Printing Textile Fabrics with Xerography

IMP-L49

By W. W. CARR, F. L. COOK, W. R. LANIGAN, M. E. SIKORSKI and W. C. TINCHER, Georgia Institute of Technology, Atlanta

Over the past few years, the textile industry has moved toward quick response, just-in-time delivery and shorter process runs to facilitate frequent style and color changes. Reduced process efficiency accompanies short runs unless changeover downtime is small. Processes such as continuous carpet dyeing have been modified to minimize time required for changeover. However, current fabric printing systems do not lend themselves to rapid changeover.

Rotary screen printing, currently the predominant method of fabric printing, has several disadvantages. Color and pattern changes require long process set up time. Screen production is slow and expensive. Screens have relatively short lives and require considerable storage space when not being used. Thus a new technology for fabric printing is needed that will permit frequent style and color changes with minimum downtime for changeover and will allow computer storage of design information. Xerographic printing has the potential of meeting these requirements.

ABSTRACT

A three-phase investigation of the use of xerography for color printing of textiles has been conducted. Phase I studied the feasibility of using xerography to produce clear prints on textiles and to identify textile toner candidates. Phase II demonstrated continuous xerographic, single-color printing of polyester/cotton sheeting fabric. Phase III involved scale up to continuous three-foot wide, three-color, complex textile printing. Textile color xerography was shown to be a feasible route to waterless, complex printing of fabrics with pigment and binders.

KEY TERMS

Binders
Colorfastness to Crocking
Electrophotography
Printing
Triboelectric Attraction
Xerography

Background

Applications of Chemicals to Textiles Without the Use of Liquids

The textile xerographic investigation was part of a larger project (*1*), funded by the U.S. Department of Energy (DOE), in which several techniques for applying chemicals to textiles without the use of liquids were investigated. The objective of the project was to develop techniques for reducing the energy consumed by the textile industry in wet processing. Much of the energy utilized in wet processes goes toward heating and evaporating water. Energy conservation research has led to a reduction in the quantity of water required in wet processing; however, liquids are still used. Further reductions in energy consumption are possible by the complete elimination of liquids.

New Technologies

Fabric printing was one area selected for study in the DOE project. Technologies eliminating water from fabric printing while having promise of relieving response time and information storage problems associated with screen printing were considered. Two major candidates were ink jet printing and electrophotography. Although ink jet printing has promise, disadvantages are associated with it. The major one is that it is liquid based which eliminated it as a candidate for the DOE project. Other disadvantages include: high resolution needed for apparel is probably unattainable; insoluble dyes such as disperse dyes and pigments are not compatible with the technique; dyes used in the process must have the proper textile characteristics and influence on rheology; and the use of three primaries to produce color is probably not attainable.

Electrophotography (*2*) involves the formation of a latent image and transforming it into a visible image or print. Two types of electrophotography were considered for fabric printing: direct imaging on the fabric and xerography. Direct imaging eliminates some of the steps of xerography, but presents two problems not associated with it. Preliminary tests indicated that cotton-containing fabrics, under standard conditions of 65% relative humidity and 20C, dissipate charge very rapidly. Thus the time available for developing the charged pattern is extremely short. Since much of the fabric to be printed contains cotton, the charge dissipation problem would have to be solved. The other problem is related to the nature of the fabric surface. Developing the charge image without the entrapment of toner in uncharged regions of the fabric would probably be difficult. Since xerography is a highly developed technology for paper printing without these problems, it was the method of choice.

Xerography

Advantages/Disadvantages

Xerography has several potential advantages for printing fabrics. One is information storage can be either optical or computerized, eliminating the need for large storage space for screens. Since the system can be computerized, fast style and color changeover are possible. Another is the potential for producing color using three primaries. The resolution needed for printing apparel fabrics should be attainable and image development can be achieved without the use of solvents. Pigments, which are generally much less expensive than dyes and offer better lightfastness and other properties, can be used for coloration. Washing and drying following printing is eliminated.

While xerography has much promise for fabric printing, current technology has been developed for paper printing. Fabric printing has requirements beyond those for paper printing. Xerographic paper printing systems have been designed primarily for operating in the batch mode (a single sheet is normally printed) and for fairly narrow widths (usually 8½ inches). Fabric printing systems will need to print much wider webs in a continuous mode. The toner requirements for paper printing are also quite different from those for textile applications. The binders in paper toners normally consist of styrene/acrylate copolymers with poor adhesion to textile fibers and low drycleaning solvent fastness.

Basic Steps

The basic steps of xerography are illustrated in Fig. 1. Metal that is electrically grounded is coated with a layer of photoconductor (PC). The first step involves charging the surface of the PC which will hold a charge in the dark. The charging is usually accomplished by passing a corona over the PC surface. The second step involves producing a latent electrostatic image by exposing the PC to light. Since light causes the PC to become conductive, charge is drained from the surface in regions that are exposed. This step is usually accomplished by reflecting light from an original or passing light through a transparency onto the PC surface. A laser driven by a computer can also be used to produce the image. The third step is developing the latent image by placing toner (pigment plus binder) in regions where electrostatic charge is located. Development involves the use of a developer system composed of carrier and toner. The carrier beads, which usually consist of metal shot coated with a polymer film, are normally much larger in size than the toner particles. The triboelectric characteristics of the toner and carrier are such that when they are thoroughly mixed, they become oppositely charged and attract each other. The carrier is oppositely charged from the PC surface. When carrier which holds toner on its surface is brought into contact with the PC, the toner is attracted to charged regions of the PC. Transfer of toner to these regions on the PC develops the image. The fourth step is the transferring of the developed image to the substrate being printed. The substrate is brought into contact with the PC. The back of the substrate is strongly charged, usually by using a corona, so that the toner transfers to the surface of the substrate. The fifth step is fixing the toner to the substrate. The temperature of the toner is raised, causing the resin binder to flow. Pressure is often used as well as a heat source. Following fixation, the surface of the PC is cleaned and the process is repeated.

Phase I

Objective

The objectives of Phase I were to investigate on a bench scale the technical feasibility of using xerography to print woven fabrics and to identify binder materials for toners meeting textile requirements.

Apparatus

A Haloid single-page batch copier with selenium photoconductive plate was used for printing on 50/50 polyester/cotton sheeting fabric (WestPoint Pepperell) and for screening potential textile toners.

Materials

Initial tests were performed using paper-toners; however, since paper toners have not been designed to meet textile requirements, screening of binder materials with potential of meeting textile requirements was begun. Two toner/carrier systems designed for paper xerography were used: Red Toner No. 22-144 (Haloid Xerox Inc.) and Black Toner Type 10 (Xerox Corp.). These two toners were used to produce prints on fabric which were subjected to textile tests.

