CHAPTER IV

RESULTS AND DISCUSSIONS

Untreated and treated cellulose fabrics indicated in Chapter III were analyzed for the stages of cellulose polymorphs, the degree of polymerization, the fabric strength, and the dye absorption. Results are shown as follows.

4.1 Stages of Cellulose Polymorphs

All native cellulose samples and samples prepared from various treatments were investigated for the stages of cellulose polymorphs using an X-ray diffraction technique.

4.1.1 Cellulose I

Cellulose I samples were prepared from methods mentioned in section 3.3.1 and they were characterized for the stages of cellulose polymorphs using an X-ray diffraction technique. X-ray diffractograms of these samples are displayed in Figures 4.1-4.4. From all figures, diffractograms (a) represent the diffraction patterns of the original native cellulose samples (cotton knitted and woven fabrics), diffractograms (b) represent the diffraction patterns of cellulose samples prepared from treating the original native cellulose with liquid ammonia and removing the ammonia with water, and diffractograms (c) represent the diffraction patterns of cellulose samples prepared from mercerizing the original native cellulose samples with caustic soda, then treating the samples with liquid ammonia and removing the ammonia with water.

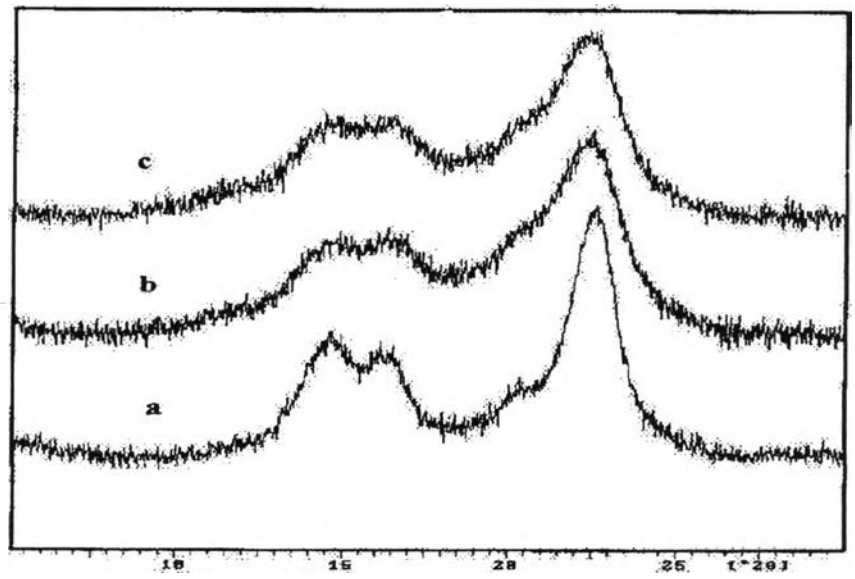

Figure 4.1 X-ray diffractograms of cellulose I samples (cotton knitted fabric, single jersey , yarn count 20/1)

(a) : original native cellulose sample.

(b) : sample (a) was treated with liquid ammonia, then removed the ammonia with water.

(c) : sample (a) was mercerized with caustic soda, then treated with liquid ammonia and removed the ammonia with water.

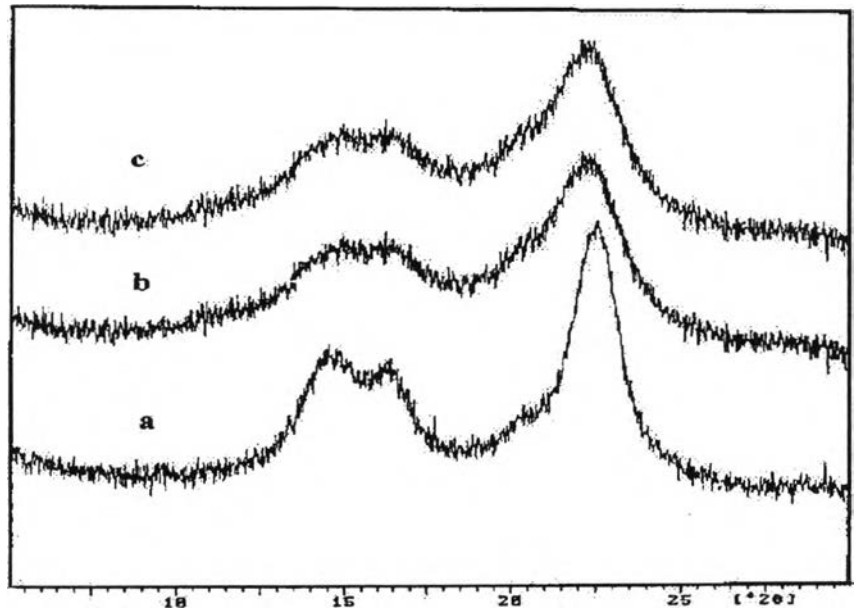

Figure 4.2 X-ray diffractograms of cellulose I samples (cotton knitted fabric, single jersey, yarn count 50/1)

(a) : original native cellulose sample.

(b) : sample (a) was treated with liquid ammonia, then removed the ammonia with water.

(c) : sample (a) was mercerized with caustic soda, then treated with liquid ammonia and removed the ammonia with water.

