CHAPTER IV

RESULTS AND DISCUSSION

In this study, an ink formula was investigated and the ink was printed on four types of fabrics, which were cotton, silk, polyester, and cotton/polyester blend. In the first series of experiment, these fabrics were not treated with any reagents, the colorants in the inks adhered on the surface of the fabrics without the effect of pretreatment.

The soluble binders used, which are GABUSEN and TORESIN from Teikoku Chemical Co., could not pass through the printer nozzles. Consequently, the results of soluble binder types were not present. The reason of this is probably caused by the fluidity under rapid impulse by piezo actuator. The soluble binders decline to give pigment dispersions a nonlinear viscoelasticity. The effective binders were emulsion types, which were NK A12, NK M302, Vanatex S711, and UA 150. The NK A12, M302, and S711 are acrylate resins, while the UA150 is a polyurethane type. The mean diameter of the particles of the emulsions was approximately 0.2-0.3 micrometer. After printing, the crockfastness and stiffness of printed fabrics were measured. Then the effects of these binders in the pigmented inks were investigated.

4.1 Viscosity and Surface Tension of Inkjet Inks

The ink formulation in this study was kept constant at a ratio of pigment to binder of 1:1 by weight based on total weight of the ink. Table 4.1 shows the viscosity and surface tension of the cyan, magenta, yellow, and black inks. The viscosity of the inkjet inks was nearly the viscosity of water, which is 1.0 mPa s.

Table 4.1 Ink viscosities of cyan, magenta, yellow, and black inkjet inks

	Viscosity (mPa s) at 25 °C, spindle # 31, and shear rate at 250 rpm			
Inks	Cyan	Magenta	Yellow	Black
I	1.51	1.58	1.56	1.84
I-A	1.79	2.13	1.88	2.39
I-S	2.04	1.86	1.96	2.30
I-M	2.54	2.01	2.12	2.59
I-U	1.78	2.22	1.92	2.29

I stands for the ink without binder, I-A for the ink with A12 binder, I-S for the ink with S711 binder, I-M for the ink with M302, and I-U for the ink with UA150 binder

From Table 4.1, we found that an addition of the binder at 1:1 ratio increased the ink viscosity to approximately 2 or 3 mPa s when comparing the ink without a binder. The viscosity increment depends on the viscosity of pigment base used. The viscosities of the pigment bases from Fuji Pigment Co. of cyan, magenta, yellow, and black were found 3.4, 3.3, 2.8, and 7.5, respectively. Therefore, the black ink was the most viscous, whereas the yellow ink was the most fluid ink (see Table 4.1).

Figure 4.1 shows the reduction of viscosities of the inkjet ink when increasing shear rate, therefore the pigmented inkjet ink behaved as the non-newtonian fluid.

However, the ink was close to the newtonian fluid because their viscosity changed a little. The inkjet ink should be the newtonian fluid, which maintains a constant viscosity regardless of shear rate. In other words, the best inkjet ink system does not become more or less fluid as it is drawn from the reservoir, shot through the nozzle, or contacts the substrate. [5]

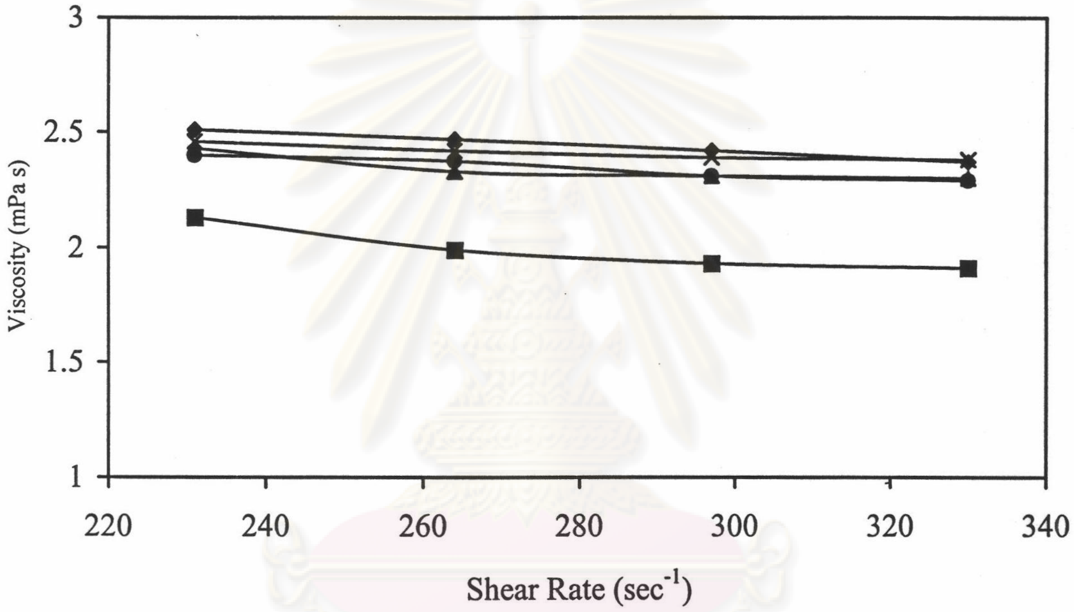


Figure 4.1 Dependence of viscosity of inkjet ink on shear rate (—◆— ,—●— , —×—, —▲—, and —■— are for I-U ink (UA150), I-M ink (M302), I-A ink (A12), I-S ink (S711), and I ink (no binder), respectively)

Considering surface tension of the inks in Table 4.2, the surface tensions of cyan, magenta, yellow, and black inks for each binder were similar. This means that the inks wet the printing substrate similarly. Water provides the highest surface tension on the order of 72 mN m^{-1}. When the water is used in an actual ink formulation, this value is reduced to 40-60 mN m^{-1} by the other ink components, including colorants, polymers, and additives.[5]

Table 4.2 Surface tensions of cyan, magenta, yellow, and black inkjet inks

Inks	Surface Tension (mN m^{-1})			
	Cyan	Magenta	Yellow	Black
I	57	59	57	58
I-A	59	59	57	58
I-S	57	59	58	58
I-M	58	59	59	58
I-U	59	59	57	58

I stands for the ink without binder, I-A for the ink with A12 binder, I-S for the ink with S711 binder, I-M for the ink with M302, and I-U for the ink with UA150 binder

4.2 Effect of Mechanical Stability and Water Uptake on Ejections of Inks

Table 4.3 shows the physical characteristics of the emulsions used in this study for the preparation of the inks. One can see that S711 is the most viscous binder, while UA150 is the most fluid among four binders used. In addition, UA150 volatiles less and is an alkaline soluble binder dispersed in anionic surfactant. The rest of the binders are acidic binder.

Table 4.3 Characteristics of four binders in an emulsion form

Property	Binder			
	S711	A12	M302	UA150
% Nonvolatile (%)	48.5	45	47	29.7
Viscosity (mPa s)	1000-1500	100-500	300	79
pH of dispersion	5	6.5	5.5	9.3
Dispersion type	nonionic	nonionic	nonionic	anionic

4.2.1 Ejections of the Pigmented Inks Containing the Emulsion Form of Binders

The prepared pigmented inks with the emulsion binder were loaded in Epson inkjet printer and then printed. The initial stage of the printing was the nozzle checking in order to check right-ejection of each individual C, M, Y, and K nozzle. The smooth and continuous lines indicate the best ink ejection. Figure 4.2 shows the nozzle checking of I-A ink (A12), I-M ink (M302) , I-S (S711), and I-U ink (UA150).

The ejections of C, M, Y, and K inks with S711 binder named I-S ink were very good because there were no discontinuous streaks. The I-S inks were capable of producing four color printing on the fabrics by a smooth production of four-color prints. The four-color inks did not obstruct the flow of the inks through the print nozzle. The fair ejections were the printing of I-A inks as shown in Figure 4.2 (b). Figure 4.2 (c) is the nozzle checking of I-M inks, in which poor ejections of the C, M, and Y inks and a fair ejection of the black ink were observed. However, the color evenness of the printed fabrics was fairly good although the printed magenta color was not so good. The worst ejections were those of I-U inks as shown in Figure 4.2 (d), the binder of which hampered significantly all C, M, Y, and K nozzles.