The carrier components of the two toner/carrier systems were isolated by solvent removal of paper toners. Attempts were made to make textile developer systems by mixing the carrier with several resins and disperse dyes, listed in Table I. Sublimable disperse dyes were included in the materials considered for toners since they had the potential of being used without binder for sublimation printing of 100% polyester fabrics.

Tests were performed on two other paper toners. One was a Kodak magenta toner and the other a blue toner provided by Hunt Chemical Co.

Research was conducted to identify commercially available resins suitable for use as the binder component of developer systems for xerographic fabric printing. Over 60 commercially available resins as well as melt blended combinations were screened. The physical/textile properties of the resins were compared with a standard screen printing resin currently used by the textile industry, Hycar 26120. The standard is a complex acrylic polymer produced by BF Goodrich Co.

Tests

Wet and dry crockfastness tests were performed using AATCC Test Method 8-1972. Samples produced by the Haloid batch system and by sprinkling powder on polyester/cotton sheeting and curing at 150C for one to two minutes were tested.

Screening tests were conducted to identify resins having the proper film/textile properties to act as a toner component in xerographic printing of woven fabrics. Desirable binder film properties included: clarity, low melt viscosity, good adhesion to substrate, good physical properties, good heat and chemical resistance, and good wearability. Physical properties were either measured or taken from the literature. The following information was compiled for the candidate resins: melt temperature, melt viscosity, film forming characteristics, adhesive properties and stress/strain properties.

Films of the resins and blends were melt formed while a film of Hycar 26120 was laid down from an emulsion using a Gardner Knife. An Instron was used to obtain stress/strain properties of the films. The mechanical properties of Hycar 26120 film were used as a standard for judging the behavior of the candidate materials.

Results and Discussion

Clear prints were made using the Haloid process and the paper toners (Red Toner No. 22-144 and Black Toner Type 10). Results of crockfastness tests for the sam-

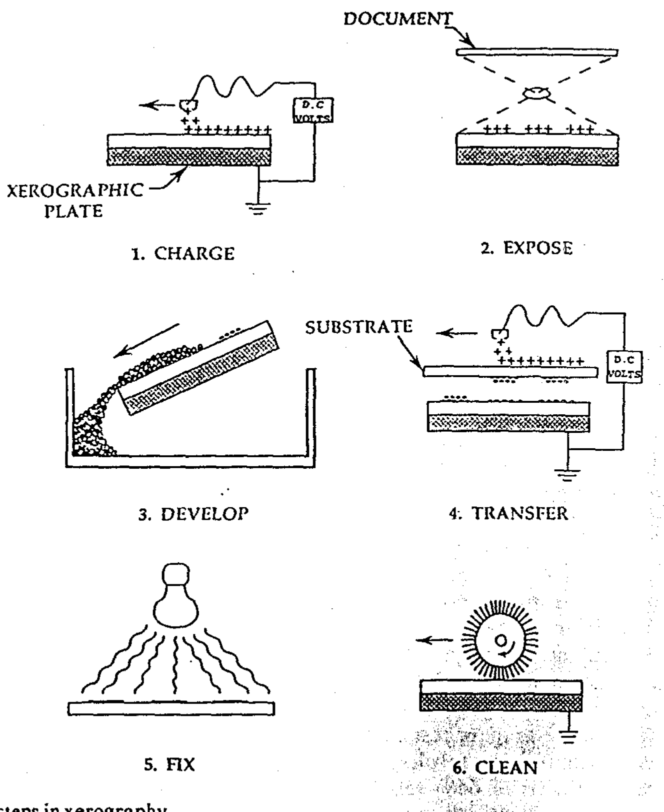

Fig. 1. Basic steps in xerography.

Table I. Coverage/Affinity of Various Toner Candidates with Carrier Beads Obtained from Paper Developer

Material	Manufacturer	Coverage/Affinity Observation	
		Bead A[a]	Bead B[b]
Yellow Epoxy Resin	Armstrong Powders	No	No
Yellow Polyester Resin	Armstrong Powders	Marginal	No
Magenta Toner[c]	Eastman Kodak	No	—
Blue Disperse Dye	Ciba-Geigy	No	No
Yellow Disperse Dye	Ciba-Geigy	No	No
Red Disperse Dye	Ciba-Geigy	No	No

[a]Isolated from Black Toner Type 10, Xerox Corp. [b]Isolated from Red Paper Toner Type 22-144, Haloid Xerox Inc. [c]Colored Paper Toner Used in Kodak Color Copier.

Table III. Results of Melt Viscosity and Dot Adhesion Tests with Various Resins and Their Blends

Sample Number	Blend Ratio	Material	Melt Viscosity[e]	Total Adhesion
1		Elvax 410[a]	6.3×10^6 cps	89%
2		AC-400[b]	610	35
3		AC-580[c]	650	42
4		AC-629[d]	200	12
5	1:1	410[a]:400[b]	2600	100
6	1:1	410:580[c]	1910	88
7	1:1	410:629[d]	2870	9
8	5:4:1	410:400:580	3150	97
9	6:2:2	410:400:580	3500	88
10	7:2:1	410:400:580	5150	84
11	7:1:2	410:400:580	6010	83
12	8:1:2	410:400:580	9000	—
13	9:1:2	410:400:580	10,000	—

[a]A polyethylene-co-vinyl acetate, Du Pont. [b]A polyethylene-co-vinyl acetate, Allied. [c]A polyethylene-co-vinyl acrylic acid, Allied. [d]An oxidized polyethylene, Allied. [e]Measured using a Model LVT Brookfield Viscometer, Spindle 4, at 200C.

ples are summarized in Table II. Since printed fabrics are generally expected to have ratings of four or above to be acceptable, the paper toners failed to meet the industrial standard.

The resins of the paper toner were likely polystyrene-co-acrylate materials, common within the paper xerographic industry. Since paper toners are not designed to meet textile fastness requirements, the results of the crockfastness tests were not surprising. The results confirmed the need for the development of new toner materials meeting textile requirements.

When the carriers isolated from the two developer systems were mixed with candidate toners, developer systems (carrier/toner) were not produced. Visual observation (Table I) of the coverage of the toner on the carrier showed that, for most materials, very little triboelectric attraction occurred between the carrier and the toner candidates. The results indicated a need for testing with a wider range of carriers so that toner could be better matched with carrier.

