of the various fabrics were observed when the fibers were heated to 100ºC. It was noted that the toner particles did melt and spread out along the fibers. This is additional evidence that wetting/spreading is not a problem with the fabrics and toners used here.

Friction plays an important role in the crockfastness test. It could be suspected that poor crockfastness results might be due to the surface morphology of the fabrics. In addition the amount of toner and the morphology of the deposited toner may influence the crockfastness results. Since wet crockfastness was found to be poor (except for silk and filament nylon), while dry crockfastness ratings were largely acceptable, the frictional properties of printed and unprinted wet and dry fabric samples were evaluated.

The apparent coefficient of kinetic friction for dry unprinted (blank) and printed cotton, silk, and filament nylon samples is not shown here in detail. From the friction measurements it can was concluded that water plays an additional role in reducing crockfastness, beyond an increase in apparent friction. Simple increase of the normal force in the dry crockfastness test did not cause poor results for fabrics that performed poor in the wet crockfastness test.

Crockfastness tests with hexadecane instead of water showed essentially similar results to water (Table 1). Therefore, liquids play a role in the crockfastness beyond hydrodynamic issues (friction), and swelling of the fibers.

The morphology of cotton fibers (virgin, unprinted tightly woven cotton) is shown in Figure 1a.

The cotton fibers show their typical fine structure (flat fibers, fibrils). Figure 1b shows the cotton fibers after application of Colorocs xerographic toner (Fused at 200ºC, 3 min, standard post-printing treatment). Especially at intersections of fibers the toner can be seen as a film connecting the fibers. The toner layer on the fibers obscures the fine structure of the fibers. Figure 1c (printed fibers after dry crockfastness test) supports the good results for dry testing (Table 1). Some cracking of the toner layer is visible, but loose debris is very limited. Figures 1d (unprinted) and 1e (printed) show the significant damage inflicted on the hydrophilic cotton fibers during the water wet crockfastness test.

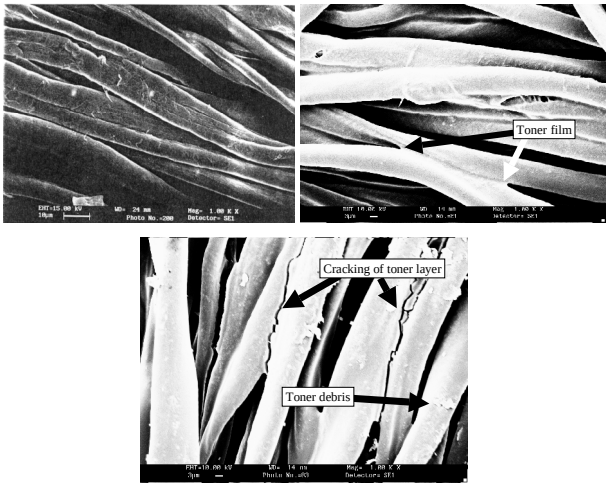

Figure 1a (left) and 1b (right), 1c (below)

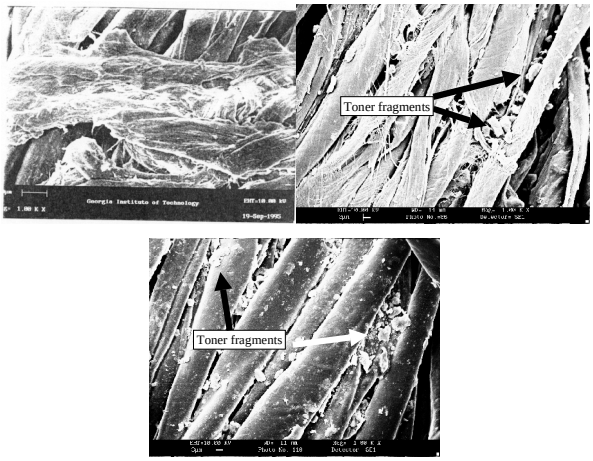

Figure 1d (left) and 1e (right), 1f (below)

Figure 1e shows that the fibers are damaged, and that toner is physically detached from the fiber surfaces. Figure 1f shows the tightly woven cotton after a wet crockfastness test with hexadecane. The crockfastness ratings for water wet and hexadecane wet tests were similarly low. Figure 1f shows no fibrillation of the fibers.

The conclusion from the morphological evidence for cotton is that the failure of the toner is both cohesive (toner fragmentation) and adhesive (removal of toner from the fibers), followed by transfer of the toner fragments from the fabric sample to the rubbing cloth.

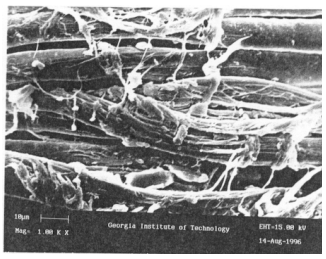

Figure 2. Colorocs printed silk after wet crockfastness test.

Surprisingly, the crockfastness results for silk (Figure 2) were outstanding, despite the serious damage. This supports the conclusion that although cohesive failure of the fibers occurred, the toner still adhered to the silk and was not removed from the fabric.

A bisphenol-A epoxy resin manufactured by HB Fuller was chosen as a thermoset toner vehicle. The toner contained benzophenone tetracarboxylic dianhydride for crosslinking, and fanal pink as the pigment. At 3-5 minutes curing time at 200C crosslinking was sufficient.

Table 1 shows the excellent crockfastness properties. This was a confirmation of our hypothesis that a crosslinked toner would show an improvement over thermoplastics. The water wet crockfastness test (Figure 3) produces some damage and fibrillation to the fibers.

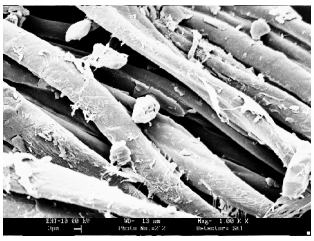

Figure 3.

The very good crockfastness results for the thermoset toner indicate that this vehicle solves some of the problems of low wet crockfastness for xerography of textiles.

Conclusion

The textile print property most difficult to obtain by xerographic printing is the wet crockfastness (simulating washing of the fabric). The most significant issue appears to be the failure of the toner/fiber interface. Good properties can be obtained if the toner is physically crosslinked. A major obstacle to industrial application is the need to allow the toner to wet/spread, and potentially crosslink. The speed for full-scale fabric production (50-100 yards/min) would require very large curing zones. Rapidly crosslinking systems are needed. Small samples of new patterns, however, could be easily produced.

References

1. 1998 Annual Report, National Textile Center, 2207 Concord Pike, Wilmington, DE 19803.
2. W. W. Carr, D. S. Sarma, F. L. Cook, S. Shi, L. Wang, and P. H. Pfromm, Journal of Electrostatics, 43, 249 (1998).
3. W. W. Carr, F. L. Cook, W. R. Lanigan, M. E. Sikorski, and W. C. Tincher, Text. Chem. and Color, 23 (5), 33 (1991).
4. L. Wang, Studies on toner properties and fabric performance properties for xerographic textile printing, M.S. thesis, Georgia Institute of Technology, School of Textile and Fiber Engineering, December 1996.

Biography

Peter H. Pfromm received his M.S. from the University of Stuttgart, Germany. He worked at Membrane Technology and Research (Menlo Park, CA) and the Fraunhofer Institute for Interfacial Engineering in Stuttgart, Germany before receiving his Ph.D. in Chemical Engineering (Fall 1993) from the University of Texas at Austin. His research interests are in membrane separations, thin polymer structures, and in applications of polymers with respect to their physical properties.