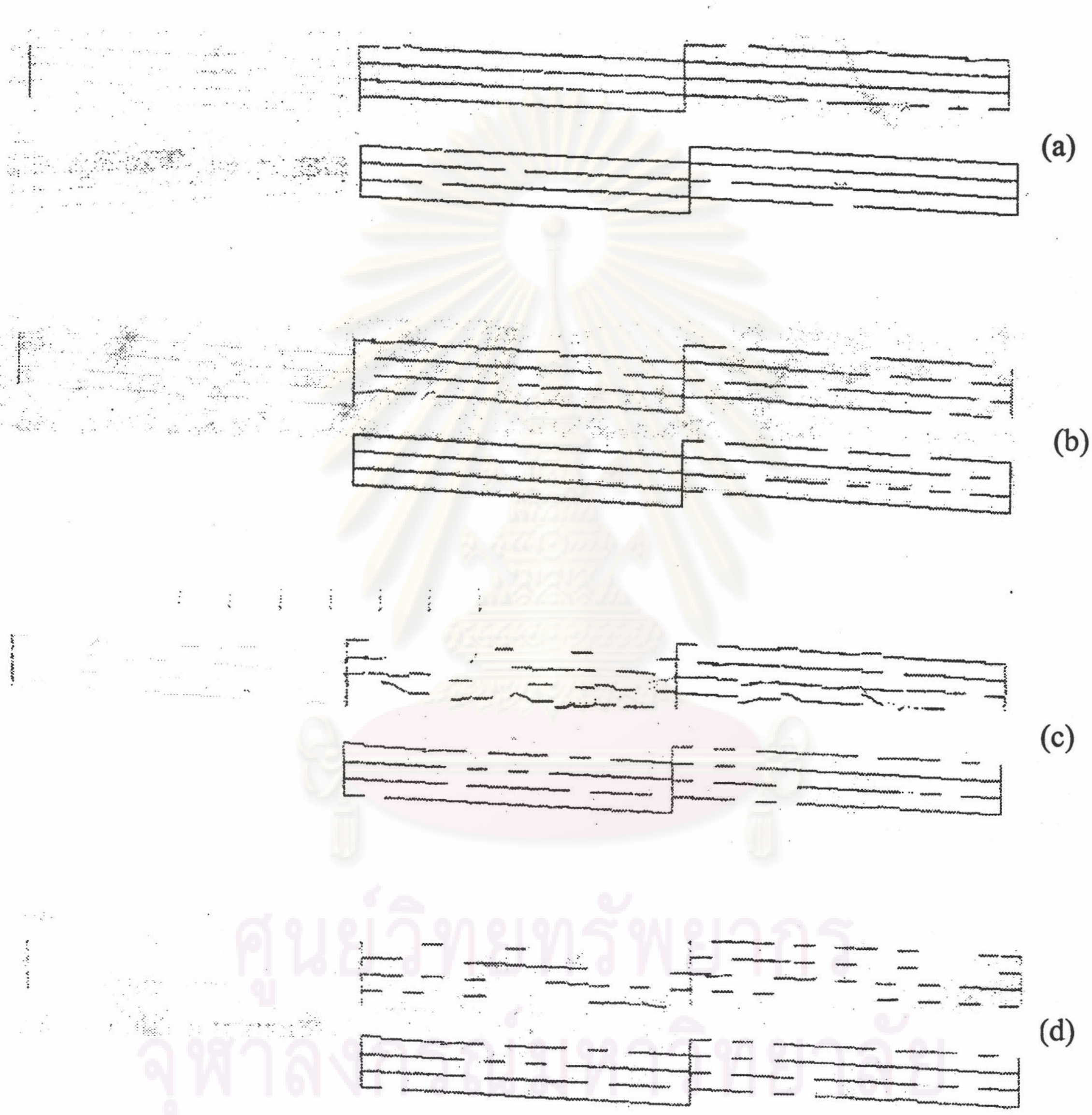
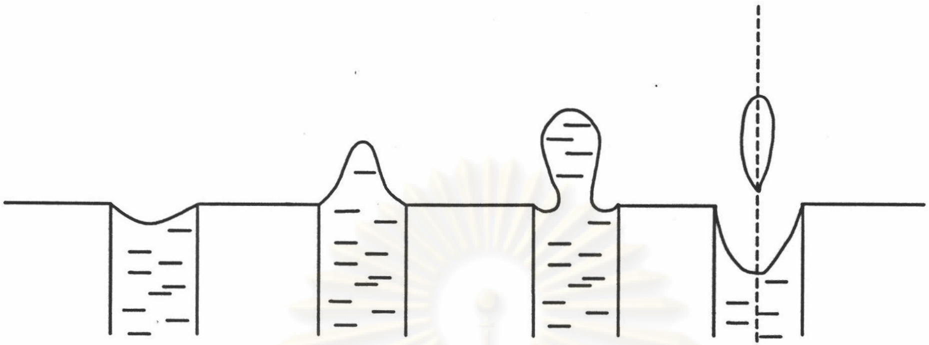
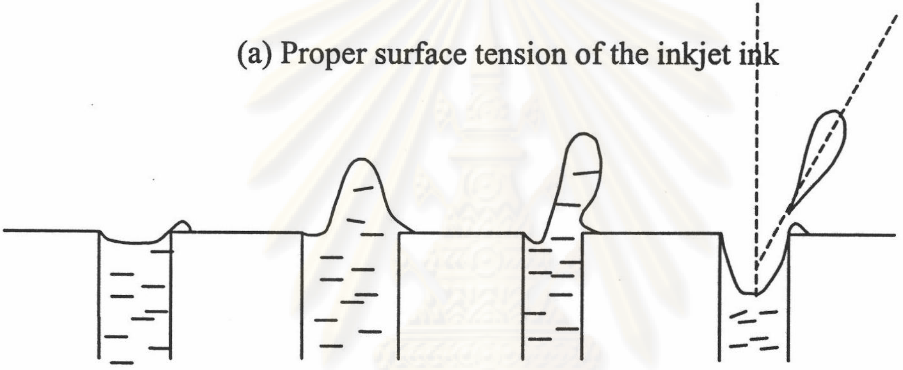



Figure 4.2 Nozzle checking of ejections on printing (a) I-S inks (S711) (b) I-A inks (A12) (c) I-M inks (M302), and (d) I-U inks (UA150)

Figure 4.2 (c) shows the misdirection lines due to the misdirection of ejection of ink droplets. The misdirection might be caused by the improper surface tension of the ink as shown in Figure 4.3.[17]



(a) Proper surface tension of the inkjet ink



(b) Too low surface tension of the inkjet ink

Figure 4.3 Surface tension and direction of droplet ejection (▤ is for the ink) [17]

4.2.2 Mechanical Stability and Water Uptake of Binders

The mechanical stability and water uptake of the emulsion forms of the binders were measured to investigate the relation of ejection characteristics on inherent properties of emulsions and print qualities. Mechanical stability of the emulsions were shown in Table 4.4.

Table 4.4 Mechanical stability of the emulsion forms of the binders

Emulsion	Appearance of emulsion after stirring	Solid residue (%)
S711	pale white liquid	0.02
A12	pale white liquid	0.12
M302	pale white liquid	0.10
UA150	many coagulation particles	1.28

Based on the solid residue, Table 4.4 shows that UA150, anionic emulsion, has the weakest mechanical stability, whereas S711, nonionic emulsions, has the strongest stability among these emulsions. The non-ionic emulsions of A12 and M302 have the intermediate stability. Ink ejection mechanism by piezoelectricity generated the ink droplets by vibrations of piezoelectric transducers [20]. The weak mechanical stability of UA150 dispersion might be the cause of pigment or binder flocculation during printing process. That is, the interaction between the binder and pigment was poor caused by the inherent properties of the binders, reflecting in the viscosity value of the binder itself. In other words, the binder cannot accommodate the pigment particles to obtain a good (binder) vehicle-pigment dispersion.

Table 4.5 shows the water uptake of the dried films of four binders. Hydrophilic property of polymers is important to moisture content of the dried film. The film of S711 was found to have a water uptake 84%, whereas the UA150 film gave a low water uptake of 17%. In other words, hydrophobic and hydrophobic properties of polymers influence their water uptake. The more hydrophilic polymers, in general, can take high amount of water than the hydrophobic polymers. Likewise, the monomer composition also influences the water uptake.[21] The S711 contains rather higher amount of the hydroxyl group as shown in Figure A-1 of Appendix A. We possibly state that the S711 has the higher hydrophilicity than those of A12, and M302. We found the urethane functionalities of the NH, C=O, and COO functional groups in Figure A-2 of Appendix A.

Table 4.5 Water uptake by weight of binder films

Binder	Water uptake (%)
S711	84
A12	43
M302	49
UA150	17

As a consequence, S711 acrylate resin having the hydrophilic property is compatible very well with the aqueous inks, which contain water as a major solvent of the inks. In contrast, the lower hydrophilicity of UA150 emulsion causes a phase separation, which easily leads to binder coagulation.

4.3 Physical Properties of Free-Film of the Binders

4.3.1 Yellowing, Hand Stiffness, and Abrasion Resistance of Free-Film of the Binders

Yellowing, hand stiffness, and abrasion resistance of free-film of four binders: S711, A12, M302, and UA150 were observed as shown in Table 4.6. The clear film of

A12 binder had become yellowing after several days. Films of S711 and UA150 binders became stiff hand when touching, whereas films of A12 and M302 binders became soft hand. Abrasion resistance of the S711 film was weaker than the films of other binders. The hand stiffness was found that it is related to both film modulus and glass transition temperature.

Table 4.6 Yellowing, hand stiffness and abrasion resistance of the free-film of binders

Binder	Yellowing	Hand stiffness	Abrasion resistance
S711	none	stiff hand	low
A12	high	soft and elastic	medium
M302	low	soft and elastic	medium
UA150	none	stiff hand	high

4.3.2 Young's Modulus, Glass Transition Temperature, and Hardness of Free-Film of the Binders

Table 4.7 Young's Modulus, glass transition temperature (T_g) and hardness of the free-film of binders

Binder	Young's modulus (MPa)	$^{a}T_g$ (K)	Hardness by pencil test
S711	1.3	341	4B
A12	0.8	283	4B
M302	0.4	280	4B
UA150	4.4	370	B

4B stands for hardness scale of 4B, B for hardness scale of B

[a] obtained by DSC technique

Table 4.7 shows Young's modulus, glass transition temperature, and hardness of the free-film of the binders. The free-film of S711 and UA150, which gave stiff hand, had the higher modulus and higher glass transition temperature than the soft film of A12 and M302 binders. However, S711 film showed the low abrasion resistance and low hardness (4B) whereas UA150 showed the high abrasion resistance and high hardness (B). The film of UA150 binder, which is a polyurethane, had the elastic modulus more than the films of all acrylate polymers: S711, A12, and M302 and the S711 film had the highest modulus among these groups. The high glass transition temperature, T_g, of the UA150 and S711 film might yield the higher modulus than the films of A12 and M302 binders. T_g is affected by polymer structure. The effects of the nature of the chain repeat units on T_g are closely related to intermolecular forces, chain stiffness, and symmetry. Probably, the most important factor among these is hindrance to free rotation along the polymer chain resulting from the presence of stiff bonds or bulky side groups, the branching and crosslinking. The higher concentration of chain ends in a branched polymer increases the free volume and thus lowers the T_g, whereas crosslinking lowers free volume and raises the T_g. As the degree of crosslinking is increased, the material becomes harder and give higher tensile strength values.[22]

4.4 Ink Absorption of Fabrics

4.4.1 Wicking Test and Dynamic Permeability Test

The fabrics: cotton, polyester, cotton/polyester blend, and silk fabrics were tested for the ink absorption by wicking test and dynamic permeability test. The wicking test is a static absorption for 3 sec set by this experiment, whereas the dynamic permeability test is a dynamic absorption when the contact time was 2 msec.