After over 60 commercially available materials as well as melt blended combinations of materials were screened as potential binders for fabric toners, Elvax 410 (a polyethylene-co-vinyl acetate produced by Du Pont) was selected as the primary candidate. Elvax 410 had good film forming and adhesive properties while having stress/strain properties (see Fig. 2) reasonably in the range of the standard, Hycar 26120 resin. The major problem associated with Elvax 410 was that its melt viscosity (approximately 10^6 cps) was appreciably higher than the target value (approximately 1000 cps) believed to be needed for good flowability. Blends of Elvax 410 with several other materials were made in an attempt to reduce melt viscosity of the base Elvax 410 polymer while maintaining desirable binder film properties. Materials used in the blending tests included various Allied Chemical copolymers of the ethylene or ethylene acrylic copolymer type, but with lower molecular weight. The results of melt viscosity and dot adhesion tests are shown in Table III. Two of the blends, samples 5 and 6, at a 1:1 weight ratio gave promising melt viscosities, while yielding adhesion results comparable to virgin Elvax 410.

Table II. Wet/Dry Crockfastness Test Results for Xerographic Print on Polyester/Cotton Sheeting Fabric[a]

Paper Toner	Dry Crock Rating	Wet Crocking Rating of Paper Toner
Red (Haloid)	3-4	3
Black (Xerox)	2-3	1
Magenta (Kodak)	4	1

[a]Tests were performed according to AATCC Test Method 8-1972.

Four of the other blends (samples 8-11) had melt viscosities in the 3000 to 6000 cps range and acceptable adhesion results.

In Fig. 2, the stress/strain behavior of selected Elvax 410 blends are compared with those of virgin Elvax 410 and the standard, Hycar 26120 resin. The film produced from Hycar 26120 resin had a low initial modulus and an extremely high elongation-to-break. Of the candidate binders, Elvax 410 came closest to duplicating the stress/strain properties of the standard. Although Elvax 410 had a higher initial modulus than the standard, its elongation to break and breaking strength were similar to those for the standard. The film properties of the blends did not compare favorably with those of the Hycar 26120. For example, the stress/strain plot for 8:1:2 and 9:1:2 blends (samples 12 and 13 in Table III) are shown in Fig. 2. Even small amounts of AC-400 and AC-580 blended with Elvax 410 caused brittleness, resulting in high initial moduli and breaking strengths but extremely low elongations to break. Based on the results, the melt blend approach was abandoned and the virgin Elvax 410 was chosen as the primary candidate for textile toner development.

Phase II

Objective

The objectives of Phase II were to continue the development of a suitable toner for xerographic printing of polyester/cotton sheeting fabric and to demonstrate the continuous xerographic printing of fabric. A beam-to-beam printing process with a single color was developed.

Apparatus

A review of commercial paper xerography copiers was made to identify a copier that could be most easily modified for continuously printing fabric. Hunt Chemical, a paper toner manufacturer, assisted in this part of the project and recommended a Xerox Model 3100 copier. The layout of the copier facilitated conversion from paper feed to fabric feed which would allow continuous printing of 8½ inch wide fabric. One of the Xerox copiers was used to obtain the operational characteristics of the model. Another copier was modified to allow manual control of major components of the system and to permit continuous operation for fabric printing. Under manual control, it was possible to vary copier parameters during testing. The following modifications were made to the Xerox 3100 copier: installation of variable speed motor to allow control of fabric speed; rewiring of exposure light; installation of a variable voltage power supply to allow varying magnetic brush speed; installation of controls for fusing system; installation of let off and take up rolls for the fabric; and attachment of power supplies to four corotrons and the developer cage.

Materials.

Paper developer systems (toner plus carrier) compatible with the Xerox 3100 copier were used initially to demonstrate continuous xerographic printing of fabric. While the continuous xerographic fabric printing system was being constructed and demonstrated, work continued on textile developer systems to satisfy textile printing requirements. Textile toners for polyester/cotton blend fabric and 100% polyester fabric were sought. The toner for polyester/cotton blend fabric consisted of a binder plus pigment while toner for 100% polyester fabric was sublimable dye without binder. The latter concept was to use heat to transfer the sublimable dye into the polyester so that binder would not be needed.

Based on the results of Phase I, polyethylene-co-vinyl acetate resin (EVA) was selected as the primary binder candidate for the toner for polyester/cotton blend fabrics. In addition to Elvax 410, MU 760 (another polyethylene-co-vinyl acetate which is similar to Elvax 410 but produced by U.S. Industries) was also investigated. Neither of the two resins were produced commercially with pigment, and pigmented samples could not be obtained. Attempts were made to produce toner by melt blending of the resins with 5% by weight of phthalocyanine blue pigment and grinding. The blends were processed through a Wiley mill, a cryogenic grinder, an air mill and then sieved.

Candidate toners for polyester fabric were produced two ways. One was produced by grinding and sieving blue disperse dye cake (Cibacet Blue E-GBN, C.I. Disperse Blue 3) obtained from Ciba-Geigy. The other was made by grinding and sieving the same blue disperse dye diluted with lignin sulfonate filler/dispersing agent.

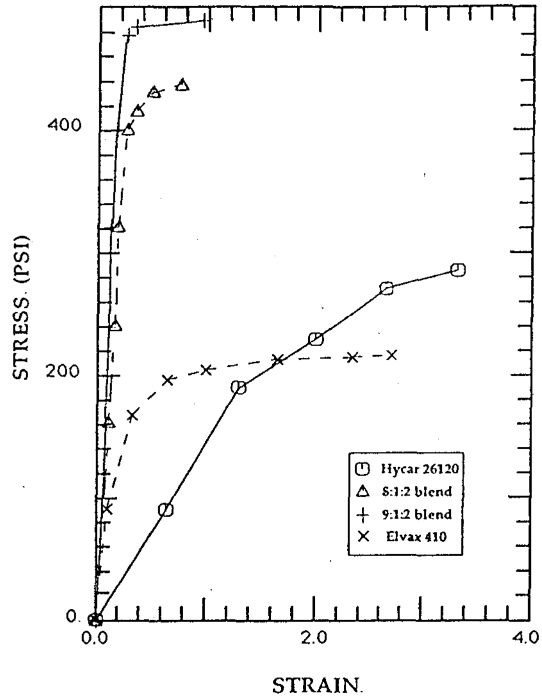

Fig. 2. Film stress/strain curve comparisons of blend and virgin resins.

Production of developer systems using the textile toners required finding carriers compatible with the toners. Samples of the four textile toners were evaluated by Hunt Chemical in an effort to match each of the toners with a suitable carrier.

The physical properties of the four candidate toners were evaluated by Hunt Chemical. The triboelectric properties of the nonpolar disperse dye samples were such that very little charge was generated when the material was thoroughly mixed with various carriers. Thus a developer system could not be made using the Ciba-Geigy disperse dye with the available carriers compatible with the Xerox 3100 copier.

Hunt's studies revealed that the particle size of the EVA toner pigmented by melt blending was too large and contained fiber like material even though the material had been processed through several grinding

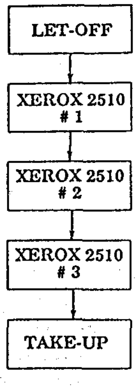

Fig. 3. Continuous 36-inch wide xerographic printing line.

operations. Subsequent attempts to grind the material were unsuccessful. Apparently the material is too amorphous for facile grinding and tends to fibrillate instead of fragmenting into small particles.

