Integration of the Weaving and Printing Processes

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Abstract

Integration of fabric production and coloration offers the benefits of almost immediate style changes with an unlimited color palette. However, this would require a sizing agent to also function as a printing agent, able to provide the correct conditions for printing upon the previously created fabric without any intermediate processing. In this study, a link between the weaving and printing of cotton fabric was discovered and evaluated with good results. This discovery will allow the integration of weaving and printing to progress one more step closer to reality.

Introduction

In the traditional creation of printed woven cotton fabric different processes are involved. First the yarn is treated with size, a polymeric coating usually consisting of starch or polyvinyl alcohol, which protects the yarn from abrasion during the weaving process.[1] The yarns are then woven into a fabric and then subjected to wet processing. In wet processing desizing, scouring, bleaching, and sometimes mercerization are done to remove the size, clean the fabric, and provide it with a uniform white color. Afterwards, the fabric may be dyed prior to printing, depending on the desired background color, and then printed, usually with roller screen printing, which although fast, requires the use of engraved screens, which are time consuming to create. Additionally, roller screen printing requires a separate screen for each color used as well as the creation of different screens for changes in patterns.

Alternatively, digital inkjet printers, while slower than roller screen printing, offers the advantage of not requiring screens which allows for almost immediate pattern changes and an infinite range of color availability due to the additive effect of combining colors to achieve the desired hue. Although digital inkjet printers currently have speeds up to 12 meters per hour, as opposed to 30 to 100 meters per minute for roller screen printing, the speeds of digital inkjet printers have been increasing and most likely will continue to do so.[2,3]

Usually reactive dyes, water soluble anionic compounds, are used to print on cotton due to the formation of covalent bonds between the cellulose molecules contained in the cotton fibers and reactive dye molecules, as depicted in Figure 1.[1] In Figure 1, RG-Cl represents a chlorinated reactive group, while H-O-CELLULOSE represents the cellulose molecule. This reaction requires a basic pH to be successful, which is usually provided by the application of sodium carbonate to the fabric prior to printing. At the same time, urea is often applied to the fabric to absorb moisture during the printing process. The formation of a covalent bond between the cellulose and dye molecules provides for superior color retention properties, compared to other dye types used to color cotton.

As the speed of digital inkjet printers increases, it will start to approach the speeds of weaving looms. As such, it then may be possible to integrate fabric formation with coloration by linking a loom with a digital inkjet printer so that as the fabric is created it is printed, thus combining two processes and eliminating the wet processing steps described previously, resulting in processing time and labor reductions. Additionally, this combination would allow for immediate style changes in both the fabric produced as well as the pattern printed on the fabric. In order for this to be successful the sizing agent would also have to have the ability to provide the proper conditions to allow for the fabric to be successfully printed.

This research has focused upon integrating fabric formation and coloration for the production of woven, printed cotton fabrics, using reactive dyes as the colorant. Cotton was chosen due to its wide use in textiles, ranging from apparel to home furnishings.

Experimental

Initial evaluations focused on finding a solution that could act as both a sizing agent and a print fixative. As such, it was decided to evaluate a sizing solution as well as a solution applied to cotton fabric prior to digital inkjet printing. The sizing solution consisted of 85% water and 15% corn starch, while the pre-print solution consisted of 85% water, 10% urea, 2.5% sodium carbonate, 1.5% Noveon Carbopol 2491 thickener, and 1% Degussa Aerosil 200 silica. The solutions were padded onto plain weave cotton fabric created on a Sumagh 400 end sample loom using 20/2 Ne cotton yarns supplied by Huntingdon Mills, with a Werner Mathis lab padder at 80% wet pick up. The fabrics were dried with a Tsuji Senki Kogyo through air oven at 130°C for two minutes.

$$\text{DYE-RG-Cl} \quad + \quad \text{H-O-CELLULOSE} \quad \xrightarrow[\text{- HCl}]{\text{Base}} \quad \text{DYE-RG-O-CELLULOSE} \quad + \quad \text{SALT}$$