Table 4.8 shows that the polyester fiber could not absorb the water-based inkjet ink, whereas the cotton and silk fibers could absorb more than polyester fiber. The cotton/polyester blend fabric shows the higher absorption than 100%cotton fabric due to the loose structure of the cotton/polyester blend fabric.

Table 4.8 Ink absorption of the fabrics by wicking test[a]

Fabric	Structure of fabric	Length of absorption (cm)
Cotton	dense weave	2.2
Silk	loose weave	2.0
Cotton/polyester blend	loose weave	3.0
Polyester	dense weave	0.7

[a] for UA 150 ink

Table 4.9 Ink absorption of the fabrics by dynamic permeability test[a]

Fabric	Absorption at 2 msec ($cm^3\ cm^{-2}$)
Cotton	0.0065
Silk	0.0050
Cotton/polyester blend	0.0040
Polyester	0.0027

[a] for UA 150 ink

Table 4.9 shows the highest absorption of the cotton fabric, whereas the polyester fabric shows the less absorption. Tables 4.8 and 4.9 indicate that the cotton and silk fabrics absorbed the ink easily, whereas the polyester fabric absorbed the ink poorly.

Table 4.10 Water swelling property of textile fibers [23]

Fiber	Approximate Volume Swelling in Water (%)
Cotton	40
Silk	30-40
Polyester	None

Table 4.10 shows the volume swelling in water of textile fibers. When fiber absorbs water, they change in dimensions as a swelling property. In considering water absorption of the textile fibers, we must take into account of the interaction between the water molecules and the molecules of the fiber substance. All the natural animal and vegetable fibers have polar groups in their molecules that attract water. The cellulose molecule such as molecule of cotton fiber contains three hydroxyl groups for each glucose residue, there are hydrogen bonding between hydroxyl groups of fiber and water. The water attract on protein fiber such as silk fiber depends on hydrogen bonding between their side groups and water.[11] As a consequence, the cotton and silk fibers having the hydrophilic property can absorb the ink, which contain water as its major solvent.

4.5 Ink Penetrations of Printed Fabrics

Ink penetrations of the printed, nontreated fabrics of cotton, silk, polyester, and cotton/polyester blend fabrics were observed in terms of the depth of the ink penetration. We found the deep penetration of the ink into the polyester fabric (about 100%) and there was less ink adheres on polyester fiber, whereas the cotton, silk, and cotton/polyester blend fabrics showed the ink penetration of approximately 40-50%. The reason might be that the hydrophobic fiber of the polyester fabric repelled the high surface tension water-based inkjet ink to adhere to the surface causing the low viscosity inkjet ink flowed through the vacancies of the fabrics. Then the remaining ink was held in the capillary tubes between the polyester fiber (see Figure 4.4 (b)). The fibers of cotton and silk are hydrophilic, therefore the water-based inks were absorbed and the fibers were swollen by the inks. The top surface of these hydrophilic fabrics could localize the ink and absorbed all of the ink, because the drop volume of inkjet printing was very fine (picoliters), thus the depth of ink penetration was minimal (see Figures 4.4 (a), (c), and (d)).

Since the polyester fiber is hydrophobic, it did not absorb water as shown in Tables 4.8, 4.9, and 4.10. The reason of such deep ink penetration of polyester fabric might be the easy flow of low viscosity inkjet ink. The polyester has a high wicking property, which indicates that the moisture move rapidly along the fiber surface and will pass through the fabric quickly.[22] The retention of ink in the printed fabric was affected by the alignment of the spaces between fibers. The polyester fiber was circular fiber, which were close-packed and the vacancies of the close-packed fibers were filled with the ink as shown in Figure 4.5 (a).[11]

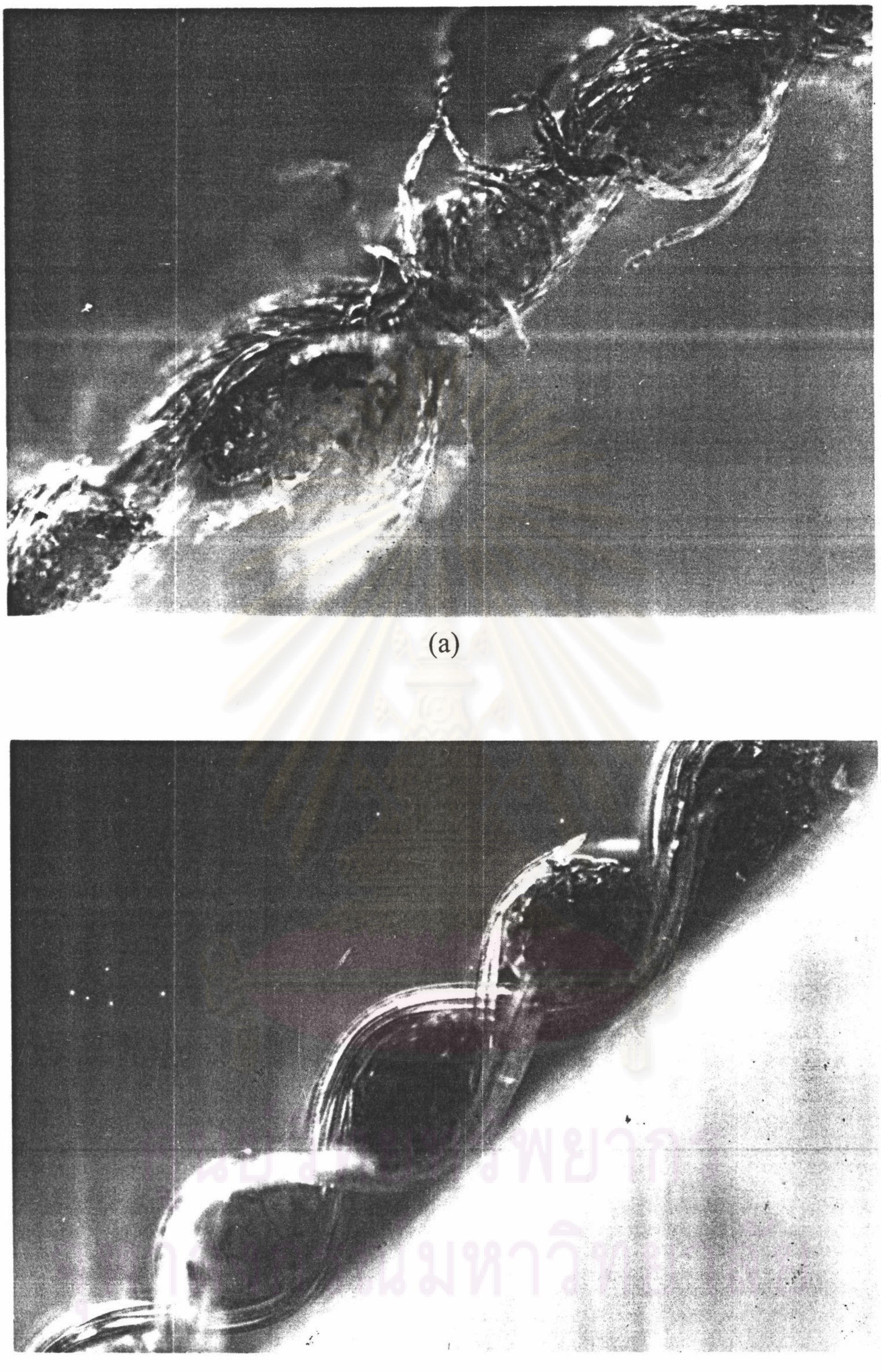
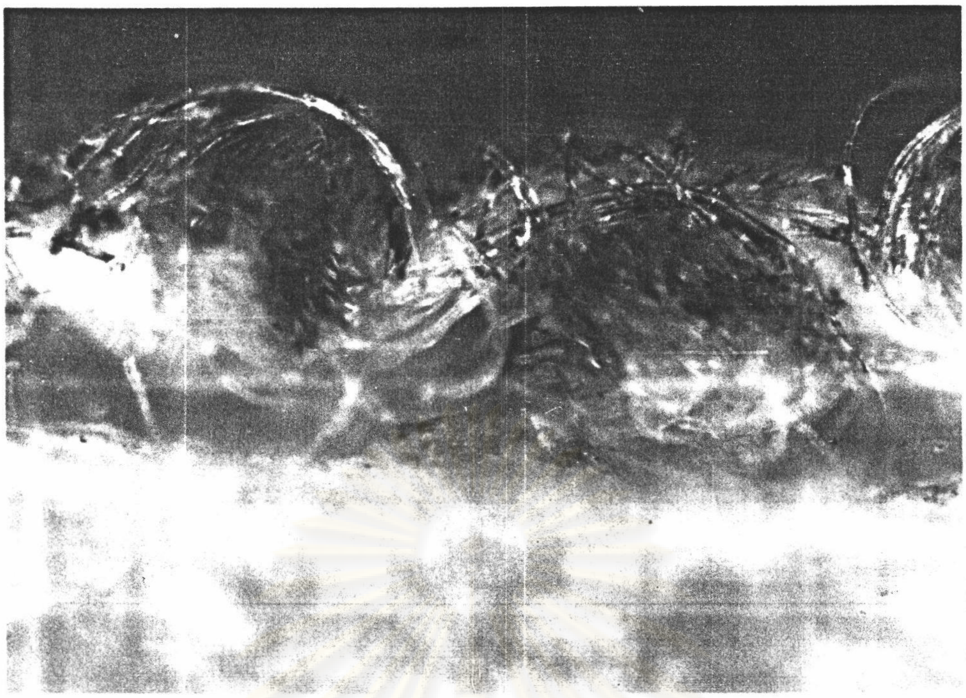
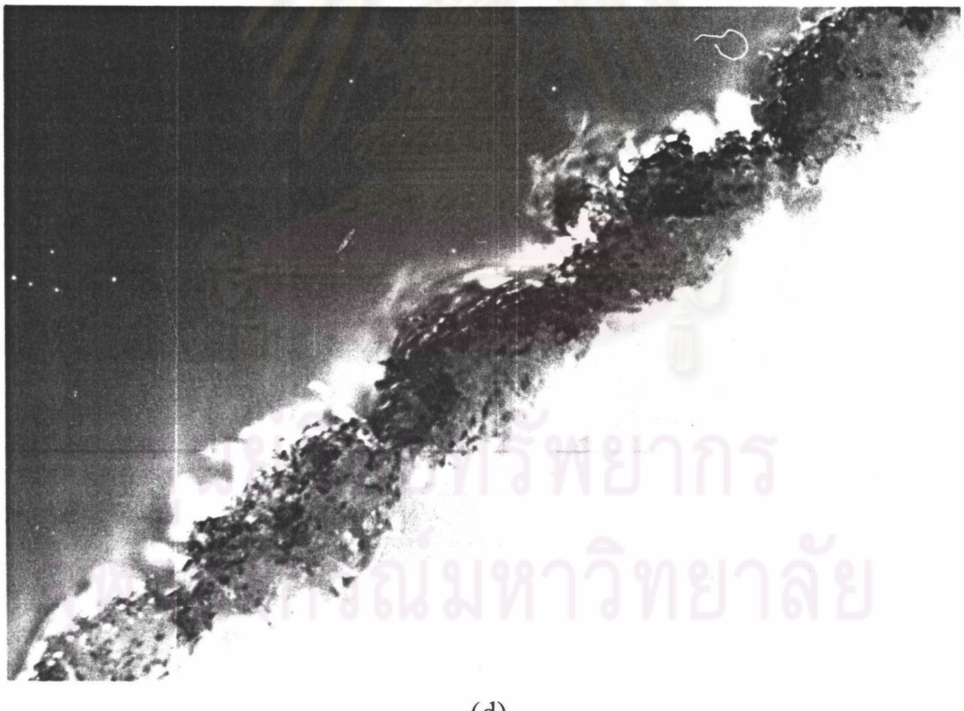