Hunt attempted to produce an EVA based toner by spray drying an emulsion produced by Pierce and Stevens. The first attempt was unsuccessful because particle formation did not occur. Instead, the material coated the inside of the dryer. A second attempt was made using EVA emulsion loaded with wax, silica and pigment. Although spray drying resulted in the formation of small particles, the triboelectric properties of this EVA toner were such that very little charge was generated when the toner was mixed with various carriers. Generation of a developer system was thus not possible from spray drying the EVA emulsion.

As mentioned in the discussion of Phase I, BF Goodrich's Hycar 26120 was used as the standard textile printing material. Toner could not be produced from it by grinding due to the nature of the material. Thus it was not given serious consideration as a xerographic toner in Phase I. During Phase II, Hunt Chemical proposed that a toner be produced via spray dyring. Hycar 26120, which is an emulsion containing complex acrylic polymer, was loaded with silica and pigment and spray dried. Samples of toner were produced; however, the complex acrylic toner proved to be a thermoset material and started to deteriorate before it melted. Thus it was also not a suitable toner for textile xerography.

One candidate toner was found by

Table IV. Wet/Dry Crockfastness Test[a] Results with Textile Xerography

Specimen	Dry Crock Rating	Wet Crock Rating
Xerographic Prints		
Blue Kativo	5	3-5
Red Kativo	4	3-4
Screen Prints[b]		
Red	4-5	3
Black	4-5	3
Blue	5	4-5

[a]Tests were performed according to AATCC Test Method 8-1981. [b]Control obtained from a leading sheeting manufacturer.

serendipity. Xerography printing was also being investigated as a method of pattern bonding nonwovens. Kativo, which is a modified epoxy produced by H. B. Fuller, was being tested as a candidate toner for binding nonwovens. Pigmented Kativo was available in a range of colors. Red and blue Kativos were used to produce textile toners. The red Kativo contained two pigments—Naphthol Acrylamide (C.I. Pigment Red 170) and Pyrazol Orange (C.I. Pigment Orange 34, #21115). The blue Kativo contained a phthalocyanine blue pigment, Iron Blue #27 (C.I. Pigment Blue 27, #77510). The triboelectric properties of the Kativos were such that sufficient charge was generated when they were mixed with carrier supplied by Hunt Chemical. Developer systems were made by sieving the red and blue Kativos using a 325 mesh screen and mixing them with carrier.

Tests

Continuous runs on the modified Xerox 3100 Copier were made using the blue and red Kativo toners. Single-color prints were made on fabric having a width of approximately 8½ inches. Process speeds ranged from four to nine feet per minute and runs lasting up to approximately ten minutes were made. Samples produced during the optimized continuous runs were heat-treated for ten minutes in an oven at a temperature of 150C. Crockfastness tests were then run on the prints using AATCC Test Method 8-1981.

Results and Discussion

Crockfastness test results are summarized in Table IV. The dry crockfastness of the blue Kavito prints was excellent with all samples exhibiting ratings of 5, but the wet crockfastness was not as good, ranging from 3 to 5 depending on the size of the printed area—the smaller the area, the higher the rating. The crockfastness ratings of the red Kativo toner were lower than those for the blue Kativo. The crockfastness ratings for dry specimen were 4 while ratings for wet samples range from 3 to 4. Although the wet crockfastness of the Kativo prints was not as good as would have been desired, they were as good as those for standard red and black screen prints from a textile supplier (Table IV).

Phase III

Objectives

Phase III involved scaling up to continuous 36-inch wide, three-color textile printing. One of the objectives was to demonstrate a xerographic process for printing 36-inch wide polyester/cotton sheeting fabric. The prints were to contain three colors with regions having single colors and two and three overlapping colors. The second objective was to continue development of a toner meeting textile requirements.

Apparatus

During the previous two phases of the project, Hunt Chemical determined the toner and carrier combinations for the project. For Phase III, the decision was made to develop in-house capabilities for making electrical measurements of toner and carrier materials to arrive at optimum textile developer combinations. The following three measurement systems for characterizing toner were either built or purchased.

- Electrical measurement apparatus for the evaluation of carrier materials
- Triboelectric apparatus to evaluate the charge generating characteristics of toner/carrier combinations
- An impedance bridge and sample cell for dielectric measurements of toner and carrier candidate materials

Since building a 36-inch wide copier in-house would have been very difficult and prohibitively costly, a survey was made to locate an existing 36-inch wide copier that could be modified for continuous runs. Several 36-inch wide copiers were identified on the international market, but most were expensive, costing from $50,000 to more than $100,000. One of the copiers, the Xerox Model 2510, was priced in the $3000 to $4000 range. An evaluation of the Xerox 2510 copier indicated that it could be modified and used for continuous printing of fabric. The copier is an optically based, batch type machine that can make reproductions having widths up to 36 inches. It is basically a blue print reproduction machine that is best suited for printing lines. Solid areas are difficult to print with the Xerox 2510

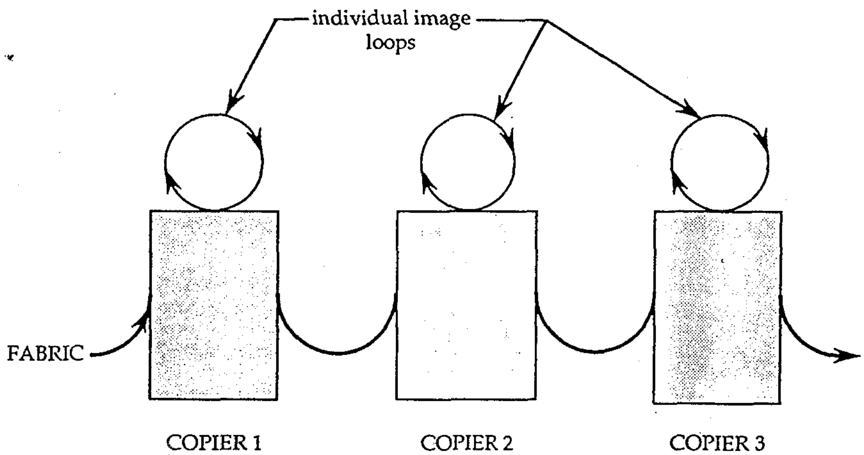

Fig. 4. Initial imaging configuration.

