UV-Curable Pretreatments for Digital Printing Textile Substrates

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Abstract

Textile substrates for digital printing requires pre- and post-treatments to minimize problems such as ink bleeding and poor wet, light and smear fastnesses, which are mainly associated with the porous nature of textile substrates and the dyes and inks used. We investigated the pretreatments for cotton print fabrics using β-cyclodextrin dispersed in UV-curable acrylic emulsion to improve the digital print quality. The woven and knit cotton fabrics were pretreated by spraying with two recipes containing different amounts of β-cyclodextrin, polyethylene glycol diacrylate (a UV-curable resin), and 2-hydroxy-2-methyl-1-phenyl propanone (a photo initiator). The curing of the resin on treated fabrics was achieved with different dosage of UV radiation. HP DeskJet 820CSE printer was used for printing a test pattern on the treated cotton fabrics. The print quality such as line width and color variation was determined with Personal IAS System™ supplied by the QEA (Burlington, MA). It was found that the best print quality, which is comparable to photographic paper used as control, can be achieved with 10% β-cyclodextrin and 90% resin cured at 6 m/min under UV intensity of 118 W/cm. The coated fabrics showed a harsh hand and were somewhat stiff, which is undesirable in applications requiring drape and suppleness.

Introduction

It has been shown that UV curing is energy efficient compared to other forms of drying or curing. Moreover, UV curing is environmentally friendly. These advantages enabled manufacturers to have developed UV curable inks and systems that can address a number of industrial needs.[1]

UV curing system requires a UV light source, photoinitiator, a monomer or oligomer and a substrate. The photoinitiator is needed to initiate the polymerization process. In the initiation step, the photoinitiator produces free-radicals, which attack the acrylate double bonds in the monomer (see Figure 1). Now free radical monomers react with monomers to form chains (propagation) until the polymerization process is terminated. Termination occurs by either combination of polymer chains or forming a chemical bonds. It should be noted that β-cyclodextrin does not take a part in the polymerization process. It is merely an inert additive as a colorant host on the treated substrates.

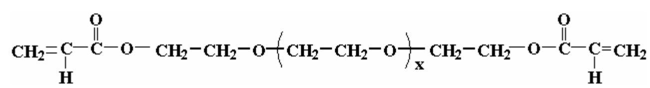

Figure 1. Polyethylene Glycol Diacrylate

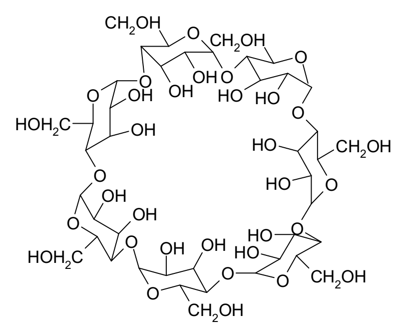

Figure 2. β-cyclodextrin

Cyclodextrin is a cyclic oligosaccharide that consists of six, seven or eight glucose rings and are named α, β and γ-cyclodextrin respectively. The chemical structure of β-cyclodextrin is shown in Figure 2.

It is a hollow molecule with a hydrophilic exterior and a hydrophobic interior that can host guest molecules. The hydrophilic/hydrophobic nature of cyclodextrins is exploited successfully in the pharmaceutical, cosmetics and foodstuffs industries.[2] Cyclodextrins are also used in the textile industry to deposit fragrances on fabrics to remove and hold unpleasant odors from the skin such as sweat. The unpleasant odors can then be removed from the fabric by washing.[3] Current research focus is to use cyclodextrin as a warp size and latent colorant while combining fabric production and printing.[4]

Experimental

The chemicals used in the research were β-cyclodextrin (Sigma-Aldrich Chemicals, St. Louis, MO), Polyethylene Glycol Diacrylate (SR 610, Sartomer Company, Inc., Exton, PA) and the photoinitiatior (Darocur 1173, Ciba Specialty Chemicals Co., High Point, NC).

A UV curing system equipped with 15cm wide conveyor belt (model C6/300, American Ultraviolet Co., Lebanon, IN) was used to cure samples up to 15 cm (6 inch) wide. The unit includes optical shielding, a conveyor belt speed control, tri-level power lamp switching, an elliptically focused heatsink reflector, a Nomex-coated fiberglass conveyor belt, and a metal halide mercury lamp. All samples were cured on the belt of the UV-curing unit.