Figure 4.4 Photomicrographs of cross-section of the printed fabrics (x10): (a) cotton fabric, (b) polyester fabrics, (c) cotton/polyester blend fabric, and (d) silk fabric

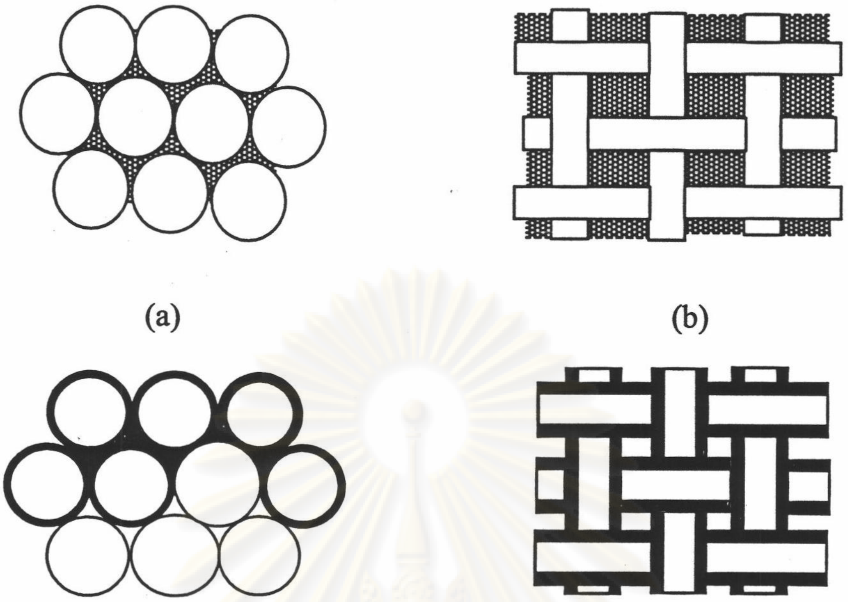


(c)



(d)

Figure 4.4 Photomicrographs of cross-section of the printed fabrics (x10): (a) cotton fabric, (b) polyester fabrics, (c) cotton/polyester blend fabric, and (d) silk fabric



(a) (b)

(c) (d)

Figure 4.5 Models of ink absorption of hydrophobic and hydrophilic fabrics: (a) cross-section model of hydrophobic fiber, (b) longitudinal view of hydrophobic fiber, (c) cross-section model of hydrophilic fiber, and (d) longitudinal view of hydrophilic fiber (☐ is for the fiber of fabric, ▨ , and ■ are for the inks)

Figure 4.5 shows the ink absorption models of the printed fabrics, which were made from the photomicrographs. For the printing on the hydrophobic fiber, the fiber could not absorb the ink causing all vacancies of the fabric were filled with the ink (see Figure 4.5 (a), (b), and Appendix A). On the contrary, the hydrophilic fiber could absorb the aqueous vehicle of the ink. When the ink was dried, there were the solids of pigments and binders were densely deposited around the fiber of the top surface of fabric (see Figure 4.5 (c), and (d)). The ink absorption model in Figure 4.5 affects the stiffness of the printed fabrics, which shall be discussed in Section 4.6.

4.6 Effect of Inkjet Inks on Stiffness of Printed Fabrics

The four nontreated fabric types: cotton, polyester, cotton/polyester blend, and silk fabrics were measured for their stiffness before and after the printing process. The bending length value can indicate the stiffness of fabrics. The bending length of fabric reflects the stiffness of fabric when bent in one plane under the force of gravity. The higher bending length value means the higher stiffness of fabric. Table 4.8 shows the bending length of four non-printed fabrics (the bending length of fabric before printing) and the bending length of printed fabrics (the bending length of fabric after printing). Then, the relative bending length was calculated from Table 4.11 as follows:

$$\text{Relative bending length} = \frac{\text{bending length of printed fabric}}{\text{bending length of non-printed fabric}} \qquad (4.1)$$

Table 4.11 Bending length of non-printed and printed fabrics

Fabric types	Bending length (cm.)			
	Non-printed fabric		Printed fabric	
	MD	CD	MD	CD
Cotton	2.7	2.1	2.9	2.3
Silk	2.1	3.6	2.3	4.5
Polyester	2.1	1.7	3	2.7
Cotton/polyester blend	2.3	2.4	2.8	2.7

MD stand for machine direction, and CD for cross-machine direction

The relative bending length (Eq. 4.1) indicates the increase of bending length of the printed fabric after printing by which the bending length of the printed fabric was compared with the bending length of non-printed fabric.

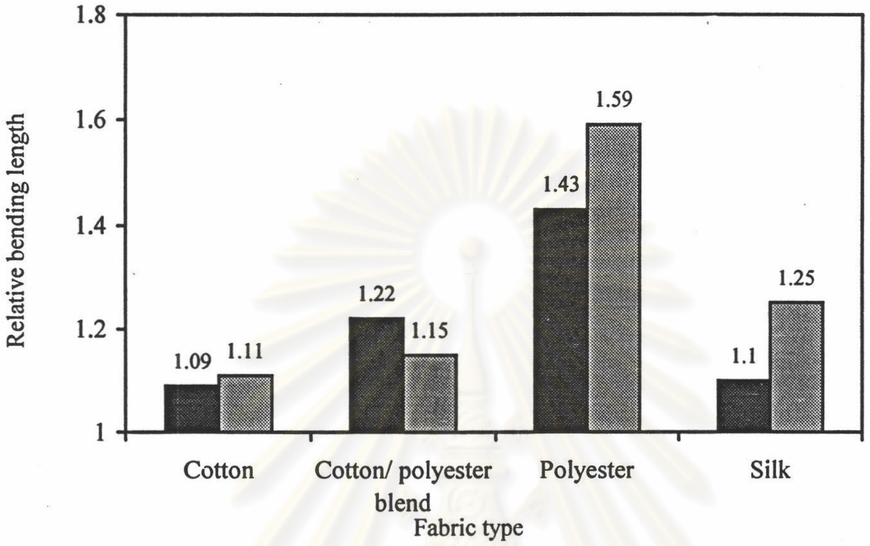


Figure 4.6 Relative bending length of four fabric types (■ and ▨ are for machine direction (MD), and cross-machine direction (CD), respectively)

Figure 4.6 shows that the printed cotton fabric had the lowest relative bending length, and the printed polyester fabric had the highest relative bending length. In other words, the increase of stiffness of printed cotton showed the minimum increase and the increase of stiffness of printed polyester showed the maximum increase.