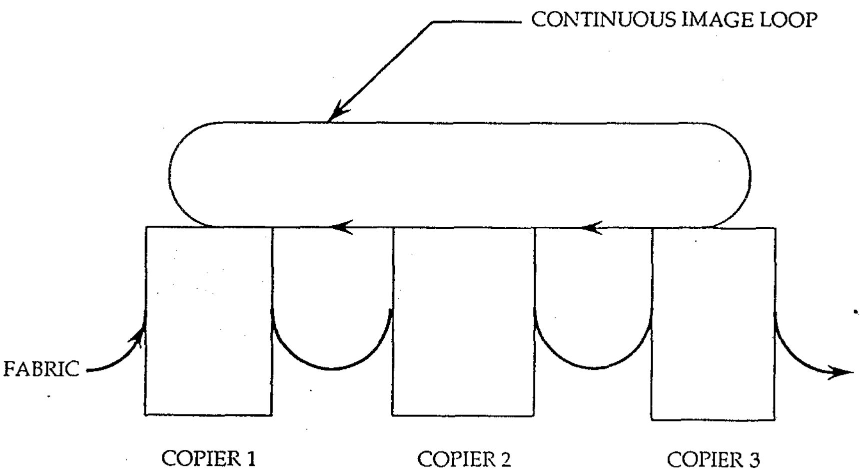

Fig. 5. Final imaging configuration.

copier, and some difficulty in printing dark, solid areas with the unit was anticipated. However, the Xerox 2510 was suitable for demonstrating the continuous xerographic printing of 36-inch wide fabric.

Since the Xerox 2510 is a batch type machine for making one-color prints, several modifications were necessary to allow continuous operation. Three of the machines were used in tandem to produce three-color prints. The Xerox Corp. cooperated in this phase of the project, providing assistance and advice in setting up and conducting the demonstration. A schematic of the set up is shown in Fig. 3. Modifications were made to facilitate continuous feeding of fabric through the copiers and to allow operator control of copier functions. In addition, take-up and let-off rollers were added to the arrangement.

The Xerox 2510 utilizes an optical system in copying an original. The initial set up for making three-color prints used three original image designs made in continuous loops with one mounted on each machine, as shown in Fig. 4. This arrangement proved unsatisfactory, as the pattern printed inconsistently. This occurred because the images were friction driven and slippage occurred. The loops could not be made with exactly the same lengths and the relative positions of the loops thus changed with run time.

The problem was solved by making one continuous loop image that passed through all three copiers, as shown in Fig. 5. Slippage was not a problem since the image shifted as a unit. This arrangement proved satisfactory for the demonstration and for producing prints for textile testing; however, it would not be acceptable for a commercial machine. For commercial applications, the operation obviously would be more complicated, with the images produced using lasers driven by computers. Problems involving color registration would have to be addressed but should be solvable.

Materials

The primary materials used in this phase of the project were: paper toners compatible with the Xerox 2510; candidate toners for textile applications; carriers used with the toners to produce developer systems compatible with the Xerox 2510; and additives to enhance the properties of the developer systems. The paper toners (Xerox 1025 toner, styrene-acrylate copolymer) were provided by Xerox and were compatible with the Xerox 2510 copier. Three colors of Xerox 1025 paper toners (red, blue and green) were matched with carrier to produce developer systems for testing. Since the paper toners had been developed for operation in the systems closely matching the Xerox 2510 copier, they were very useful in demonstrating the feasibility of continuously printing fabric using xerography. However, the required textile properties were not generated using these materials.

The materials considered as candidates for textile toners in this phase of the project included Kativo, the modified epoxy produced by H. B. Fuller, and two types of polyethylene-co-vinyl acetate produced by U.S. Industries. Since pigmented Kativo was commercially available, it qualified as a toner if it could be matched with a carrier. Kativo with several different colors of pigments were tested with carrier for triboelectric characteristics. Three colors—red, blue and green—were selected for the Kativo printing tests. The pigments contained in the toners were: red toner—blend of Naphthol Acrylamide (C.I. Pigment Red 170) and Pyrazol Orange (C.I. Pigment Orange 34, #21115); blue toner—Iron Blue 27 (C.I. Pigment Blue 27, #77510) and green toner—blend of Iron Blue 27 and Diarylide Yellow (C.I. Pigment Yellow 14, #21095).

The EVA materials were not commercially available with pigment and samples containing pigment could not be obtained from the manufacturer. Since attempts to produce pigmented samples via melt blending Elvax 410 and grinding and through spray drying pigmented EVA emulsions were unsuccessful (see earlier discussions), the decision was made to stain EVA samples using a disperse blue dye (Cibacet Blue E-GBN, C.I. Disperse Blue 3) so that print locations could be observed. Although the fastness properties of the stained materials would not be meaningful, the xerographic performance of the materials and the tactile properties of the prints could be assessed. Since two U.S. Industries polyethylene-co-vinyl acetate resins, MU 760 and FE 532, were commercially available in the desired particle size (five microns), they were selected. The ratios of ethylene to vinyl acetate for the two materials were 82:18 and 91:9, respectively.

Eight different types of carriers were tested during this phase of the investigation. These carriers, which were supplied by Hunt Chemical and Xerox, had electrical resistivities ranging from low to high values. The low resistivity carriers are used to best advantage for area printing, whereas the high resistivity materials are well suited for line reproduction.

An additive, Cab-O-Sil, was used to prevent the polymer particles from blocking and to enhance triboelectric charging. Cab-O-Sil is fused silica having a chain-like structure that tends to keep the toner particles separated.

The substrates used for the 36-inch wide continuous xerographic printing tests were rolls of paper and 50/50 polyester/cotton sheeting fabric. The paper was used to set up the three Xerox 2510 copiers in series to run continuously to assure the machines were functioning properly. Once the line was operational, the fabric was printed using paper toners and then textile toners were incorporated.

Tests

A number of tests were run to characterize toner and carrier. The most useful tests were those characterizing the triboelectric properties because the results indicated the compatibility of toner and carrier for attaining good quality xerographic prints. The test consists of placing a small sample (approximately three grams) of well mixed toner and carrier in a small stainless steel cylindrical cage. The mixing causes the toner and carrier to rub against each other and become oppositely charged. The cage or holder has 400-mesh stainless steel screens at its end walls. The holes in the screens are large enough to permit the toner particles to leave the cage, but are small enough to prevent the carrier particles from leaving. When dry nitrogen is blown back and forth across the cage, the charged toner particles are blown away and the charged carrier particles remain inside. The outside of the cage will be oppositely charged from the carrier. An electrometer lead attached to the support for the metal cage permits the recording of the electrical charge that has been stored on the cage as a result of the friction between the particles of toner and carrier.

The polarity of the photoconductor drum used in the Xerox 2510 copier is positive. Thus the desired polarity to be developed on toner for use with this copier is negative. Obviously, when this occurs the carrier particles which remain in the cage after the triboelectric test will be positively charged and the electrometer will indicate the magnitude of that charge. The results of the test is referred to as the triboelectric number, and its units are microcoulombs per gram of toner.