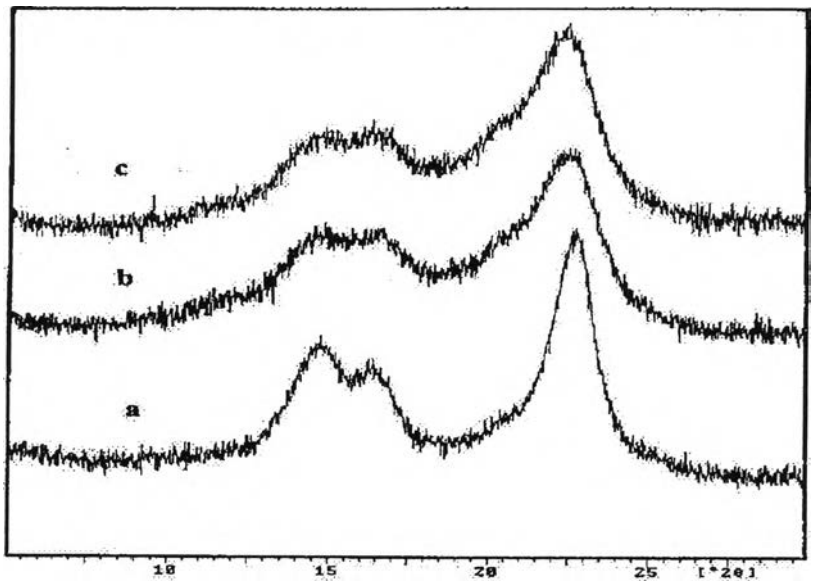

Figure 4.3 X-ray diffractograms of cellulose I samples (cotton woven fabric, plain structure)

(a) : original native cellulose sample.

(b) : sample (a) was treated with liquid ammonia, then removed the ammonia with water.

(c) : sample (a) was mercerized with caustic soda, then treated with liquid ammonia and removed the ammonia with water.

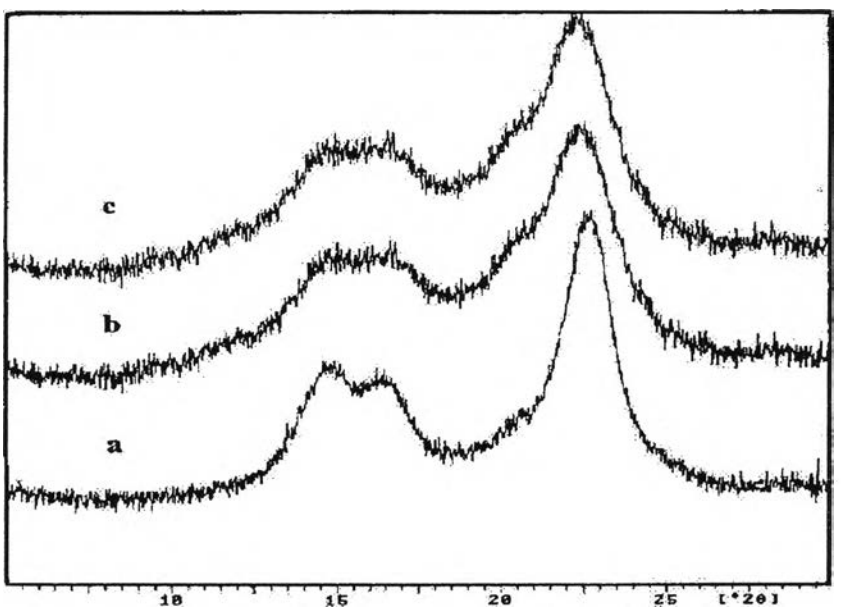

Figure 4.4 X-ray diffractograms of cellulose I samples (cotton woven fabric, satin structure)

(a) : original native cellulose sample.

(b) : sample (a) was treated with liquid ammonia, then removed the ammonia with water.

(c) : sample (a) was mercerized with caustic soda, then treated with liquid ammonia and removed the ammonia with water.

The X-ray diffractograms (a) in Figures 4.1-4.4 of all the original native cellulose samples show similar pattern of cellulose I with peak positions located at diffraction angles 2θ equal to 14.8, 16.3 and 22.6.[13,8] After an ammonia treatment on these native cellulose samples followed by an ammonia removal with water, the samples still remain at cellulose I polymorph as indicated in diffractograms (b) of previous 4 figures. When these native cellulose samples were mercerized with caustic soda and then treated with liquid ammonia followed by an ammonia removal with water, the samples also show diffraction patterns of cellulose I polymorph as shown in diffractograms (c). Diffractograms (b) and (c) show diffraction patterns of cellulose I similar to diffractograms (a) but only contain broader peaks than the diffractograms (a). The treatments on samples of diffractograms (b) and (c) must have decreased the crystallinity of cellulose. Results from section 4.1.3 indicated that an ammonia treatment on the native cellulose samples or mercerized cellulose samples followed by an ammonia evaporation causes the transformation of cellulose I to cellulose III (see diffractograms (a) and (b) of Figures 4.9-4.12). While treating native cellulose samples or mercerized cellulose samples with liquid ammonia followed by an ammonia removal with water does not transform cellulose I to cellulose III or to other polymorphs (see diffractograms (a) and (b) of Figures 4.1-4.4). This has shown that the transition to cellulose III occurs only when the ammonia is removed from the ammonia-cellulose system by an ammonia evaporation, otherwise removing the ammonia by water produces cellulose I. This result also agrees with the work done by Lewin and Roldan.[25] and Mannan.[43]

4.1.2 Cellulose II

Cellulose II samples were prepared from methods mentioned in section 3.3.2 and they were characterized for the stages of cellulose polymorphs using an X-ray diffraction technique. X-ray diffractograms of these samples are displayed in Figures 4.5-4.8. From all figures, diffractograms (a) represent the diffraction patterns of the cellulose II samples prepared from mercerizing the original native cellulose samples with caustic soda, and diffractograms (b) represent the diffraction patterns of cellulose II prepared from mercerizing the original native cellulose samples with caustic soda, then treating the samples with liquid ammonia followed by an ammonia evaporation, and finally mercerizing with caustic soda again.