It is found that the deep penetration of the ink gave the high relative bending length, in other words, more ink penetration tended to give more stiffness of the printed fabric. The 100% ink penetration of the printed polyester fabric and the larger solid of the dry ink inside the fabric after drying might affect the high stiffness of the printed polyester fabric (see Figure 4.5 (a), and (b)). Whereas, the 40-50% ink penetration of more hydrophilic fabrics: cotton, silk, and cotton/polyester blend fabrics showed the lower stiffness because there was no large piece of the dry ink inside the fabrics (see Figure 4.5 (c), and (d)).

4.7 Effect of Different Binders of Ink on Stiffness of Printed Fabric

Four types of binder: A12, M302, S711, and UA150 were applied in the four ink formula: I-A (A12), I-M (M302), I-S (S711), and I-U (UA150). These inks were printed on the four types of the nontreated fabric: cotton, polyester, cotton/polyester blend, and silk fabrics. The bending lengths of printed fabrics tested with these inks were shown in Figure 4.7.

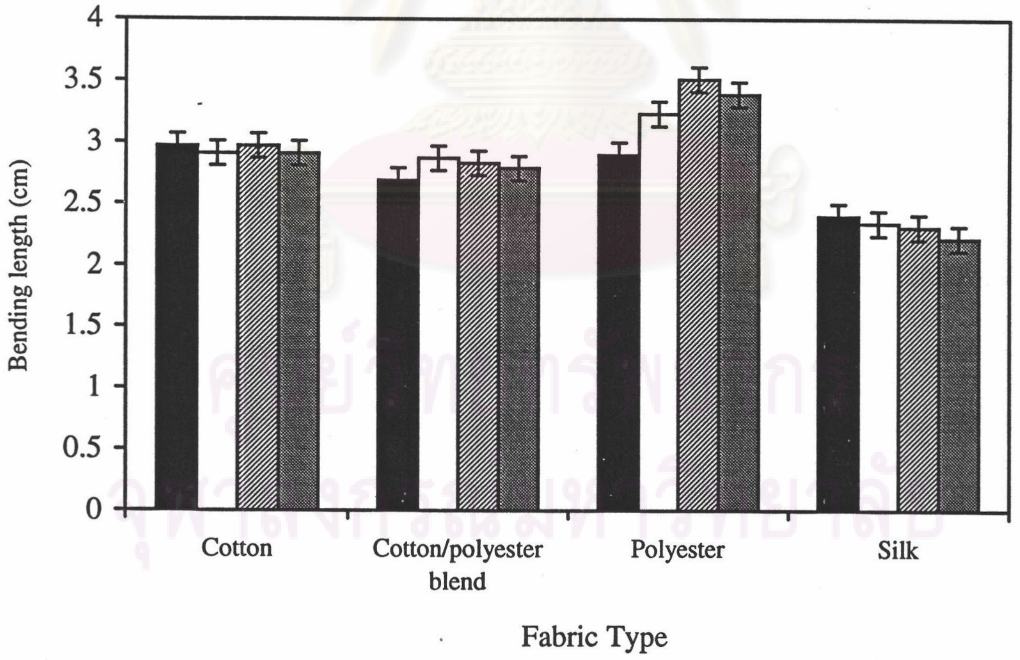


Figure 4.7 Bending lenght of four printed fabrics with four inks (■, □, ▨, and ▩ are for I-M (M302), I-A (A12), I-S (S711), and I-U ink (UA150), respectively).

The stiffness of printed fabrics was measured using the bending length measurement. Figure 4.7 shows that the bending lengths of the printed polyester fabric were different by the four different binders, whereas the printed cotton, cotton/polyester blend, and silk fabrics did not show a significant difference by changing the type of ink binders.

It is found that the bending length of the printed polyester fabric depended mainly on the Young's modulus of the binder. The reason might be that the large solid dry ink inside the polyester fabric controlled the modulus of the binder of the ink. As shown in Table 4.7, Section 4.3, the M302 binder, which showed the lowest elastic modulus, gave the lowest bending length of the printed polyester fabric due to its stiff chains (see Figure 4.7). Whereas, the high elastic modulus binders, which were S711, and UA150, gave the high bending length of the polyester fabric (see Figure 4.7). However, I-U ink did not give the higher bending length than the bending length of I-S ink, because of poor ejection of the I-U ink and excellent ejection of the I-S ink.

For the printed cotton, silk, and cotton/polyester blend fabrics, most of the ink localized on the top of these fabric surfaces and there was not a large solid phase of the dry ink (see Figure 4.5 (c), and (d)). Consequently, the bending length of these fabrics did not show the clear difference between the different binders. Since the limited amount of binders of ink formula was tested in order to prevent the obstruction of nozzle in this study, the conclusion might be different when more amount of the binder were investigated. In other words, 4% binder of the inkjet ink in this formulation might give the less effect on the stiffness of the printed fabrics.

4.8 Effect of Different Binders on Crockfastness of Nontreated Fabrics

Table 4.12 shows the dry crockfastness of the four inks: I-A ink (A12 binder), I-M ink (M302 binder), I-S ink (S711 binder), and I-U ink (UA150 binder) printed on the four types of nontreated fabrics.

Table 4.12 Dry and wet crockfastness of the different binders for the nontreated fabrics

	Dry crockfastness on fabric type			
Ink	cotton	polyester	cotton/polyester blend	silk
I-U	3-4	4-5	3-4	3-4
I-S	3	4	3	3-4
I-A	3-4	4	3-4	3
I-M	3-4	4-5	3-4	3-4

	Wet crockfastness on fabric type			
Ink	cotton	polyester	cotton/polyester blend	silk
I-U	2-3	4	2	2-3
I-S	3	3	2-3	3
I-A	3	3	2	2-3
I-M	3	3-4	2-3	3

5 stand for excellent, 4 for good, 3 for fair, 2 for poor, 1 for very poor , I-U for the ink contained UA150 binder, I-S for the ink contained S711 binder, I-A for the ink contained A12 binder, and I-M for the ink contained M302 binder

The I-S ink shows the lower dry crockfastness than those of other inks of about 0.5 unit of crockfastness level, because the I-S ink contained the low abrasive resistance of S711 binder (see Table 4.6). When the properties of the binder films were considered as shown in Table 4.6, Section 4.3, the film of S711 binder showed the lowest abrasion resistance, whereas the films of A12, and M302 binder showed the medium abrasion resistance and the film of UA150 binder showed the most abrasion resistance. However, the I-U ink, which contained the polyurethane binder (UA150), did not show the higher crockfastness more than those of the I-A and the I-M inks. It probably means that polyurethane binder adhered poorly on the textile fibers except polyester fiber. The good adhesion of polyurethane binder on the polyester fabric showed the high level of wet crockfastness (see Table 4.12). The I-U ink gave level 4 (good), whereas the other binders gave level 3 (fair) for the polyester fabric.

Table 4.12 shows that I-U ink gave the lowest wet crockfastness on all types of fabric, except the polyester fabric. The wet crockfastness of the polyester was level 4, whereas cotton, silk, and cotton blends fabrics were level 2 (poor) to 2-3 (poor to fair). For the acrylate based inks: I-S, I-A, and I-M inks, they gave better adhesion on the cotton, cotton/polyester blend, and silk fabrics than that of I-U ink as shown in Table 4.12.

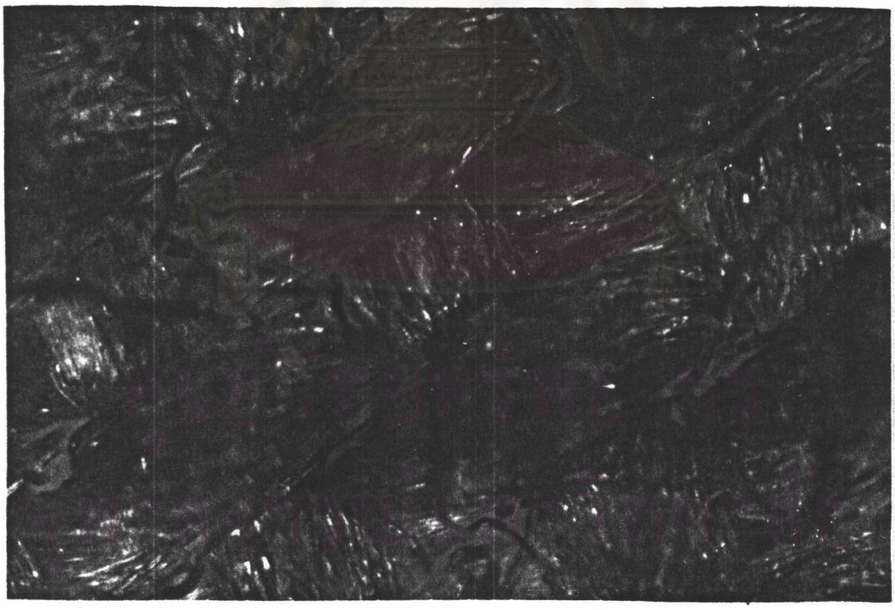
4.8.1 Crockfastness of Fabrics Types

Four nontreated fabrics: cotton, polyester, cotton/polyester blend, and silk were printed with the four inks: I-A (A12 binder), I-M (M302 binder), I-S (S711 binder), and

I-U (UA150 binder). The results of crockfastness show that each type of fabric exhibited nearly at the same level for all binders.