Figure 1. Illustration of the formation of a covalent bond between a reactive dye molecule and a cellulose (cotton) molecule.[1]

These two fabrics as well as a control fabric that was untreated were printed with four color stripes, consisting of CIBACRON Turquoise MI700, CIBACRON Red MI500, CIBACRON Yellow MI100 and CIBACRON Black MI900 with a Mutoh ink jet printer containing an Epson print head. The fabrics were then subjected to the usual post ink jet printing processes of steaming, rinsing, and soaping at the boil to affix the dye to the cotton fibers and remove any unfixed dye from the fabric. Steaming was done with an Arioli steamer at 103ºC for eight minutes followed by a 5 minute rinse in a beaker with cold water, while soaping at the boil was accomplished with a solution of water and Synthrapol detergent heated in a beaker on a hot plate.

The fabrics were allowed to condition for 24 hours at standard temperature and humidity conditions before being evaluated for colorfastness to laundering, light, and wet and dry crocking. Washfastness was evaluated with an Atlas Launderometer according to AATCC 61, while a Q-Sun 1000 Xenon light chamber was utilized to evaluate lightfastness according to AATCC 16, using 20 and 40 hour exposure times. Wet and dry crocking was performed with an Atlas vertical rotary crockmeter in accordance with AATCC 116.

Based on the colorfastness evaluations as well as a desire to better understand the role of the different compounds in the post printing treatment solution, different possible post printing treatment solutions were padded onto yarns and evaluated for possibility as sizing agents. Three different solutions are prepared to evaluate their potential as a sizing agent.

Solution A: Control, no treatment
Solution B: 85% water, 10% urea, and 5% sodium carbonate
Solution C: 86% water, 10% urea, 2.5% sodium carbonate, and 1.5% thickener
Solution D: 85% water, 10% urea, 2.5% sodium carbonate, 1.5% thickener, and 1% silica

Solution B, C, and D were padded onto 20/2 Ne yarns, supplied by Huntingdon Mills using the same conditions as before. These yarns were evaluated for tenacity before and after abrasion in order to determine if solutions B-D would be effective as sizing agents. Twenty yarn specimens of solutions A-D were evaluated for single end tenacity according to ASTM D2256 with a Testometric SDL constant rate of elongation tensile tester. These yarns were the pre-abrasion specimens. The twenty post-abrasion specimens from solutions A-D were subjected to an abrading force of one pound for 75 cycles of a CSI flex tester, usually utilized to measure flat abrasion, similar to the type and amount of abrasion that would be incurred on a loom during the weaving process. After abrasion these yarns were also tested to determine single end tenacity.

These same solutions were also applied to the plain weave cotton fabric described previously, using the same padding and drying procedures. The fabrics were then printed with lines of CIBACRON Black MI900 reactive dye with the Mutoh printer, in widths of 0.25, 0.50, 0.75, and 1.0 points. A control of photo quality glossy paper, which currently provides the highest quality print line, was also printed with the same lines. After the same post printing processes for the fabric described earlier, the lines on the fabrics and the paper were analyzed for line raggedness, line width, and line density, according to ISO 13660. A Personal IAS (Image Analysis System) by Quality Engineering Associates was utilized to measure these components of line quality. Line raggedness is a measure of the straightness of the edges of the lines, taken as an average of both edges. Line width is a measure of the actual line width as compared to its theoretical width, while line density, measured with a color filter and compared to density standard, is a measure of the line darkness, expressed in units of optical density (OD),