The following types of continuous xerographic tests were conducted: paper toners on paper, using Xerox 1025 toner (red, green and blue) with Xerox 2510 carrier; paper toners on fabric, using the same developer system as in the initial runs; Kativo toners (red, green and blue) on fabric, using Kativo mixed with Xerox 2510 carrier as the developer system; and FE 532 on fabric, using FE 532 tinted with blue disperse dye mixed with Xerox 2510 carrier. The prints made during the first three types of tests contained three colors with regions having two and three overlapping colors. The last test produced single-color prints.

Several tests were performed to evaluate the quality of the prints produced using xerography: wet/dry crockfastness; color-

Table V. Triboelectric Numbers for Xerox 1025 Toners with Xerox 2510 Carrier

Toner Color	Triboelectric Numbers (μC per g)
Red	26.2
Blue	16.8
Green	22.2

fastness to laundering; colorfastness to chlorine; colorfastness to drycleaning; colorfastness to light; flammability; and stiffness of print. All of the tests were performed on the Kativo prints, but the tests were not performed on the FE 532 prints since the resin did not contain pigment. The FE 532 prints were compared visually with the Kativo prints for print quality.

Wet and dry crockfastness tests were performed on the prints according to AATCC Test Method 116-1983. The amount of color transferred from the specimen under investigation was evaluated by means of the AATCC Gray Scale for Staining.

The colorfastness to laundering of the treated fabrics, when subjected to accelerated conditions of home laundering, was evaluated according to AATCC Test Method 61-1986. The test conditions of Test No. 3A were used. The color change of the test specimens was evaluated using the Gray Scale for Staining and the Gray Scale for Color Change.

The colorfastness to chlorine was evaluated using Test Method 61. Test conditions were from Test No. 5A. The color change of the test specimens was evaluated using the Gray Scale for Color Change and the Gray Scale for Staining.

The colorfastness of the treated fabrics to drycleaning solvent was evaluated according to AATCC Test Method 132-1985 with one exception—the steel disks were replaced by stainless steel balls. The effect of perchloroethylene on the color of the test specimen was classified by the Gray Scale for Color Change.

The colorfastness of the prints to light was determined by AATCC Test Method 16E-1979. The samples were exposed for 45 and 65 hours. The black panel temperature was 117F and the relative humidity was 15%. The results were rated by the Gray Scale for Color Change.

The flammability of the printed fabrics was evaluated by ASTM Standard D1230-61. The time of flame spread was noted, as well as the number of fabric ignition attempts. The results were categorized according to the three classes of flammability defined in the test method.

A Wild Macroscope was used to make an optical examination of xerographic prints produced using paper and experimental textile toners. The xerographic prints were compared with screen prints produced commercially on sheeting fabric similar to the fabric used for the xerographic prints. After making a straight cut of the 50/50 polyester/cotton sheeting fabric, slides of top and side views of the fabric were taken. The magnification of the pictures varied from 25 to 50X. The slides illustrated the details on a microscopic scale of the nature of flow of toner materials over and into the fabric surface. Effects of fusion temperature and of crocking were also illustrated.

Results and Discussion

The tests to characterize the triboelectric properties of toner and carrier were useful in assessing the compatibility of toner and carrier. After the paper and textile toners were tested with a number of different carriers, Xerox 2510 carrier was selected for the printing tests because it gave acceptable triboelectric numbers and was readily available. Table V gives results of the triboelectric tests to assess the potential of printing with the Xerox 1025 paper toners and Xerox 2510 carrier. The triboelectric numbers for these developer systems were sufficiently high that no charge enhancer was needed. The initial continuous runs were made using a composition consisting of 2% (by weight) of toner and 98% of carrier.

The triboelectric numbers for developer systems produced from red, green and blue Kativo mixed with Xerox 2510 carrier are given in Table VI. The effect of low concentrations of a charge enhancer, Cab-O-Sil, on the triboelectric number is shown. The addition of Cab-O-Sil at a level of approximately 1% on weight of toner was needed to obtain sufficiently high triboelectric numbers for successful printing on the polyester/cotton sheeting fabric. Higher levels of Cab-O-Sil were not used because the triboelectric numbers were not appreciably changed with increasing concentration. Also, toner properties can be negatively affected by high levels of additives. For the initial runs, the Kativo toners were sieved to a particle size of approximately 45 microns and premixed with Cab-O-Sil. The developer system consisted of 2% (by weight) of the toner mixture and 98% of the Xerox 2510 carrier.

Tests with the EVA toners revealed that Cab-O-Sil was needed not only as a charge enhancer but also as an antiblocking agent. Without the addition of Cab-O-Sil, the FE 532 and MU 760 materials blocked to the extent that sieving was impossible. When Cab-O-Sil was added, the material could be sieved and triboelectric tests performed. The triboelectric test results for the EVA toners with 1% additive are given in Table VII. The triboelectric number for FE 532 was very high (+40.5 μC per gram) with only 1% Cab-O-Sil. Since a higher level of additive was required to obtain a similar triboelectric number for the MU 760, FE 532 was selected as the EVA material of choice for the textile xerography tests.

Table VI. The Effect of Cab-O-Sil on the Triboelectric Numbers for Kativo Toners and Xerox 2510 Carrier

Toner Color	Triboelectric Numbers (μC per g) Cab-O-Sil (%) 0	1.0	1.5	2.0
Red	+4.1	+7.0	+6.5	+7.8
Green	+2.3	+9.2	+2.9	+6.2
Blue	+0.6	+8.2	+9.1	+6.7

The initial continuous runs were made using the Xerox 2510 paper toners and 36-inch wide white paper. The pattern definition was satisfactory but the depth of color of large solid areas was only fair on medium shades. Solid areas are difficult to print with the Xerox 2510 copier since it was designed to be a blue print (line) copier; i.e., the toner delivery system on the copier was not designed to deliver large quantities of toner required for printing solid regions.

The next step involved using the paper toners to print on fabric. The pattern definition was acceptable but the depth of shade again was only fair. In an effort to improve the depth of shade, the concentration of the paper toner in the developer mixture was increased to approximately 3% by adding toner to the developer tray. The depth of color was improved without a sacrifice in pattern definition; however, results were not consistent from shade to shade. The shade of color in decreasing

Table VII. The Effect of Cab-O-Sil on the Triboelectric Numbers for Two U.S. Industries EVA Toners Stained with Disperse Dye

Toner	Triboelectric Numbers (μC per g) Cab-O-Sil (%) 0	0.5	1.0	1.5	2.0	5.0
FE 532	—	+2.7	+40.5	+39.9	+18.8	+38.2
MU 760	—	—	+5.6	—	+17.5	—

order of depth was green, red and blue. Since this was the order in which the printing was conducted on the continuous line, it was hypothesized that the fabric was being dried during contact with the fuser drum, changing the fabric's dielectric properties. As a result, less toner was being picked up in subsequent copiers. However, in tests with moist air forced across the fabric between the copiers, the shade did not change significantly. Microscopic examination of the printed areas indicated that increased deposition of toner would darken the shade. The concentration of toner was increased to approximately 4% and a run was made. The color was darker but the inside of the copier was covered with toner. At this level of toner, the carrier was not able to control it and considerable dusting occurred.