Figure 3. Mini Conveyorized UV-Curing System

Two formulations of UV curing resin system were prepared. Each formulation weighed 100g. The amount of photoinitiator in the formulae was based on 2% of the monomer weight only, as shown in Table 1.

Table 1. Coating Recipes

	Cycoldextrin	Monomer	Photoinitiator
Recipe #1	10%	90%	1.8g
Recipe #2	20%	80%	1.6g

Two types of cotton fabric, 400M-print woven and 437-knit, from Testfabrics Inc., Pittston, PA, were used. Each type of fabric was cut into eight of 75 x 280mm strips. The samples were weighed prior to coating. A hand held paint sprayer (Wagner Power Painter Pro, model 300) was used to coat four woven and four knit cotton strips with recipes shown in Table 1. Each coated strip was run twice (once on each side) through the UV curing machine at one of the following four settings and then weighed to determine the amount of coating.

The samples were coded according to the following scheme: 20k300-50 means that 20% β-cyclodextrin on knit fabric (if w is in place of k, it is woven fabric) treated with 300 watt per inch (wpi) UV radiation at a conveyor speed of 50ft/min. Uk is used for untreated knit fabric, Uw for untreated woven fabric, and Pp for photo quality paper.

The average coating add-on on knit fabric was 65% except for 10w300-50 which had a coating add-on of 47%. The average coating add-on on woven fabric samples was 72%.

Table 2. UV Curing Settings

	UV Intensity	Belt Speed
Setting #1	200wpi	20ft/min
Setting #2	200wpi	50ft/min
Setting #3	300wpi	20ft/min
Setting #4	300wpi	50ft/min

Once all of the coated samples were cured, they were mounted on heavy craft papers of the swatch size. Using the Hewlett Packard DeskJet 820Cse, the chosen pattern consisting of colors and lines (see Figure 4) was inkjet printed on all of the pretreated fabrics, a piece of photo quality paper, and two untreated fabric samples of knit and woven.

The Personal IAS System (QEA, Burlington, Massachusetts) was used for print quality analysis of the sample produced. A total of five measurements for line width and L*a*b* color metrics were recorded and the average was taken. The width of the lines in µm was measured by centering the system's sensor over the line and hitting the line analysis button. The color quality (%R, L*, a*, and b*) was measured using CIELAB color space with a D50 Illuminant and 2° observer, by placing the sensor over the desired pattern and hitting the area analysis button. The data were saved on the machine and later transferred to Microsoft Excel using for further analysis.

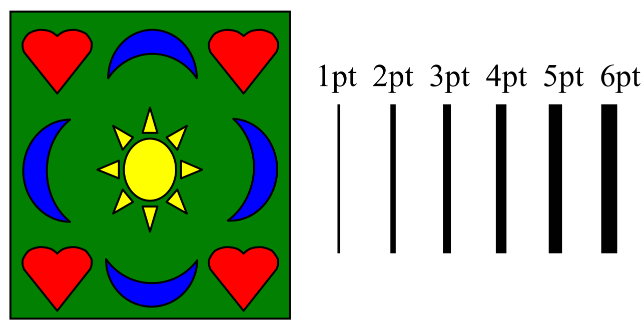

Figure 4. Patterns used in the research

Results and Discussion

Line Widths on Treated Fabric Samples

The line widths, shown in Fig 5, on all of the pretreated knit fabric samples were narrower than that of the photo paper, including the untreated fabric for all but the 1pt line. The coated knit fabrics did bleed less than the untreated knit fabric with the exception of the 20k300-50 sample, which had a slightly larger line width for the 2pt line. The results were similar for the pretreated woven fabric samples. The 6pt line for sample 10w200-50 was the only line on the coated samples that exceeded the width of the photo quality paper and the untreated woven fabric control. The untreated fabrics, both knit and woven, had smaller line widths than the photo paper for the 3pt, 4pt, 5pt and 6pt lines. It was noted that intended line width for 1pt line is equal to 350µm and that some of the coated samples had line widths smaller than what they should be. This could be due to that the coatings were not only uneven, but also very lumpy which made it difficult for the line widths to be measured precisely. Moreover, the coarse surface texture, due to the knit or woven structure, of fabrics, compared to the photo quality paper, makes the line printing irregular leading to narrower average readings for the line width measurement.