Solution D performed as expected in the line quality analysis and subsequent color fastness tests. Based on the results of all evaluations completed thus far, it was decided to focus on solution D: thickener, silica, urea, sodium carbonate, and water; as a combination size and print fixative. Solution D was then padded onto 100% cotton 12 Ne rotor spun yarns produced with a Rieter rotor frame. The yarn was wound into seventy skeins each with a length of 210 yards and then padded with solution D with a Werner Mathis lab padder with a wet pick up between 60 and 80 percent. After padding the yarns were dried with a Tsuji Senki Kogyo through air oven at 150°C for 6 minutes and 15 seconds. Using the Sumagh sample loom, the treated yarns were woven into plain weave fabric, utilizing the treated yarns in both the warp and weft directions. Four stripes of different colors were printed on the fabric by using the four pure reactive colors described previously with the Mutoh printer, while lines of the four point sizes were also printed on the fabric at the same time the black dye. The fabric was then steamed, rinsed, and soaped at the boil. The fabric was subjected to line quality analysis after printing, after steaming, and after steaming, rinsing, and soaping to understand how each process affects line quality as well as to determine if solution D survived the weaving process to also function as a print fixative.

Results and Discussion

The initial evaluations were designed to determine if the traditional sizing agent of a starch solution could also function as a pre-print treatment. This required evaluating this solution in terms of its ability to foster the formation of covalent bonds between the cellulose molecules in the cotton fibers and the reactive dyes, and comparing its results with that of the typical pre-print treatment of water, silica, sodium carbonate, urea, and thickener, as well as comparing it to a control with no treatment. However, both the control and the sized fabric lost the colors printed on them during the steaming and soaping processes, indicating that no covalent bond was formed between the cellulose and dye molecules. This is not surprising as neither the control nor the size solution contained an ingredient to create a basic solution, thus not allowing for the formation of covalent bonds. These two fabrics were not evaluated for colorfastness properties, but the fabric padded with the pre-treatment solution was, with the results provided in Table 1, where a rating of 5 is considered excellent on a scale of 1 to 5.

The fabric exhibits good colorfastness properties, with the exception of red in wet crocking, which is indicative of the formation of covalent bonds between the cellulose and dye molecules. Red cotton fibers have traditionally had poor wet crocking resistance due to unaffixed dye remaining in the fibers, so this is not an unusual result. A more vigorous soaping treatment may resolve this issue, but if not addressed, this could lead to color transfer of the red dye to other fabrics during laundering and drying.

The second set of evaluations consisted of determining if the pre-treatment solution could be utilized as a sizing agent as well as a pre-printing treatment. At the same time it was decided to evaluate variations of this solution to determine if one of those could provide superior results to the original formula. The variations were formed based on a desire to simplify the original solution which would also decrease costs in an industrial setting. Additionally, removing some ingredients from the original solution might give insight into the role each ingredient played in the properties of the final fabric.

Figure 2 graphically depicts the results of the tenacity evaluations of the different sets of yarns, both abraded and unabraided. A tenacity loss is expected after abrasion as the yarn has lost fibers, or in the case of a coated yarn, has lost its coating and then fibers, and thus is unable to undergo the same loading as an unabraided yarn. What is interesting is the amount of tenacity loss as a function of the different treatments. Solution A, the control with no treatment lost almost 15 percent of its tenacity, while solution B lost approximately 17 percent and C suffered about an 11 percent loss in tenacity as a result of this abrasion. However, solution D only lost about 4 percent of its original tenacity after abrasion. From these results it appears that the addition of coating to the yarns usually provides a decreased loss of tenacity compared to the untreated yarns, which is to be expected. But, it appears that silica, present in solution D only, may have the unexpected effect of dramatically decreasing the damage caused by abrasion, and thus allowing the yarn to only lose a slight amount of tenacity due to weaving. While this needs to be further investigated, it could be an important addition to current sizes in order to further protect the yarns from abrasion.