In the next series of tests, the Kativo toners were used to print on fabric. Based on the results with the paper toners, a 3% toner concentration was used. In the initial runs, large regions of heavy toner deposition resulted in streaking on the fabric, especially with the red Kativo. "Echo" images were observed as faint repeated images printed behind a designated pattern. In addition, excessive dusting of toner inside of the copier was noted.

The problems encountered with the Kativo toners were discussed with representatives of the Xerox Engineering Corp. They advised that the echo images observed in Kativo prints were likely caused by a toner fusing problem known as "hot offset." This phenomenon occurs when the toner is not elastic enough to "snap back" to the substrate from the fuser drum. On subsequent revolutions of the fuser drum, the toner left on it is deposited on the substrate, resulting in faint ghost images. Factors that can contribute to hot offsetting include lack of oil release on the fuser drum, too high a temperature for the fuser drum and poor elastic properties of the toner. Since the elastic properties of the toner could not be changed, efforts were made to adjust the oil release fluids and fuser drum temperature.

The wiping mechanism of the fuser assembly applies oil to the fuser drum to aid release of molten toner. Examination of the wiping mechanisms revealed that the wicks were coated with polymer, impairing lubrication. Replacing the old wicks with new wicks loaded with oil improved the short term wiping performance of the mechanism, but toner quickly built up on the wicks, hindering subsequent wiping. Obviously, modifications to keep toner on the substrate would be preferable. Noncontact approaches to fixing the toner could be used; however, developing a new system for fixing toner on the Xerox 2510 was beyond the scope of the project.

Another factor contributing to the offsetting problem was that the fuser temperature was set too high. The fuser roll temperature on the Xerox 2510 could be set between approximately 120 and 160C. This was too high for Kativo toner which has a melting point of approximately 95C. The Xerox 2510 copier was modified to allow lower fuser roll temperatures to be used. For settings at and below 90C, "cold offsetting" was observed where toner was not completely fused onto the fabric or the fuser drum. When fuser temperature was increased above 100C, hot offsetting worsened with increasing temperature. The test results indicated that the optimal temperature for minimizing offsetting was about 100C.

Since excessive dusting of toner inside the copier had occurred when toner concentration was 3%, carrier was added to the developer system to reduce the toner concentration to approximately 2%. Prints at this concentration were of better quality but were light in depth of shade. Increasing toner concentration back to 3% resulted in hot offset of toner and a return of the dusting problem. Although the carrier was able to control the paper toner at a concentration of 3%, it was unable to control the Kativo toner at the higher concentration. One possible reason was that the Kativo toner was not as well matched with the carrier as the paper toner, as indicated by the triboelectric numbers. Another was the Kativo toner particles were too large. The Kativo toner had been sieved using a mesh screen with openings of approximately 45 microns. The screen selection was based on information in the literature indicating acceptable toner particle size ranged from 5 to 45 microns. However, according to xerography experts, the typical range of toner particle size is from 5 to 20 microns.

Samples of each of the three Kativo toners were sent to a laboratory for particle size analysis with a Coulter Counter. The mean particle size for the green, blue and red Kativo toners were 18, 32 and 51 microns, respectively. The percentage of the particles falling in the desirable range was 41, 17 and 6 for the green, blue and red toners, respectively. The particle size was indeed too large for good xerographic performance.

The toners were then air milled to reduce the particle size. Due to time contraints of the project and the unavailability of a mesh screen with openings smaller than 45 microns, the ground toner was collected, sieved and loaded into the copier. Evidently, the particle size had been reduced since the prints were greatly improved, with better print quality and depth of shade. Also, when toner concentration was increased to 3%, dusting of toner inside the copier was reduced. The higher toner concentration gave darker prints.

After all the process development changes were made, a printing run was conducted where polyester/cotton fabric was printed using the three colors of Kativo toner. Although the offsetting problem was never totally eliminated, three-color prints (including two and three-color overlap regions) suitable for testing the textile properties of Kativo were produced.

The results of the textile property tests

Table VIII. Results of Fastness Tests for Prints with Kativo Toner

Specimen	Crockfastness[a] Dry	Crockfastness[a] Wet	Laundering[b] Color Change	Laundering[b] Staining	Chlorine[c] Color Change	Chlorine[c] Staining	Drycleaning[d] Color Change	Light[e] 20 hr	Light[e] 45 hr	Light[e] 65 hr
Kativo Toner										
RED	4	5	5	4-5	5	5	5	5	5	5
GREEN	4-5	5	5	5	5	5	5	5	3-4	3
BLUE	5	5	5	4-5	5	5	5	5	4-5	4
2-COLOR	4	4	5	4-5	5	5	5	5	4	4
3-COLOR	4	4	5	4-5	5	5	5	5	4	4
Screen Print[f]										
BLUE	5	4-5							5	5
BLACK	4-5	3							5	5
RED	4-5	3							5	5

[a]AATCC Test Method 116-1983. [b]AATCC Test Method 61-1986, Test No. 3A. [c]AATCC Test Method 61-1986, Test No. 5A. [d]AATCC Test Method 132-1985. [e]AATCC Test Method 16E-1979. [f]Produced by a leading sheeting manufacturer.

are summarized in Table VIII. The flammability test results indicated that no significant difference existed in the flammability of the Kativo printed samples and unprinted fabric. The crockfastness results of all three of the Kativo toners were acceptable. When compared to control, which was screen printed fabric obtained from a leading sheeting manufacturer, the Kativo toners exhibited slightly higher ratings for the wet crockfastness test. The colorfastness of the Kativo prints to laundering, chlorine and drycleaning was excellent. With the exception of the green, the colorfastness of the Kativo prints to light was acceptable but inferior to the control. Since the red Kativo print was rated excellent after 65 hours of exposure, the problem with the green should be solvable by changing pigments.

The results of flexural rigidity tests are shown in Table IX. The stiffness of the Kativo printed fabric was much higher than for the control. Thus the stiffness of the Kativo film is a potential problem that should be further studied.