When comparing the line widths with the add-on percentage of the coating, there is little difference with the exception of sample 10w300-50. All of the samples that have a coating percentage between 65% to 72% (all but 10w300-50) have line widths that vary very little. Sample 10w300-50 had an add-on of 47% and had line widths that were much smaller than the other coated samples. It should be pointed out that that sample also had line widths that are smaller than what they should be. It could be assumed that the percent add-on of coating does affect the line widths until it reaches a certain percentage at which point the percentage of coating makes no difference. It would also make sense, judging from these results, that the higher the percentage of the coating the more realistic the line width values.

Color Measurement of Treated Fabric Samples

Figure 6 shows the reflectance value for each color on each sample. The reflectance for all of the fabric samples is much greater than that of the photo paper. As the reflectance increase the depth of the color decreases. None of the fabric samples could have the color depth of the photo paper. This could be attributed to the porous fabric structure which allows the colorants to penetrate into the fabric/coating layer resulting in lighter colors on the fabric surface, whereas the surface coating on the photo paper retains ink very well on the surface leading to very saturated color depth. From the figure 6, it can also be seen that the 20k/w200-20 sample gave relatively better color depth than other treatment conditions. This should be further studied to determine if this combination of treatment conditions is really useful.

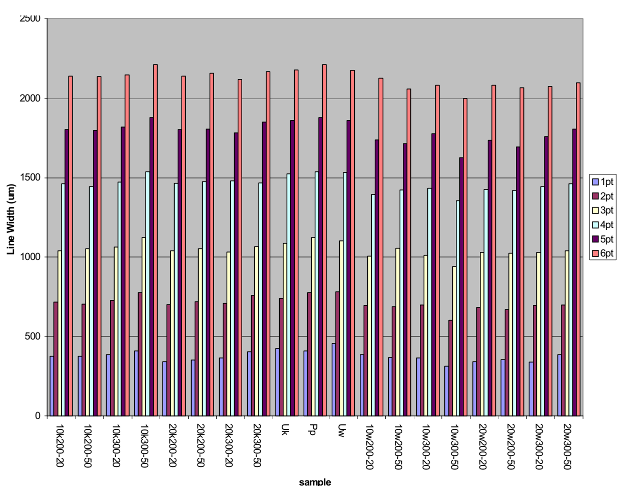

Figure 5. Line Width of Samples

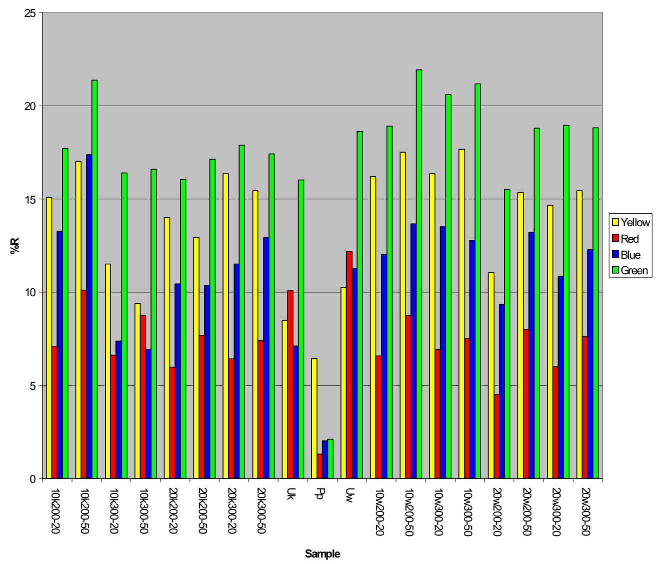

Figure 6. Reflectance of Samples

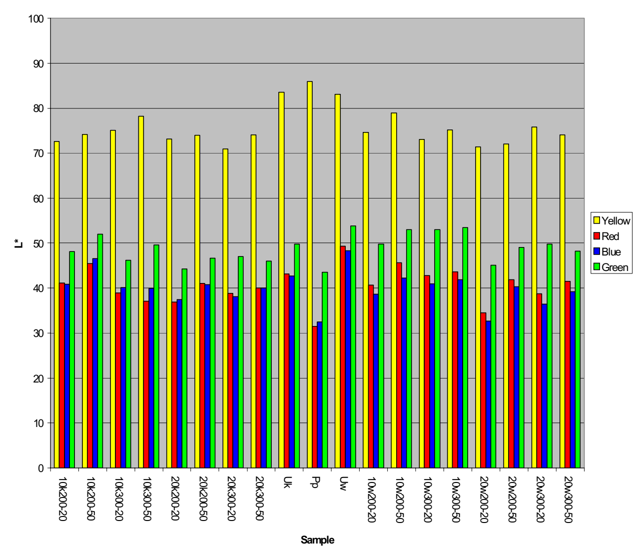

Figure 7. L* value of Samples

The L* values of the fabric samples, shown in figure 7, were in much better agreement to the values for the photo quality paper. All of the values on the treated fabrics indicated the lower color strength so the coatings did cause the colors to lose some brightness due to the slight yellowness of the chemicals used.

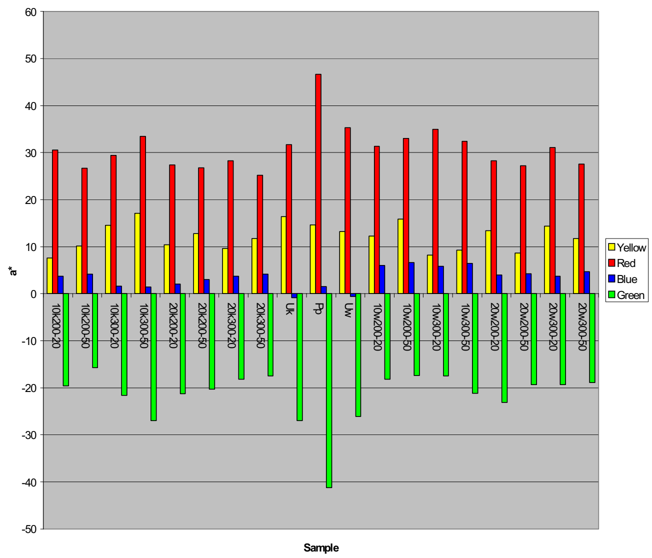

Figure 8. a Value of Samples*

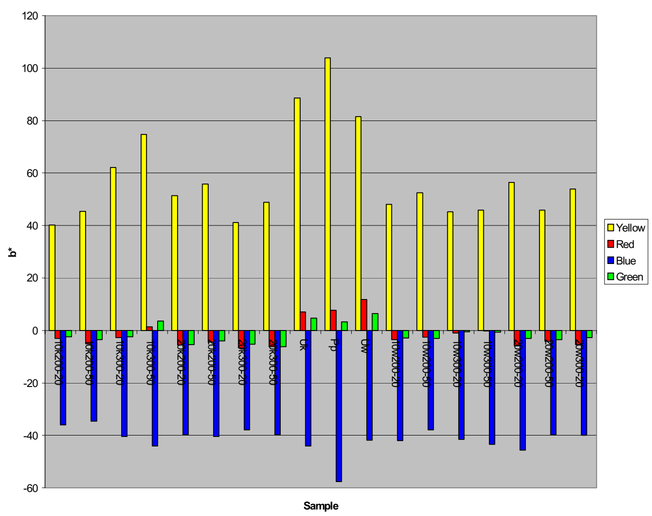

Figure 9. b Value of Samples*

The a* values (redness/greenness) for the printed red color, which can be seen in Figure 8, were all greater than zero which indicates that it is in red shade. The photo paper and the untreated fabrics did, however, have the higher chroma red color. The 10w300-20 sample did not do any worse than the untreated woven sample because the a* values were very close. Sample 10k300-50 was the only knit coating to do better than the untreated knit sample. From figure 9, it can also be seen that all but one of the coated samples (10k300-50) had a positive b* values for yellow, red and green colors like the untreated knit fabric. The woven samples 10w300-20 and 10w300-50 had b* values almost equal to zero. The photo paper and untreated fabrics had positive b* values, so they had more of a yellow tint.