Table 1: Results of Colorfastness Evaluation of Printed Fabric Coated with Pre-Printing Solution

Sample		**Colorfastness to Light 20 hrs**	**40hrs**	**Colorfastness to Laundering (Color change)**	**Colorfastness to Crocking Wet**	**Dry**
A: Control		N/A		N/A	N/A	
B: Cornstarch		N/A		N/A	N/A	
C: Sodium Carbonate/Urea Formula with Thickener and Silica	Turquoise	5	5	5	4	5
	Red	4-5	4	5	3	5
	Yellow	5	4-5	5	4	5
	Black	4-5	4	5	4	5

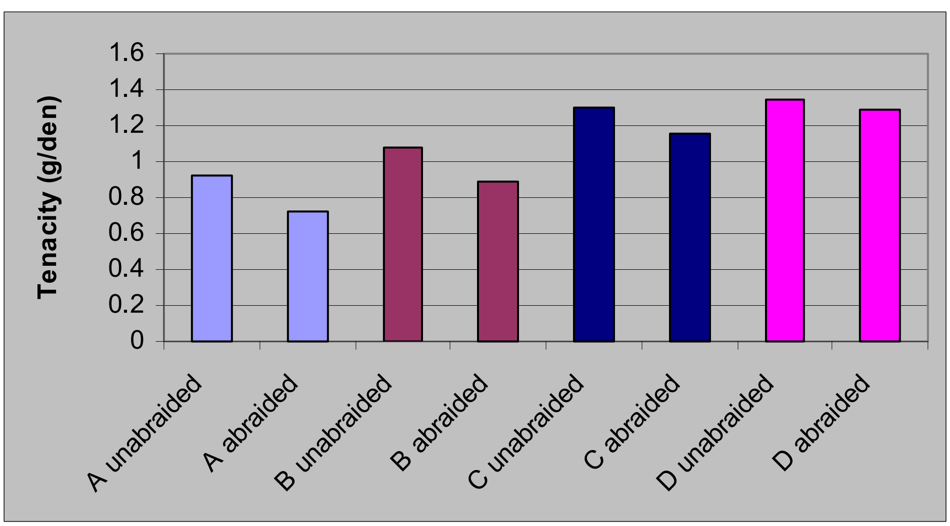

Figure 2. Average Tenacity Values of Yarns Treated with Different Print Fixative Solutions.[4]

These solutions were also evaluated for their ability to provide good line quality of printed fabrics. Line quality is important as it directly affects the quality of the print as well as how much text and fine detail can be displayed on the fabric. Thus, the printed fabrics are compared to printed photo quality glossy paper which is believed to offer the best printed line qualities. The closer the values of the printed fabrics are to those of the paper, the greater the quality of the lines. Figure 3 depicts images, not to scale due to different magnifications, of the four differently sized lines printed on fabric treated with solution D, as captured by the IAS device.

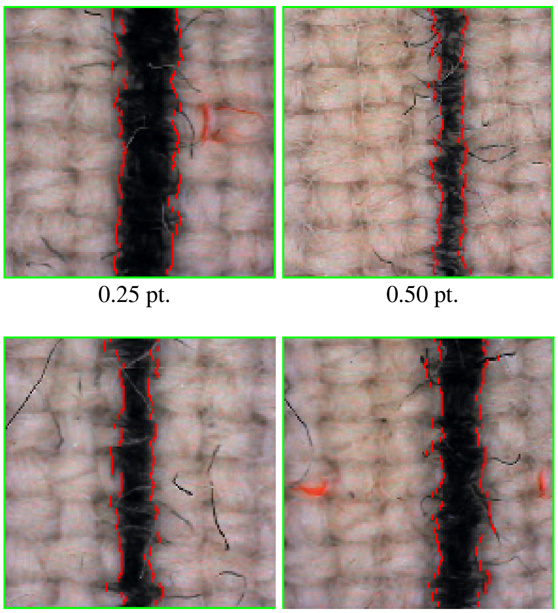

Figure 3. Photo images of digitally printed samples on 100% cotton, plain weave fabric, with solution D, for Line Quality Analysis testing in four point sizes, (0.25 pt, 0.50 pt, 0.75 pt, and 1.00 pt.).[4]