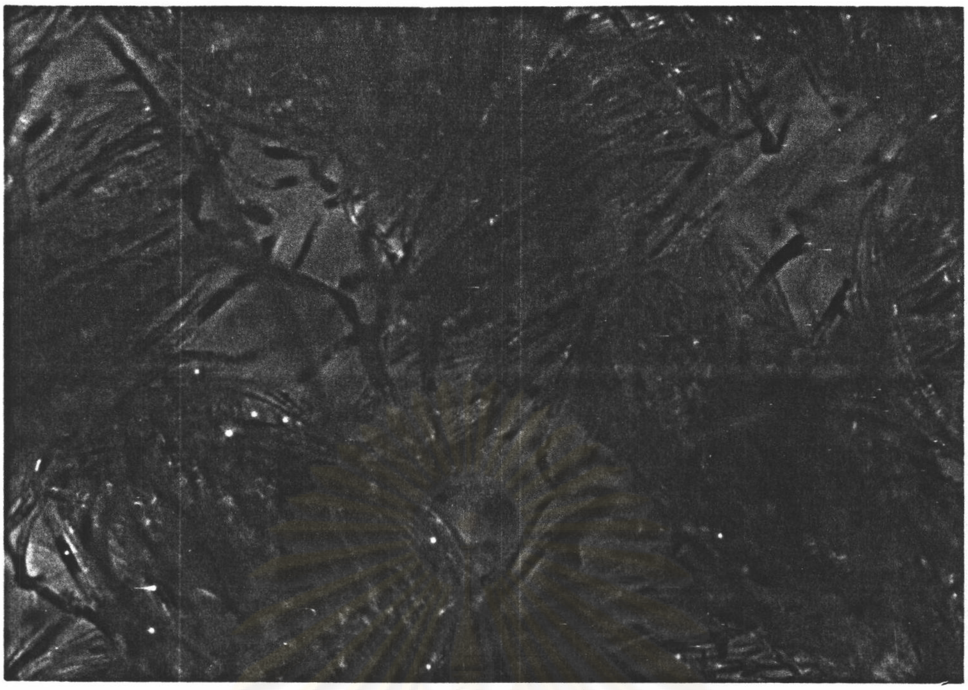
Table 4.12 shows that the crockfastness of the printed polyester fabric was better than other fabrics. The high crockfastness of the printed polyester fabric was caused by the low ink pick-up of the surface of fabric.[13] Figure 4.8 (a) shows that there was the less ink adhered on the surface of the polyester fabric, because almost 100% of the ink penetrated into the fabric as described in Section 4.5. On the contrary, the ink pick-up of the surfaces of cotton, silk, and cotton/polyester blend fabrics was similar and there was more ink adhered on the surfaces than on the surface of the polyester fabric. The high amount of the ink adhered on the surface of the fabric was the attribute of the lower level of crockfastness. Besides the influence of the ink pick-up, the damage of the fiber of fabric after crocking also affects the crockfastness level. Since the polyester fabric is made from its filament yarns, which provide excellent strength, high abrasion resistance and better crockfastness. Therefore, both dry and wet crockfastness of the printed polyester fabric, from the filament yarns, gave the better qualities of the above-mentioned properties.

(a)



(b)

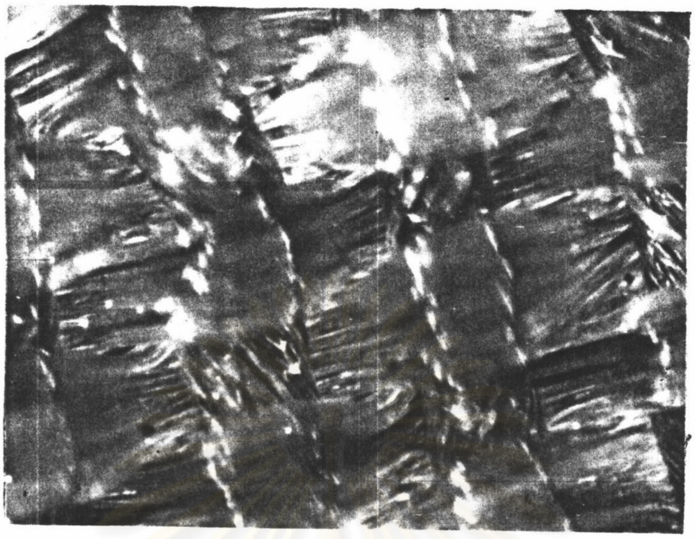
Figure 4.8 Photomicrographs of the printed, nontreated fabrics: (a) polyester fabric, (b) cotton fabric, (c) cotton/polyester blend fabric, and (d) silk fabric (x 10)



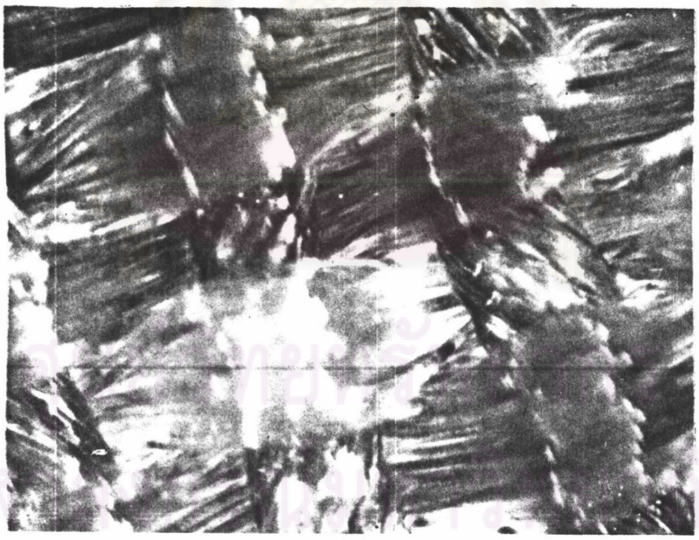
(c)

(d)

Figure 4.8 Photomicrographs of the printed, nontreated fabrics (x 10): (a) polyester fabric, (b) cotton fabric, (c) cotton/polyester blend fabric, and (d) silk fabric



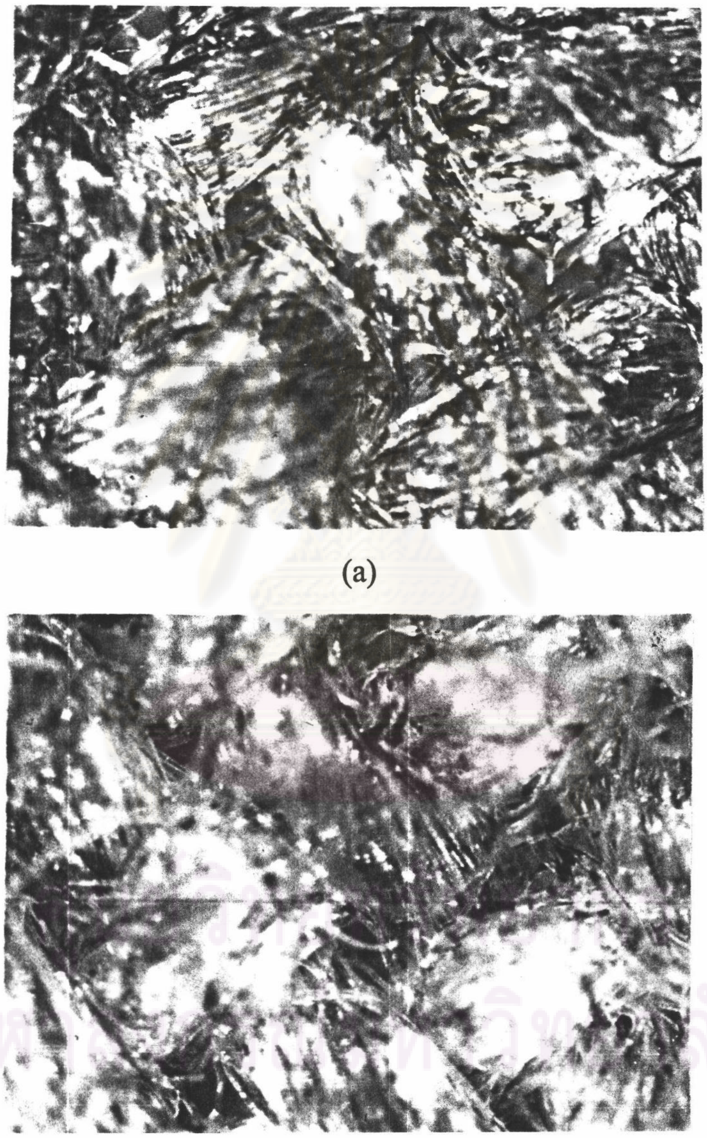
(a)



(b)

Figure 4.9 Photomicrographs of the printed polyester fabrics (x10): (a) after crocking, (b) before crocking

For wet crockfastness, the cotton/polyester blend fabric showed the lowest level. Figure 4.10 shows that the cotton/polyester blend fabric was seriously marred after the wet crocking test. The fiber of spun yarn was damaged and the ink was transferred to the crock cloth. [15]



(a)

(b)

Figure 4.10 Photomicrographs of the printed cotton/polyester blend fabric (x6): (a) before wet crocking, (b) after wet crocking

4.9 Effect of Pigmented Inkjet Printing on the Pretreated Cotton Fabric

4.9.1 Whiteness of the Pretreated Cotton Fabric

Cotton fabrics were pretreated with aluminum oxide dispersed in poly(vinyl alcohol) solution by 100% pick-up ratio of padding. Table 4.13 shows the whiteness of the nontreated cotton fabric (the whiteness of cotton fabric before pretreatment) and whiteness of the pretreated cotton fabrics (the whiteness of cotton fabric after pretreatment).