Since the triboelectric number for FE 532 (EVA) toner was very high with only 1% Cab-O-Sil additive, it was selected over MU 760 toner for producing xerographic prints. The FE 532 toner which had been stained using blue disperse dye was loaded into an unmodified Xerox 2510 copier and prints were made. Colorfastness tests were not performed on the prints because a commercial toner would contain pigment, not disperse dye, and thus the colorfastness of the toner stained with disperse dye would not be meaningful. The FE 532 toner outperformed the Kativo toner xerographically. Although the prints were light in color, due to the small amount of disperse dye absorbed by the toner, the clarity and definition of the prints were superior to those produced using Kativo toner. Also, the aesthetic properties of the prints were qualitatively judged superior to the Kativo prints.

The results of the optical microscopic examination revealed that the wetting and penetration obtained with the Kativo and FE 532 toners were similar to those obtained with conventional printing. Photographs taken of the xerographic prints produced using paper toners showed that the individual toner particles, although adhering to the fabric, do not wet the individual fibers. Similar results were obtained for several types of paper toners including toner for the Haloid system and three colors of Xerox 1025 toner. In these cases, there was no penetration of the toner material into the interior of the fibers. In contrast, the wetting of fibers by the Kativo toners of all three colors was excellent. The toner material was observed on top of the fabric as well as in the cut region. With heavy toner concentrations, bridging of the spaces between fibers was also evident.

Table IX. Stiffness of Kativo Prints

	Flexural Rigidity (mg-cm)	
Specimen	**Mean**	**SD**[a]
1-Color	354	132
2-Color	365	124
3-Color	352	196
Control	194	20

[a]The large deviations between values resulted from inconsistent coverage of Kativo patterns along the specimen length.

The FE 532 material, stained with disperse dye, also had excellent fiber wetting properties. The cross-sectional view indicated a complete penetration of the fibers. The thickness of the deposited material appeared to be less than for the Kativo toner.

The control fabric, which had been screen printed in a commercial process, was also examined under the microscope. The wetting and penetration were similar to those observed for the Kativo and FE 532 toners.

Conclusions and Recommendations

The use of xerography for printing fabric appears to be technically feasible; however, the successful commercialization of xerography for printing fabric will require further research to develop textile toners yielding darker shades. A prototype copier designed specifically for printing fabric should be developed.

Two potential textile toners have been identified. Further research on both of these materials is needed before commercialization of the textile xerography process. Although the Kativo toner (a modified epoxy which is a thermoset) appears to have promise as a textile toner, work is needed to improve it in several areas. The flow characteristics of the modified epoxy could be changed to eliminate the offsetting problem. One approach might be to increase the size of the oligomer which would change the flow characteristics of the material at the melting temperature. Another approach to solving the offsetting problem is to change the fixation process to a noncontact system. Darker shades than those obtained will be needed. Different pigment types and loadings should be explored. The effects on color shades as well as on triboelectric numbers should be studied. Kativo toner particle size should be optimized, which should improve triboelectric numbers and allow darker shades to be produced. Once the toner is optimized, xerographic prints should be produced and compared aesthetically with control prints produced via screen printing.

Further work with the EVA (polyethylene-co-vinyl acetate) toner should be conducted. The results of the current study indicated that the EVA toner behaved better xerographically than Kativo toner and caused less stiffening of the fabric. Unfortunately, the unavailability of pigmented EVA left many questions unanswered.

A copier should be developed specifically for printing fabric. The demonstration was conducted using the Xerox 2510 copier, designed specifically for line printing on paper in a batch mode. Information for producing the copies was fed in optically. A copier for printing textiles would be different since it must operate continuously at speeds up to approximately 50 yards per minute. Information storage and input for image formation should be accomplished using a computerized system which would facilitate fast style and color changeovers, as well as aid in the production of new designs. Since different pigments affect the dielectric and triboelectric properties of the toner, each colored toner must be tailored for the copier in which it is to be used. Since a range of colors would be needed for most fabric printing operations, the production of a toner for each color would not be feasible. Thus the commercial textile xerographic printing system will likely utilize three primaries plus black, as currently incorporated in color paper xerography to produce thousands of shades via overlap printing: mauve, cyan and yellow with black. The production of color using three primary toners should be studied.

Acknowledgements

The research reported in this paper was funded by the Office of Industrial Programs of the U.S. Department of Energy and its support is gratefully acknowledged. Special thanks are due to Robert Massey and Bill Sonnett, DOE project monitors, for their advice, guidance and support throughout the project. The DOE/Georgia Tech Industrial Working Group for the project was very helpful and generous with its time, advice, materials, supplies and equipment. Its support is gratefully acknowledged. Elisha Shephard, research associate, conducted much of the research to identify binders and textile toners. Her efforts are gratefully acknowledged. We wish to acknowledge the assistance and hard work of a number of textile engineering students: Brian Failor, Craig Johnson, Leighton LeBoeuf, Allen Pendergrass and Marla Weinberg.

References

(1) Cook, F. L., et al., Application of Chemicals to Substrates Without the Use of Liquids: Solid-on-Solid Processing, Funded by the Office of Industrial Programs of the U.S. Department of Energy, Final Report, August 1990.

(2) Schaffert, R. M., *Electrophotography*, The Focal, London, 1965.

Author's Address

Dr. Wallace W. Carr, School of Textile Engineering, Georgia Institute of Technology, Atlanta, Ga. 30332

TEXTILE CHEMIST AND COLORIST

PUBLISHED BY THE AMERICAN ASSOCIATION OF TEXTILE CHEMISTS AND COLORISTS

May 1991/Vol. 23, No. 5
ISSN 0040-490X

TEXTILE CHEMIST AND COLORIST, Vol. 23, No. 5, May 1991. Published monthly by the American Association of Textile Chemists and Colorists, P. O. Box 12215, Research Triangle Park, N. C. 27709 (tel. 919/549-8141). Annual subscription price (surface postage) to AATCC members: $15; nonmembers: $30 U.S. and Canada, $40 other countries. Single copies $3 each in U.S., Canada; $5 each elsewhere. Single copies of the July issue (annual AATCC Buyer's Guide), $66 ($33 to AATCC members). Air delivery rates on request. Second Class postage paid at Durham, N. C., and additional mailing offices. Postmaster: Send notification Form 3579 to Textile Chemist and Colorist, P. O. Box 12215, Research Triangle Park, N. C. 27709.

BPA Member of Business Publication Audit of Circulation, Inc.

Features

Departments

THE COVER: This rugged little pier doesn't look like it belongs on a deserted island, but that's where Claudia Deaton found it with her camera. Portsmouth Island, which has been abandoned nearly 20 years, is midway between Cape Hatteras and Cape Lookout on North Carolina's Outer Banks. Claudia is AATCC's newest staff member, signing on in January as a laboratory technician.

IF YOU HAVE A PHOTO YOU THINK WOULD MAKE AN APPEALING COVER, PLEASE LET US HEAR FROM YOU