Figure 4 depicts the average line raggedness, expressed in microns, of the four different printed materials: the paper and the three treated fabrics. In three of the four point sizes solution D has the closest values to those of the paper, labeled as A in Figure 4. Solution C had the second closest values to those of the paper. This seems to indicate that the thickener, shared by solutions C and D, has performed its role in helping to keep the dye printed on the fabric from wicking to other areas of the fabric, which would distort the line. The silica, contained only in solution D, has an additive effect in preventing the movement of the dye from where it was applied to the fabric, and thus allows for the creation of straighter, less ragged edges, leading to an improvement in line quality. None of the fabrics exhibit the same straight lines of the paper, but this is to be expected as the surfaces of the two materials are vastly different. The fabric has an irregular surface due to the interlacing of the warp and weft yarns. Additionally, since the yarns consist of staple cotton fibers, they are not completely smooth, but are instead hairy, and this will affect the straightness of the edges. As of this point it is unknown how exactly surface roughness affects the print quality of the fabric, but will be investigated at a later time.

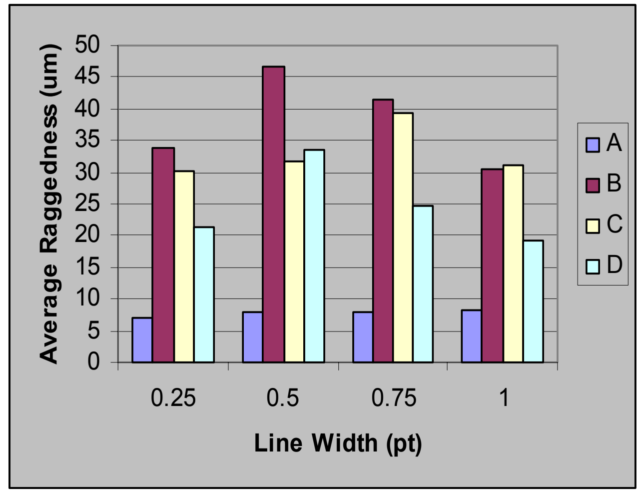

Figure 4. Line Quality Analysis Results: Average Line Raggedness (μm).[4]

Line density or darkness of the materials is depicted in Figure 5. Line density can be a good measure of the bonding between the cellulose and dye molecules, as a lighter line may indicate decreased bonding between the two if other factors, such as clogged print heads can be eliminated. The results of the line density evaluations seem to indicate that the bonding between the dye and the paper is superior to that between the dye and the fabric. However, it may be possible that loose fibers from the fabric contacted the print heads and caused them to become clogged, thus decreasing the line density. Solution D does exhibit improved line density in two of the point sizes, although in the other two sizes the other solutions have better values. The results of the line density are somewhat inconclusive, although the differences between the different solutions are reduced compared to the raggedness values.

Average line width values are depicted in Figure 6. The paper exhibited the closest actual line widths to the theoretical line widths, but this could be merely due to the difference between the paper and fabric surfaces, with the hairs and irregular surface of the fabric causing the lines to distort during the printing process. Although the differences between the different fabric treatments are close, they are much greater than the width values of the paper. This seems to indicate that the dye may have wicked or absorbed into other areas of the fabric when printed on it. This could be due to the dye rolling off the mostly round yarns when initially applied to the fabric and could be a result of the movement of the fabric through the printer before the dye has had a chance to fully be absorbed by the fibers in the yarns. If this is the case, then as digital ink jet printing speeds increase the difference between actual and theoretical line widths may increase also. This needs to be further investigated to determine if yarn shape has an effect upon printed line width. These results are somewhat inconclusive, as solutions B and D each have the closest results to the paper in two point sizes.