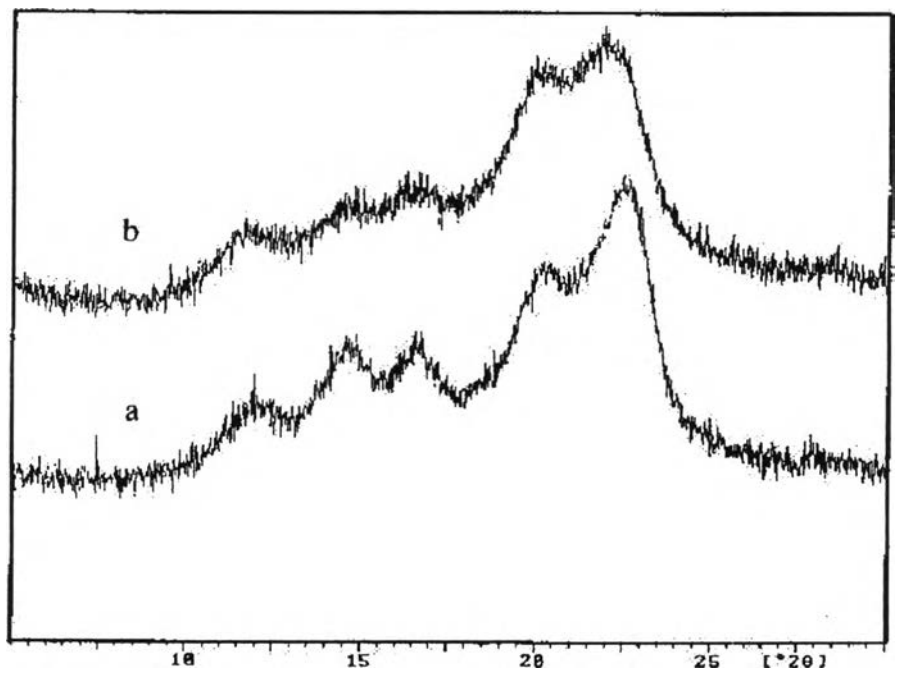

Figure 4.5 X-ray diffractograms of cellulose II samples(cotton knitted fabric, single jersey, yarn count 20/1)

(a) : original native cellulose sample was mercerized with caustic soda.

(b) : sample (a) was treated with liquid ammonia followed by an ammonia evaporation, and then mercerized with caustic soda.

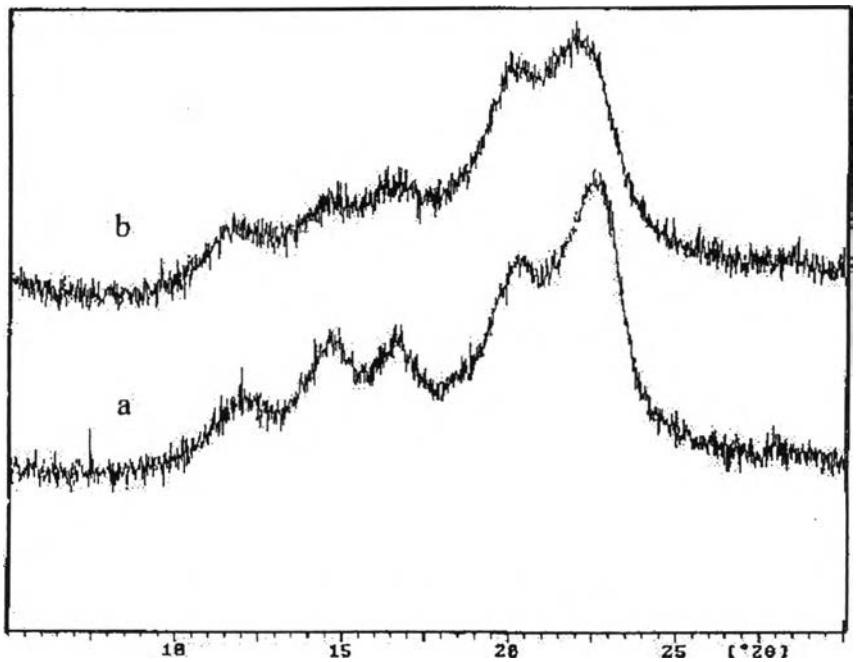

Figure 4.6 X-ray diffractograms of cellulose II samples (cotton knitted fabric, single jersey, yarn count 50/1)

(a) : original native cellulose sample was mercerized with caustic soda.

(b) : sample (a) was treated with liquid ammonia followed by an ammonia evaporation, and then mercerized with caustic soda.