The a* values for the green color can also be seen in figure 8. All of the values are negative. None of the samples came close to the green color of the photo paper. The untreated sample also did better than the coated samples, with the exception of the knit sample 10k300-50 that had a value extremely close to that of the untreated knit sample. The green color of the coated samples, with the exception of 10k300-50, like the red all had a slight blue tint. This exception and the photo paper and untreated samples had a slight yellow tint, while the woven samples 10w300-20 and 10w300-50 had b* values almost equal to zero indicating virtually no tint in the green color.

The yellow color on all of the samples had positive a* values and positive b* values. This indicates that the color was slightly orange, more so for the coated fabrics than the photo paper. Again the b* values for the untreated fabrics and the photo paper were much greater than the values for the coated fabrics.

With the exception of the untreated fabrics, which had negative a* values, the blue color on all of the samples including the photo paper had a slight red tint. All of the b* values are negative. The photo paper did have a truer blue than that of all of the fabric samples. The untreated fabrics also did better with the exception of the knit sample 10k300-50 and the woven samples 10w200-20, 10w300-20, 10w300-50 and 20w200-20, which ranked slightly higher on the b* scale. The lower the b* value the more blueness the color contains. The fact that the b* values are right in the center of the blue range (0 to -100) tells us that the color does not contain all attributes of blueness although a blue color is clearly seen.

From the above observation, we can conclude that all the shift of L*a*b* values on the treated fabrics compared to the effects on the photo paper are coming from the interaction between colorants and coating chemicals and the penetration depth.

Conclusion

If the process of coating and UV curing of cotton fabric with cyclodextrin were to be used in industry some precautions would need to be taken. It is highly important that the fabrics all be evenly coated to yield accurate results. It is also important that each fabric have the same amount of coating material. A hand spray coating does not render to achieve the goals. In commercial practices, however, the spraying systems are much more sophisticated, which would help yield better results.

It is also important that the fabrics be perfectly flat. Because of the way that the fabric samples were put under the UV lamp, most cured fabrics had wrinkles. The wrinkles make uniform printing almost impossible. The wrinkle waves in the fabric were permanently affixed. During the printing on or near the affixed wavy area, the extra thick part of the fabric actually rubbed against printing heads. This caused some samples to get stuck in the printer and smudging on all of the samples. This caused some very unattractive prints and also made the color quality analysis difficult because of the smudges. To avoid this problem a conveyor belt should have a provision of sample holding pins or clips under biaxial tension. It is essential that the fabric be kept under biaxial tension at all times to avoid the permanent wrinkles in the fabric. After curing the fabric can then be re-rolled or immediately printed on.

Most of the coatings yielded similar results, but some did stand out. Because the line width data was close, the best coatings were selected based solely on the color quality analysis. The samples that seemed the best were the knit samples 10k300-20, 10k300-50, 10k200-20 and the woven samples 10w300-20 and 10w300-50. Based on these results the best coating recipe is the recipe #1 from Table 1 with setting #3 from Table 2, 10% cyclodextrin cured at 20 ft/min under an intensity of 300 wpi. The next better one is the recipe #1 used with setting #4, 10% cyclodextrin cured at 50 ft/min under an intensity of 300 wpi, from Tables 1 and 2.

The UV curable resin treated fabrics had a hard hand and were somewhat stiff, which is undesirable in the apparel application. Therefore the coatings used in the study are not recommended for applications requiring drape and suppleness. This may have been avoided if the coating was thinner and/or elastomeric. Ideally the amount of coating on weight of fabric should have been less than 5%. Further studies will tell us if the coatings would be useful for any other applications which require no suppleness. If the coating is durable it could be used for luggage, if it is water-resistant as well it could be used for umbrellas, tents, raincoats and convertible tops. It may also be useful to look into coatings with cyclodextrin derivatives or other solvents that may be compatible.

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Biography

Qinguo Fan, an Assistant Professor of Textile Chemistry at the University of Massachusetts Dartmouth, earned his PhD in Color Chemistry from Leeds University, UK in 1995. He received an MS and a BS in Textile Chemistry from China Textile University in 1988 and 1982 respectively. Before joining the faculty at UMD in 1998, he was a Textile Chemist in charge of R&D, dyeing and finishing, wastewater treatment and customer service in Novel Textile Ltd. in Mauritius. His research interests include textile chemistry, color science, polymer and environmental compliance of textile wet processing.