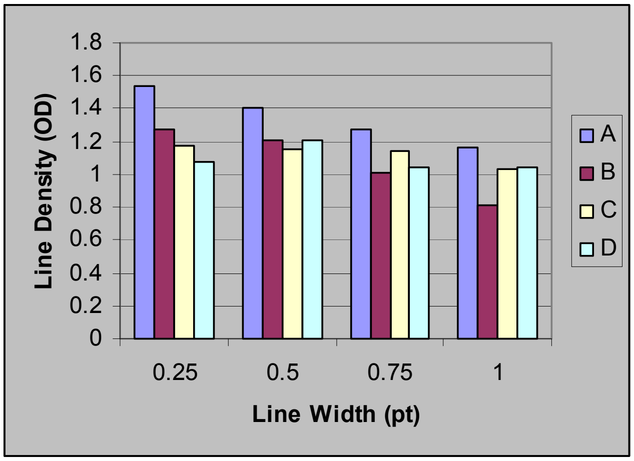

Figure 5. Line Quality Analysis Results: Average Line Density (OD) For a Given Line Width (pt).[4]

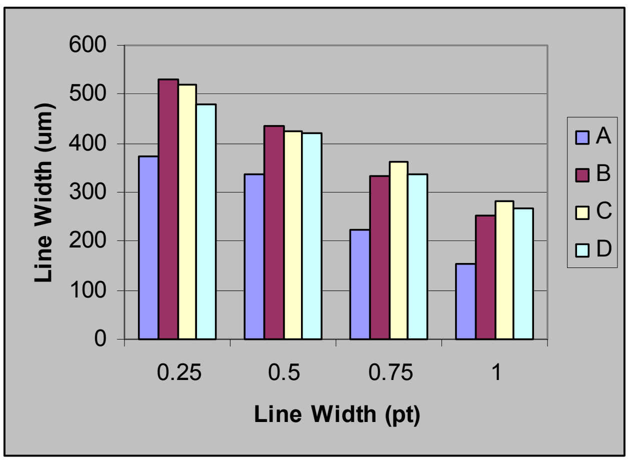

Figure 6. Line Quality Analysis Results: Average Line Width (μm) For a Given Line Width (pt).[4]

Overall, solution D seems to offer the greatest combination of yarn protection and print quality. It provided the lowest decrease in yarn tenacity after abrasion compared to the other treatments evaluated. It also provided the values closest to the paper in terms of line raggedness. In terms of line width and line density half of the time it provided values closer to the paper than the other two treatments. Thus, it can be concluded that of the three solutions evaluated that could function as both a sizing agent and a fabric pre-printing agent, solution D provides the best results. Therefore, solution D was chosen as the link to combine weaving and digital printing.

The final evaluations consisted of setting up a theoretical production combining weaving and printing. Prior to this, cotton fibers were opened, blended, carded, and spun into rotor yarn, padded with solution D, and dried. The yarns were then wound onto bobbins with most of the bobbins placed in a creel behind the loom to act as the warp yarns. The remaining bobbins were used to supply the weft yarns. Thus both the warp and weft yarns were coated prior to weaving. After weaving the fabric was removed from the loom and printed without undergoing any processing between these two stages. After printing the fabric was treated with the usual post-printing steps used to help secure the dye and remove unfixed dye, and then conditioned and evaluated. Thus, although the processes were not linked, the fabric was woven and printed as if the printer immediately followed the loom. If successful, the printed fabric would retain most of its colors after the post-printing process indicating that solution D actually did protect the yarns from abrasion and was not totally removed during the weaving process.

Figures 7, 8, and 9 display the results of the line quality evaluations for fabric created from yarns treated with solution D. The line quality was evaluated after printing, after steaming, and after steaming, rinsing, and soaping in order to understand the effects the different treatments may have upon line quality. The different line quality analyses provide similar results in that the values increase after the steaming stage. This could be due to the cotton fibers swelling due to the steam, which would distort the lines, thereby decreasing the line quality. It could also be due to unfixed dye contained within the fiber being driven to the surface of the fiber as the fiber swells due to the steam. After soaping and rinsing the fiber is no longer swollen and the unfixed dye is removed, and thus the line quality values approach those of the paper. Overall, these three figures seem to indicate that line quality measured immediately after printing seems to correlate fairly well with final line quality, but more exploration of this is required to fully draw any conclusions.