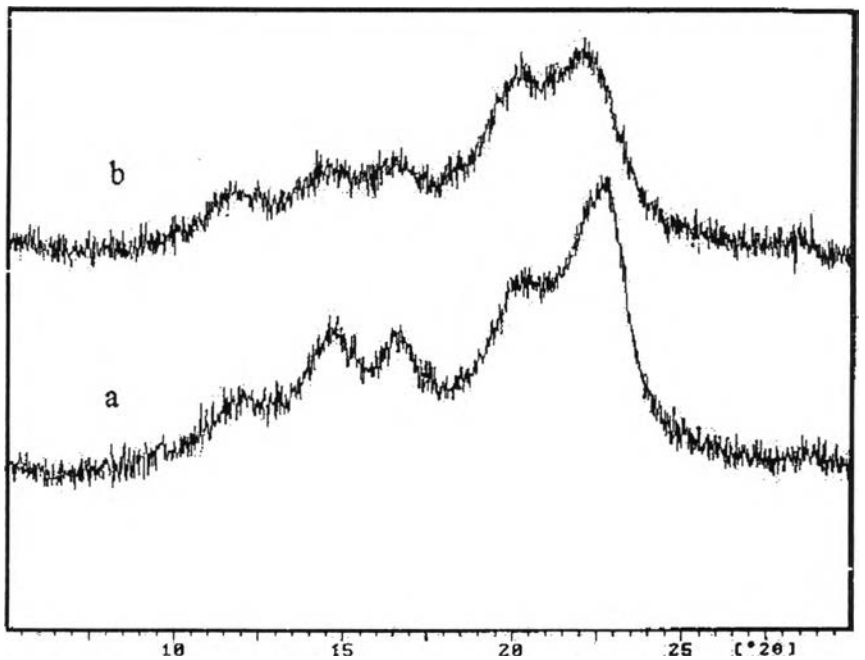

Figure 4.7 X-ray diffractograms of cellulose II samples (cotton woven fabric, plain structure)

(a) : original native cellulose sample was mercerized with caustic soda.

(c) : sample (a) was treated with liquid ammonia followed by an ammonia evaporation, and then mercerized with caustic soda.

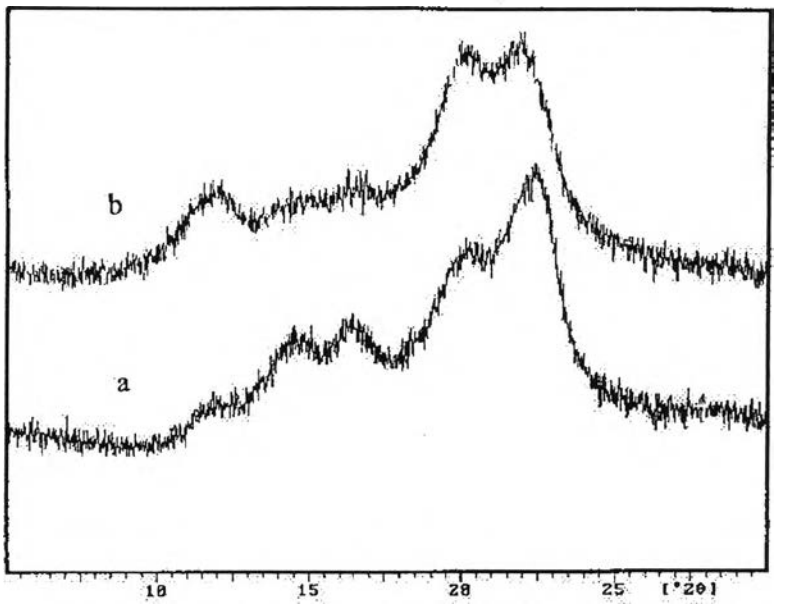

Figure 4.8 X-ray diffractograms of cellulose II samples (cotton woven fabric, satin structure)

(a) : original native cellulose sample was mercerized with caustic soda.

(b) : sample (a) was treated with liquid ammonia followed by an ammonia evaporation, and then mercerized with caustic soda.

X-ray diffractograms (a) in Figures 4.5-4.8 of the cellulose samples prepared from mercerizing the original native cellulose samples with caustic soda show similar diffraction pattern with peak positions located at diffraction angles 2θ equal to 12.1, 14.8, 16.3, 19.8 and 22.0. They are the diffraction pattern of cellulose I and cellulose II mixture in which diffraction angles 12.1, 19.8 and 22.0 representing cellulose II, [2,8] and 14.8 and 16.3 representing a part of diffraction angles of cellulose I.[8] This indicates that caustic soda mercerization preformed in this work could not completely transform the original native cellulose (cellulose I) to cellulose II. This result agrees with the work done by Ghosh and Dilanni.[10] When this cellulose mixture (celluloses I and II) was further treated with liquid ammonia followed by an ammonia evaporation and finally was mercerized with caustic soda again, the final stage of cellulose polymorph obtained from these treatments was also a mixture of celluloses I and II with a majority of cellulose II (diffractograms (b) from Figures 4.5-4.8 show lower intensity peaks at 14.8 and 16.3 than those in diffractograms (a)). To obtain cellulose II polymorph, cellulose sample with any polymorph must be mercerized with caustic soda. The overall results from this section have shown that the completion of

transformation to cellulose II occurs when cellulose has previously passed various polymorph transformations before mercerizing it with caustic soda in the final step.

4.1.3 Cellulose III

Cellulose III samples were prepared from methods mentioned in section 3.3.3 and then they were characterized for the stages of cellulose polymorphs using an X-ray diffraction technique. X-ray diffractograms of these samples are displayed in Figures 4.9-4.12. From all Figures, diffractograms (a) represent the diffraction patterns of cellulose III samples prepared from mercerizing the original native cellulose samples with caustic soda, then treating the samples with liquid ammonia followed by an ammonia evaporation and diffractograms (b) represent the diffraction patterns of cellulose III samples prepared from treating the original native cellulose samples with liquid ammonia followed by an ammonia evaporation.