Table 4.13 Whiteness of the nontreated and pretreated cotton fabric

Fabric	Whiteness
Nontreated	63
Pretreated	72

From Table 4.13, the pretreated fabric showed a higher whiteness value than nontreated fabric, because aluminum oxide is a white pigment, which gives a fair hiding power. Figures 4.12 and 4.13 show SEM photographs of the nontreated and pretreated cotton fabric.

Figures 4.11 and 4.12 also show the surface enlargement of the nontreated and pretreated cotton fabric. The pretreatment reagent was deposited on the surface of fabric and bridged across the fibers. Consequently, this reagent covered and blocked the cavities between fibers and could then retard the absorption of the inks.

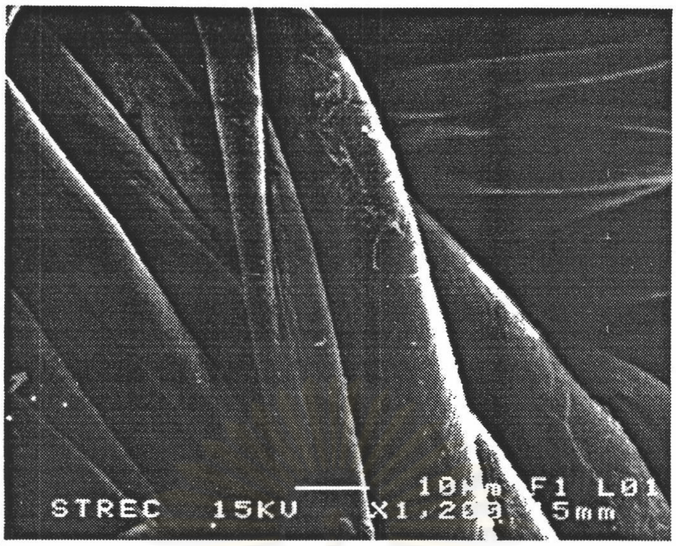


Figure 4.11 SEM of the nontreated cotton fabric (x1200)

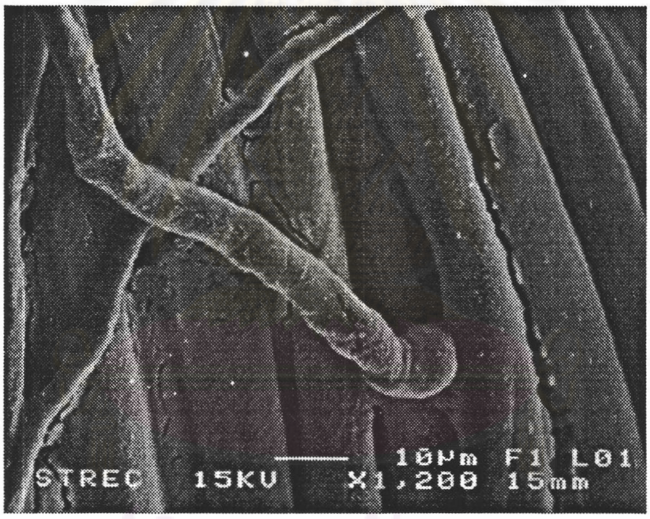


Figure 4.12 SEM of the pretreated cotton fabric (x1200)

4.9.2 Color Saturation and Crockfastness of Pretreated and Nontreated Fabric

The pretreated and the nontreated cotton fabrics were printed with I-A inks. The print colors of cyan, magenta, yellow, red, green, and blue on the pretreated and the nontreated fabrics were measured. Then the saturation of colors, S_{uv}, was evaluated.

Table 4.14 shows the color saturation of the nontreated cotton fabrics and pretreated cotton fabrics.

Table 4.14 The color saturation of nontreated and pretreated cotton fabrics

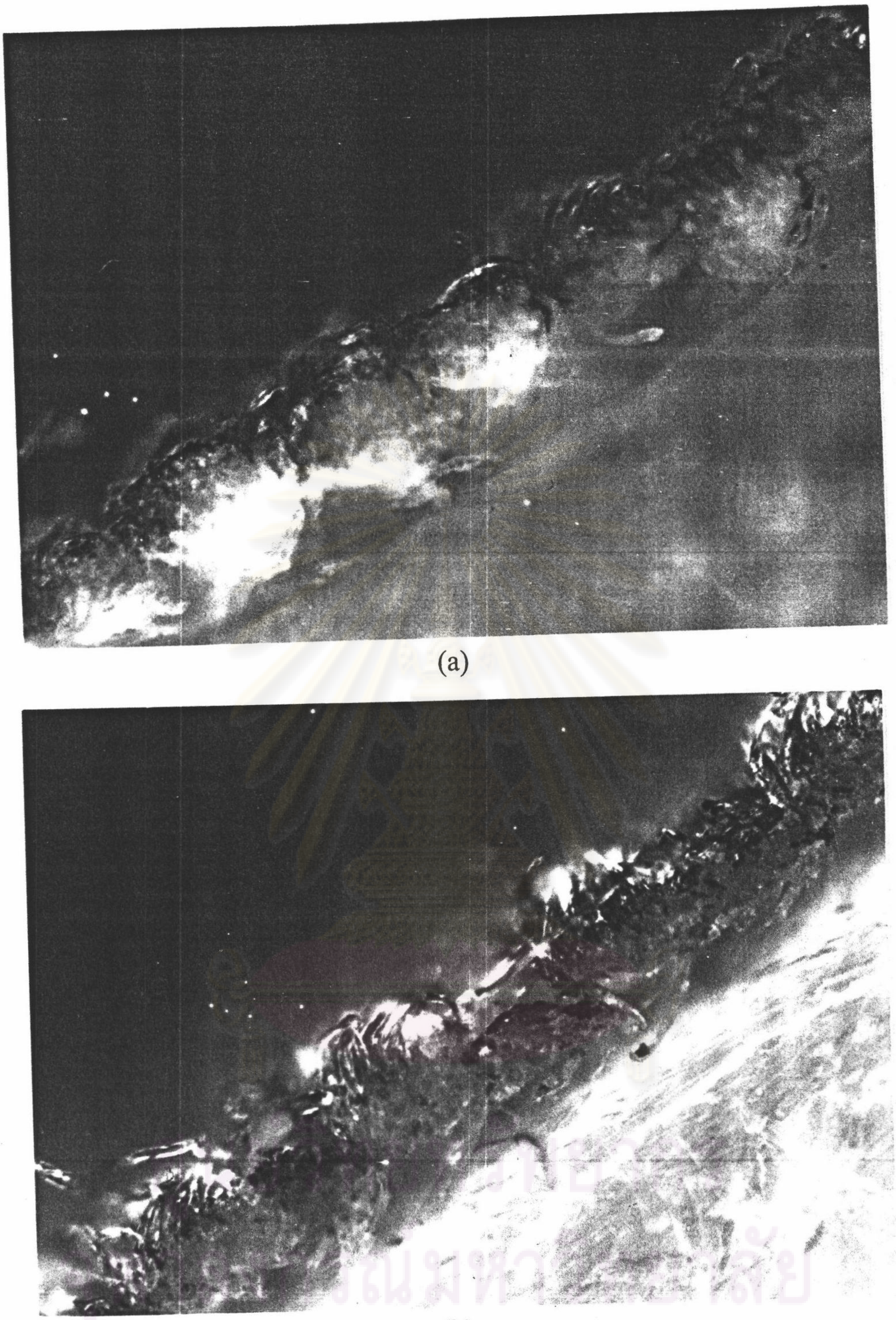
Color	Color saturation, S_{uv}		%increase
	Nontreated	Pretreated	
Cyan	1.34	1.56	13
Magenta	1.38	1.57	12
Yellow	0.91	0.98	7
Red	1.27	1.44	12
Green	0.85	0.92	8
Blue	1.19	1.35	12

Table 4.14 shows that the saturation of printed colors of the pretreated fabrics was higher than the printed colors of nontreated fabrics. The difference of color saturation between nontreated fabrics and pretreated fabrics was found that the cyan color showed the largest increase of saturation and yellow color showed the least increase of saturation.

The pretreatment exhibited a higher color saturation because the pretreatment reagent acted as the ink acceptor on the fabric before excessive spreading of the ink.[24] The SEM photographs in Figure 4.12 show that the pretreatment reagent was deposited on the surface of fabric and bridges across fibers. Figure 4.13 (a) to (b) shows a cross-section of the printed, pretreated cotton fabric and nontreated cotton fabric, respectively.

This pretreatment reagent blocked the vacancies between fibers and could retard the absorption of the inks. Consequently, the pigments were deposited on the layer of pretreatment when the ink gradually penetrated into the fabric and made the ink penetrate less than those of the nontreated fabric (see Figure 4.13). Unlike the pretreated fabric, the inks penetrated into the nontreated fabric because of the wicking property of the fibrous structure, therefore the depth of ink penetration was deeper than the depth of the pretreated fabric as shown in Figure 4.13. That is, the depth of the ink penetration could indicate the amount of the ink localized on the surface of fabric. Since more amount of pigment on the surface of pretreated fabric than that on the surface of the nontreated fabric, consequently, the color saturation of the pretreated fabric was higher than that of the nontreated fabric. Very importantly, the pretreated fabric surface is smoother with eveness and this additional property can add to the high color saturation.