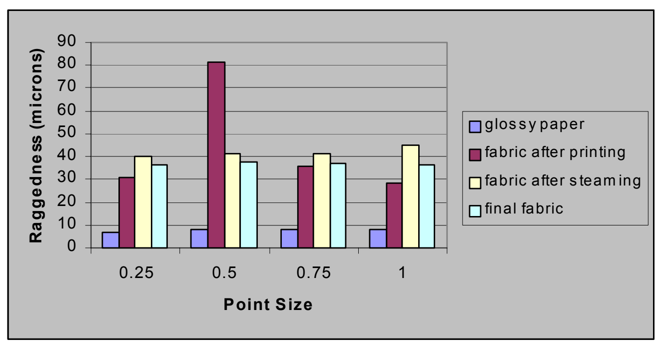

Figure 7. Average Line Raggedness For a Given Line Width.

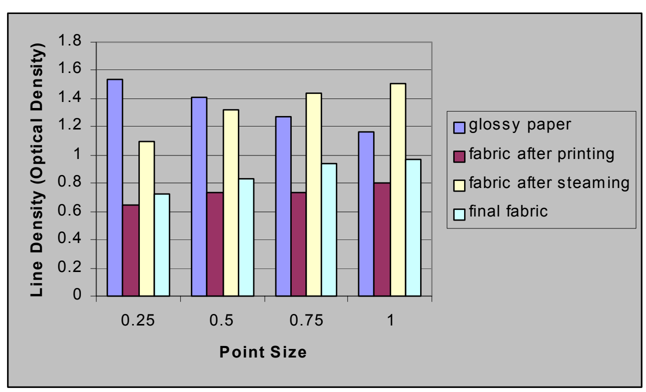

Figure 8. Average Line Density For a Given Line Width.

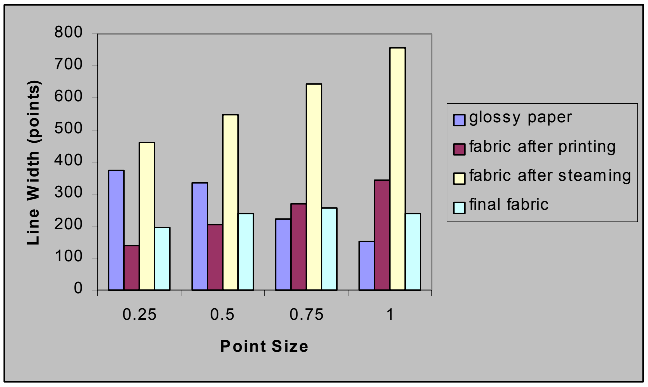

Figure 9. Average Line Width For a Given Line Width.

Table 2: Comparison of Fabric Treated With Solution D, and Yarns Treated With Solution D Woven Into Fabric: Crockfastness

Sample		Colorfastness to Crocking	
		Wet	Dry
Fabric treated with solution D and printed	Turquoise	4	5
	Red	3	5
	Yellow	4	5
	Black	4	5
Fabric containing yarns treated with solution D and printed	Turquoise	5	5
	Red	5	5
	Yellow	5	5
	Black	5	5

Table 2 depicts the crockfastness values of the initial fabric treated with solution D and then printed compared to the fabric woven with treated yarns and then printed. As the table indicates, the fabric woven from treated yarns exhibits excellent colorfastness properties indicating that enough of the solution remained on the yarns after weaving to be effective as a pre-printing treatment.

Conclusion

With rapid development in the textile industry there is evident need for the integration of weaving and printing in order to decrease processing and increase agile manufacturing. For this the sizing agent and print fixative must be the same compound. The mixture of sodium carbonate, urea, thickener and silica has proven to be an effective sizing agent and print fixative. As such, the integration of weaving and printing is one step closer to reality. Although further research will need to be conducted to make this an effective manufacturing process, a major hurdle has been cleared.

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