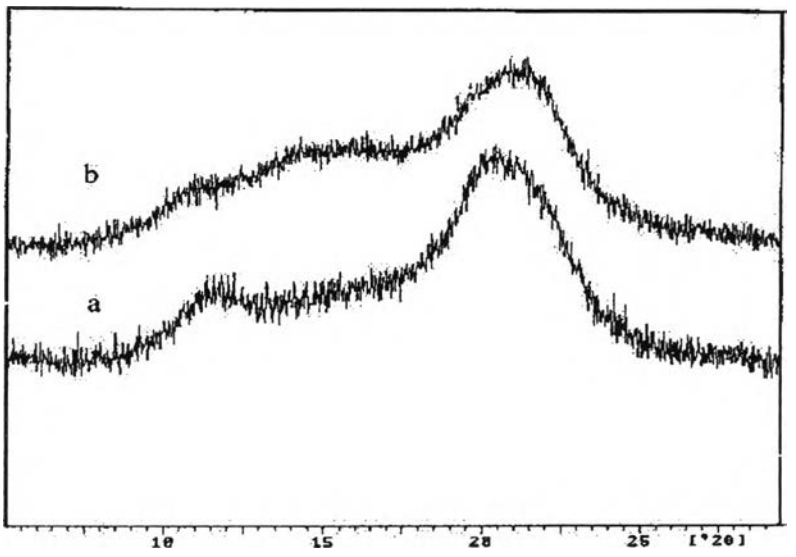

Figure 4.9 X-ray diffractograms of cellulose III samples (cotton knitted fabric, single jersey, yarn count 20/1)

(a) : original native celluiose sample was mercerized with caustic soda, then treated with liquid ammonia followed by an ammonia evaporation.

(b) : original native cellulose sample was treated with liquid ammonia followed by an ammonia evaporation.

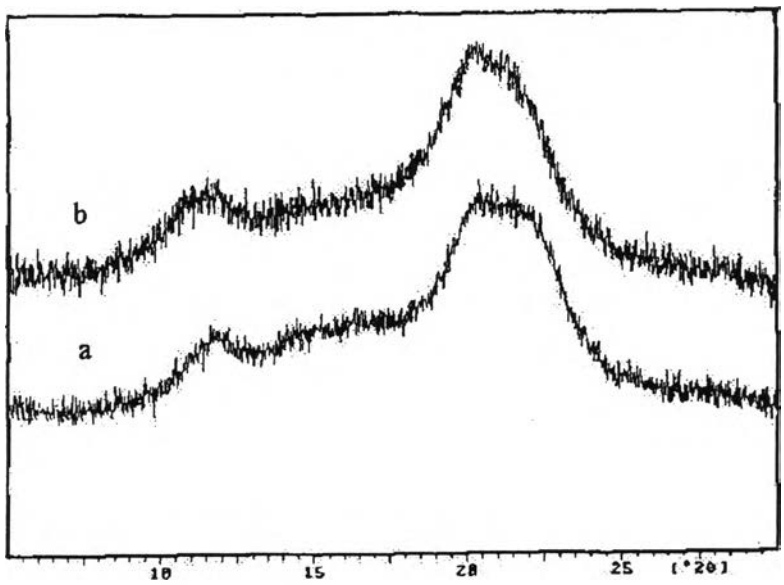

Figure 4.10 X-ray diffractograms of cellulose III samples (cotton knitted fabric, single jersey, yarn count 50/1)

(a) : original native cellulose sample was mercerized with caustic soda, then treated with liquid ammonia followed by an ammonia evaporation.

(b) : original native cellulose sample was treated with liquid ammonia followed by an ammonia evaporation.

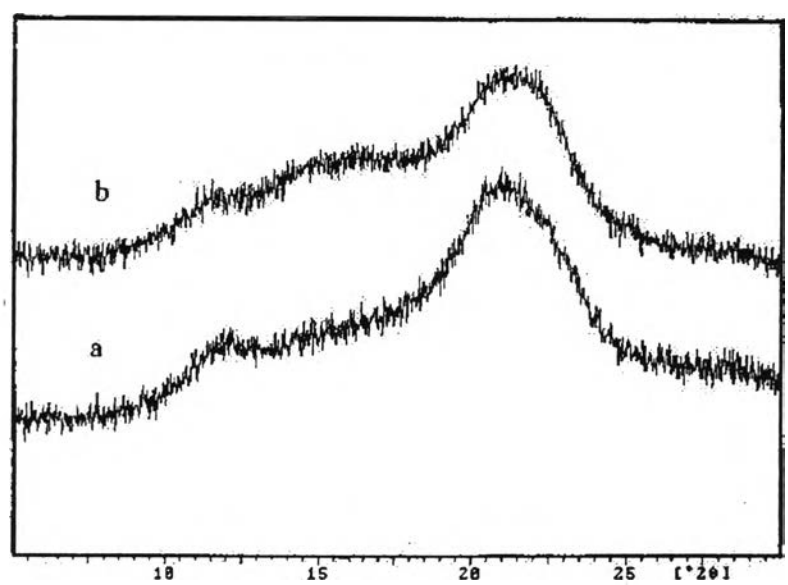

Figure 4.11 X-ray diffractograms of cellulose III samples (cotton woven fabric, plain structure)

(a) : original native cellulose sample was mercerized with caustic soda, then treated with liquid ammonia followed by an ammonia evaporation.

(b) : original native cellulose sample was treated with liquid ammonia followed by an ammonia evaporation.