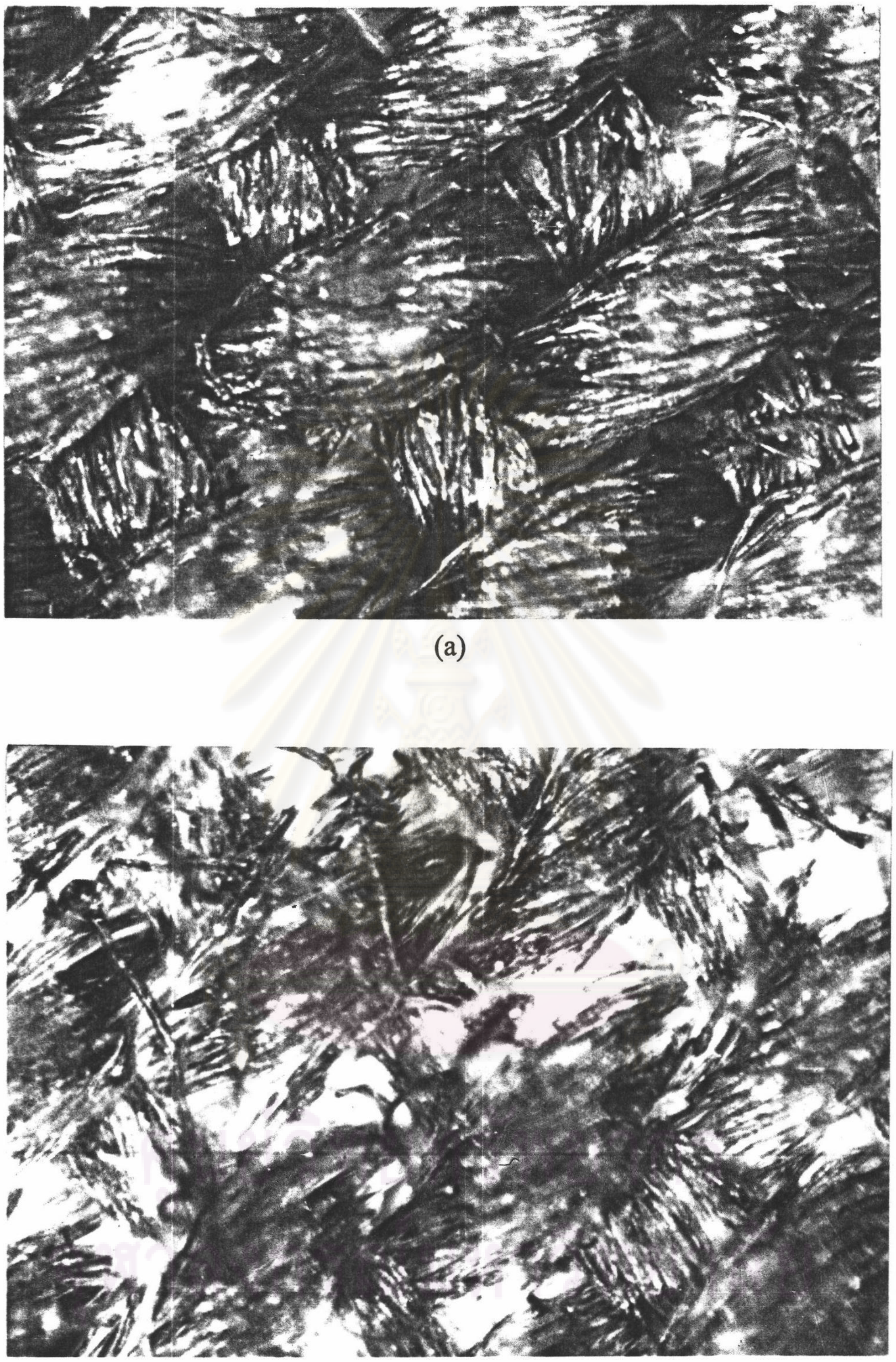
Furthermore, the pretreated fabric also had the higher whiteness value than the nontreated fabric. Therefore, the higher color saturation of pretreated fabric was not only caused by the depth of ink penetration, but also the whiteness of the printed fabric.



(a)

(b)

Figure 4.13 Photomicrographs of the depth of ink penetration of the pretreated, and the nontreated cotton fabric (x 10): (a) cross-section of pretreated cotton fabric, and (b) cross-section of nontreated cotton fabric



(a)

(b)

Figure 4.14 Photomicrographs of the pretreated, and the nontreated cotton fabric (x 10): (a) top view of pretreated cotton fabric, and (b) top view of nontreated cotton fabric

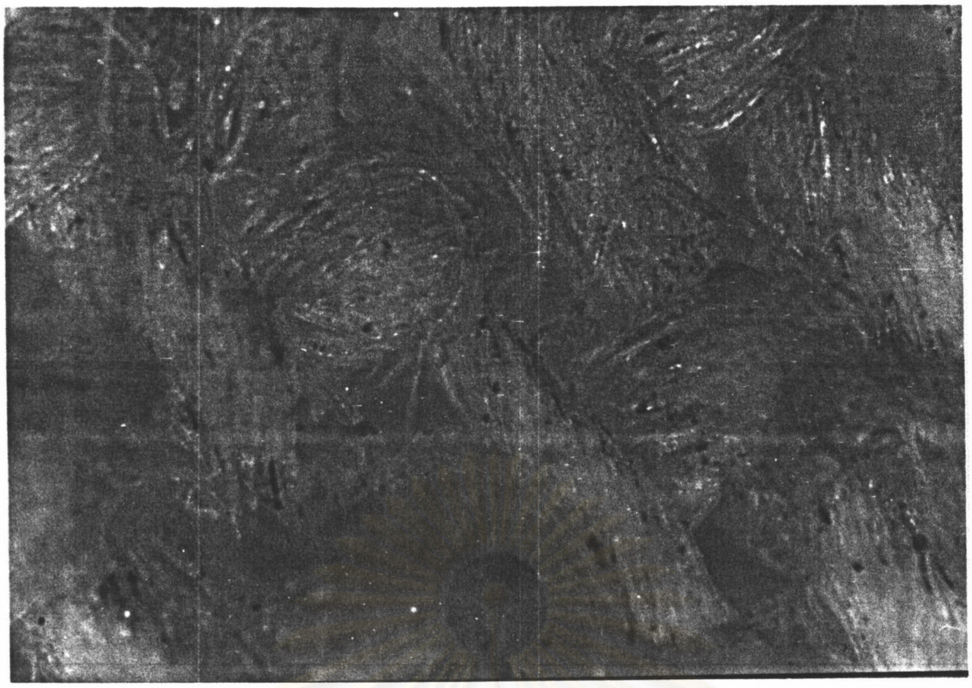
Table 4.15 shows dry and wet crockfastness of the nontreated and the pretreated cotton fabrics printed with I-A inks.

Table 4.15 Crockfastness of the nontreated and pretreated cotton fabrics

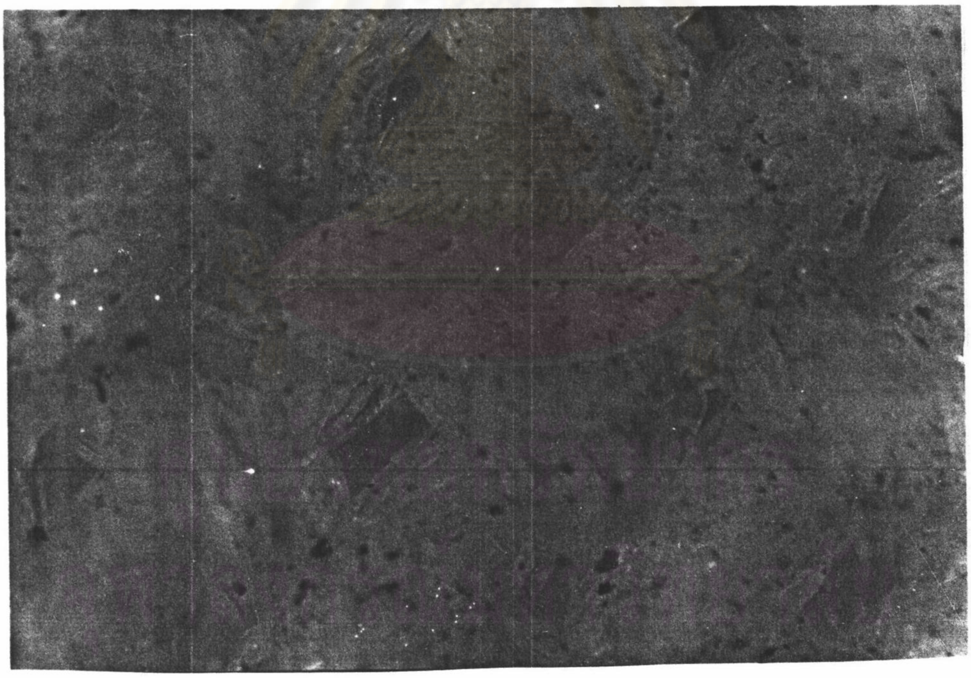
	Dry/wet crockfastness			
Fabric	Magenta	Cyan	Yellow	Black
Non-treatment	3-4/3	3/3	4-5/3-4	3-4/1-2
Pretreatment	3/2-3	3-4/2	4/3	2-3/1-2

5 stand for excellent, 4 for good, 3 for fair, 2 for poor, 1 for very poor

Both the dry and wet crockfastness of pretreated fabrics were not better than nontreated fabrics. The cause of lower fastness was claimed as that the inks deposit over the pretreatment layer, wherein the binder of the pretreatment reagent, poly(vinyl alcohol), had poor waterfastness. Figure 4.15 shows that the printed, pretreated fabric gave more color staining on the crock cloth than that of the nontreated fabric.



(a)



(b)

Figure 4.15 Photomicrographs of the crock cloth (x9): (a) crock cloth of the pretreated cotton fabric, and (b) crock cloth of the nontreated cotton fabric