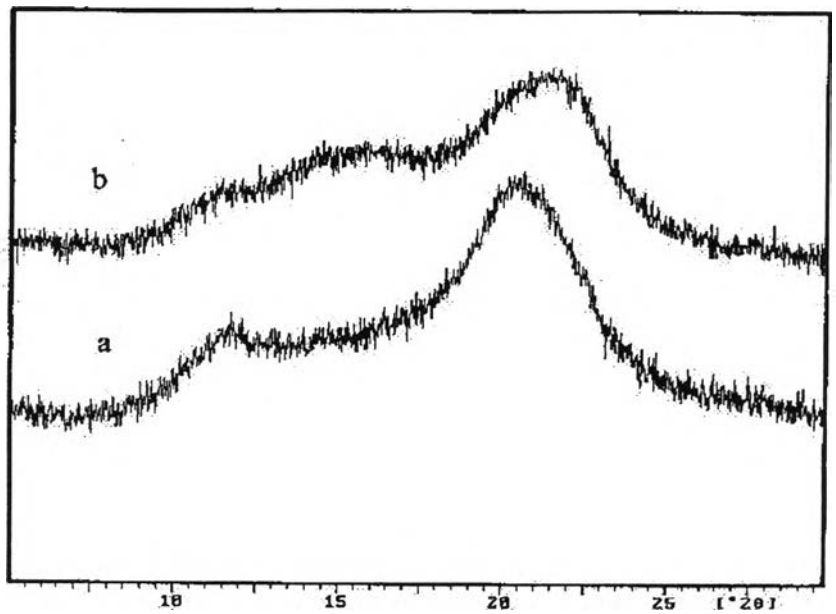

Figure 4.12 X-ray diffractograms of cellulose III samples (cotton woven fabric, satin structure)

(a) : original native cellulose sample was mercerized with caustic soda, then treated with liquid ammonia followed by an ammonia evaporation.

(b) : original native cellulose sample was treated with liquid ammonia followed by an ammonia evaporation.

X-ray diffractograms (a) of the cellulose samples prepared from mercerizing the original native cellulose samples with caustic soda, then treating the samples with liquid ammonia followed by an ammonia evaporation show similar diffraction patterns of cellulose III with peak positions located at diffraction angles 2θ equal to 11.7 and 20.6.[3,8] When the original native cellulose samples were treated with liquid ammonia followed by an ammonia evaporation, they were transformed from cellulose I to cellulose III with a small part of cellulose I left unchanged (diffractograms (b) show a broad peak at around 2θ equal to 14-18 representing the area of peak positions of cellulose I). This result agrees with the work done by Hilda et al.[44] Cellulose III can be obtained by treating cellulose samples with liquid ammonia followed by an ammonia evaporation. The overall results from this section have indicated that the completion of transformation to cellulose III occurs when cellulose was pretreated before treating it with liquid ammonia followed by an ammonia evaporation.

4.1.4 Cellulose IV

Due to unable to prepare cellulose IV samples using methods mentioned in section 3.3.4, there was no sample to be analyzed for the stage of cellulose polymorph, the degree of polymerization, the fabric strength, and the dye absorption.

4.2 Degree of Polymerization Measurement

All native cellulose samples and samples prepared from various treatments shown in Chapter III were tested for the degree of polymerization (DP) and the damage factor (S). Both data explain how much cellulose samples were damaged at the molecular level by each treatment. Treated cellulose samples with degree of polymerization closed to those of untreated samples and the damage factor not higher than 0.5 are acceptable. Results are shown in Table 4.1.

Table 4.1 Degree of polymerization (DP) and damage factor (S) of cotton knitted and woven fabrics at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	Cotton Fabric							
	Knitted, yarn 20 / 1		Knitted, yarn 50 / 1		Woven, Plain		Woven, Satin	
	DP	S	DP	S	DP	S	DP	S
Cellulose I (Native Cellulose)	1708.865	-	1697.28	-	1965.411	-	1785.474	-
Cellulose I from Cellulose III_I	1685.646	0.050	1620.517	0.078	1713.38	0.201	1624.627	0.152
Cellulose I from Cellulose III_{II}	1547.224	0.166	1436.328	0.280	1565.502	0.333	1694.157	0.085
Cellulose II_I	1547.225	0.166	1427.426	0.290	1578.169	0.322	1641.548	0.135
Cellulose II from Cellulose III_{II}	1434.015	0.291	1611.215	0.088	1442.626	0.453	1578.896	0.197
Cellulose III_I	1691.428	0.016	1604.921	0.095	1950.534	0.011	1707.865	0.072
Cellulose III_{II}	1577.443	0.133	1417.926	0.031	1571.28	0.328	1549.365	0.227

Table 4.1 shows the degree of polymerization and the damage factor of cotton knitted and woven fabrics at various stages of cellulose polymorphs. It indicates that the degree of polymerization of these fabrics decreased as the fabrics were treated with either caustic soda to form cellulose II or liquid ammonia to form cellulose I or III during the cellulose polymorph transformation. Caustic soda mercerization and liquid ammonia treatment cause the degree of polymerization of cotton knitted fabrics with single jersey structure and yarn counts 20/1 and 50/1 to decrease 1.020%-16.084% and 4.523%-16.459%, respectively, and cause cotton woven fabrics with plain and satin structures to decrease 0.757%-26.599% and 4.348%-13.224%, respectively.

The degree of polymerization shown in Table 4.1 was used to calculate for the damage factor and found that the damage factors of cotton knitted fabrics with single jersey structure, yarn counts 20/1 and 50/1 at various stages of cellulose polymorphs are 0.016-0.291 and 0.078-0.301, respectively and cotton woven fabrics with plain and satin structures are 0.011-0.453 and 0.072-0.227, respectively. All samples obtain damage factors lower than 0.5 which indicates no damage on treated samples. Therefore, it is acceptable to conclude that caustic soda mercerization and liquid ammonia treatment for cellulose polymorph transformation do not cause any damage on cotton samples. Both caustic soda and liquid ammonia have slightly broken the cellulose polymer chain into shorter polymer chains but the degree of breakage does not damage the cellulose fabrics at all.

4.3 Fabric Strength Measurement

Fabric strength can be defined as the ability of fabric to withstand rupture upon pulling or bursting known as tensile strength for woven fabric and bursting strength for knitted fabric.

4.3.1 Tensile Strength Measurement

All woven samples were tested for the breaking load and elongation at break. Results are shown in Table 4.2 and Figures 4.13-4.16 for cotton woven fabric with plain structure and Table 4.3 and Figures 4.17-4.20 for cotton woven fabric with satin structure.

Table 4.2 Breaking load and elongation at break of cotton woven fabric with plain structure at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	Breaking Load (N)		Elongation at Break (%)	
	Warp	Weft	Warp	Weft
Cellulose I (Native cellulose)	369.037	230.528	7.197	14.502
Cellulose I from Cellulose III_I	383.631	276.537	32.947	23.197
Cellulose I from Cellulose III_{II}	432.647	344.053	45.446	28.139
Cellulose II_I	507.329	381.749	35.558	23.142
Cellulose II from Cellulose III_{II}	457.366	365.059	48.225	27.057
Cellulose III_I	449.641	326.092	33.114	22.779
Cellulose III_{II}	536.025	417.782	43.531	26.389

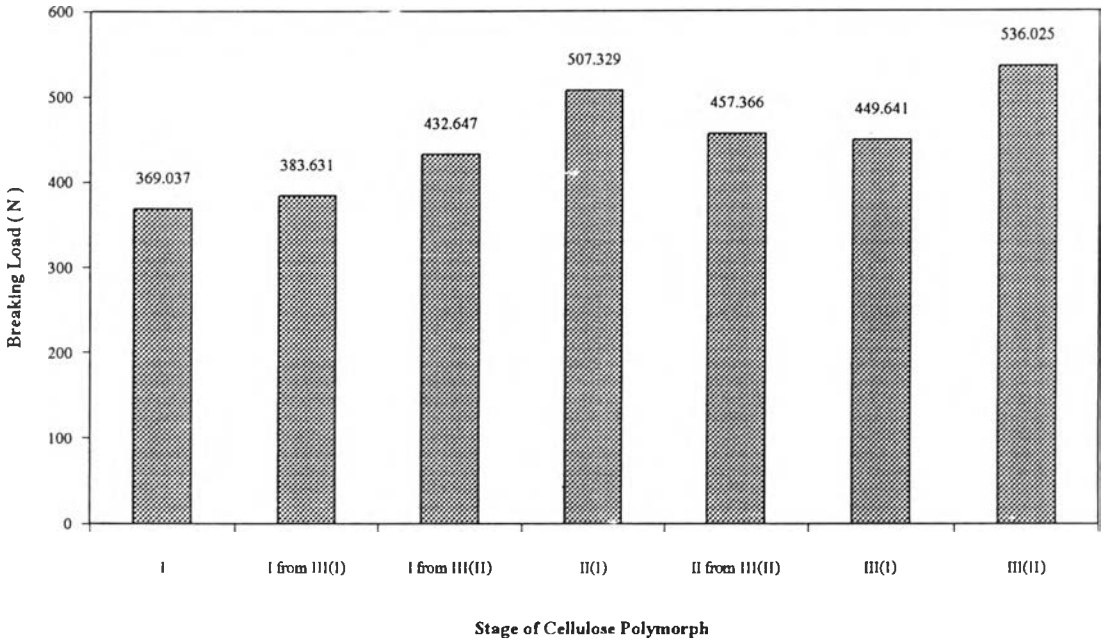

Figure 4.13 Breaking load along warp direction of cotton woven fabric with plain structure at various stages of cellulose polymorphs.

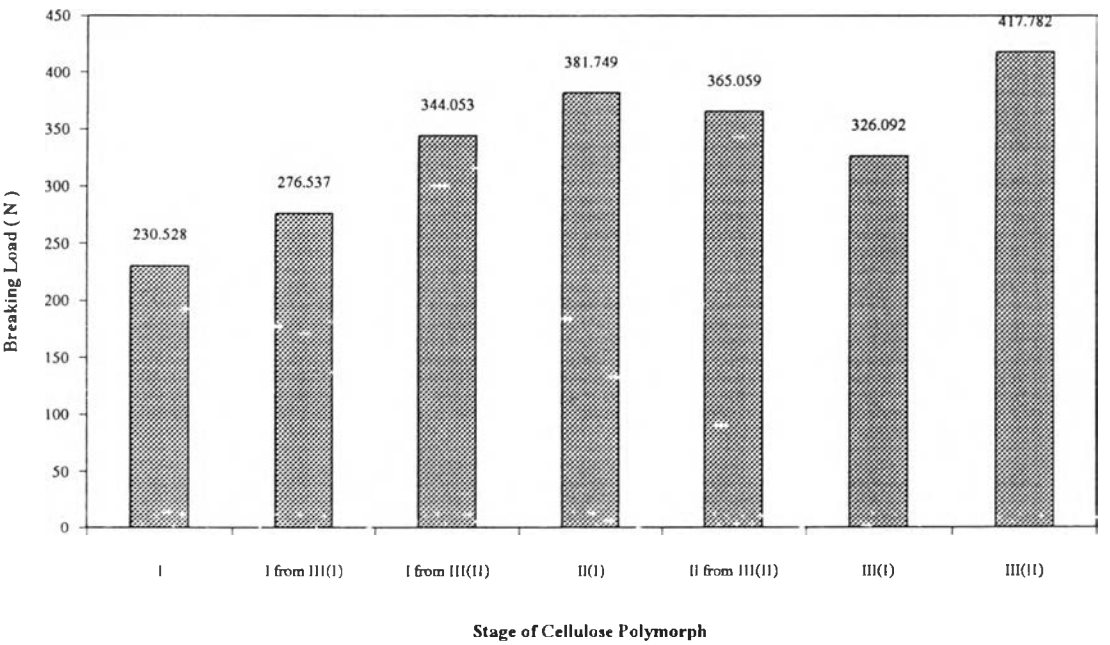

Figure 4.14 Breaking load along weft direction of cotton woven fabric with plain structure at various stages of cellulose polymorphs.

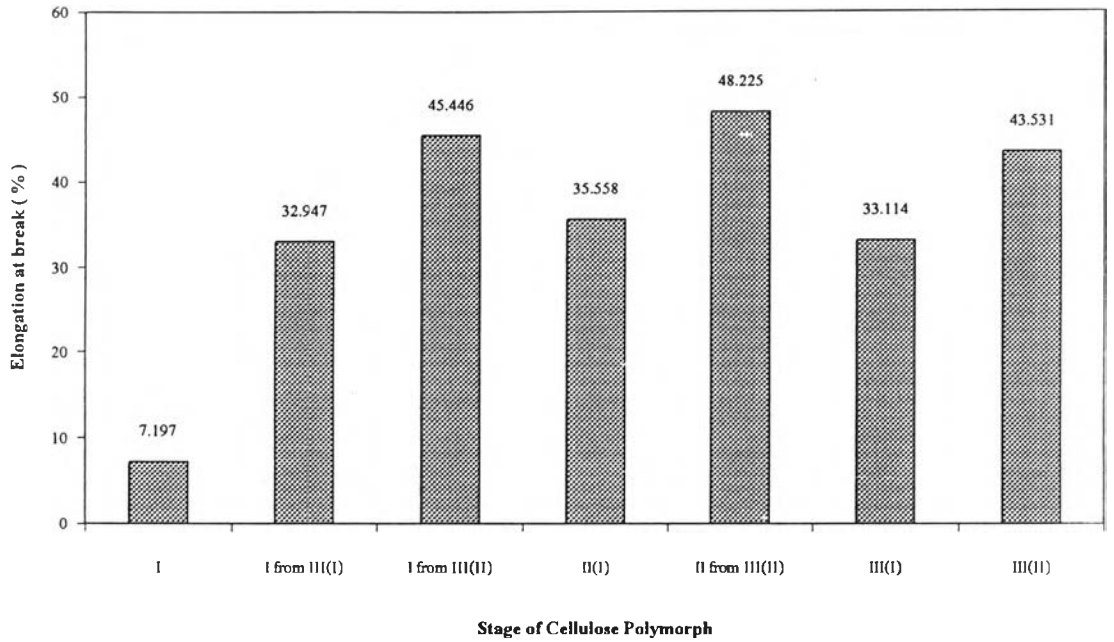

Figure 4.15 Elongation at break along warp direction of cotton woven fabric with plain structure at various stages of cellulose polymorphs.

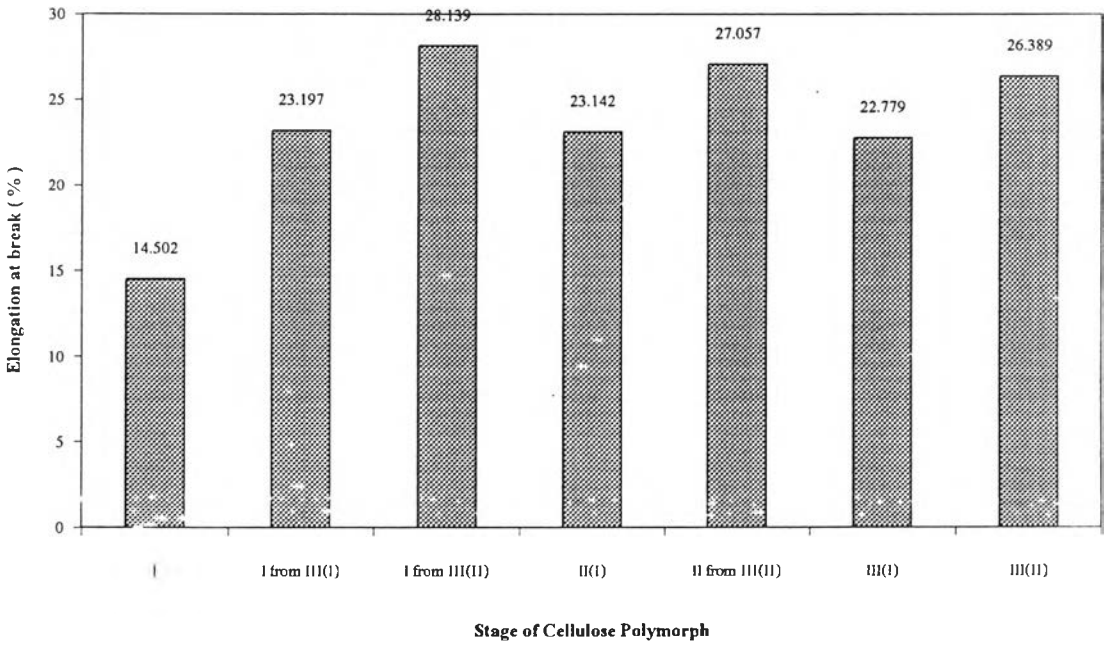

Figure 4.16 Elongation at break along weft direction of cotton woven fabric with plain structure at various stages of cellulose polymorphs.

Table 4.3 Breaking load and elongation at break of cotton woven fabric with satin structure at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	Breaking Load (N)		Elongation at Break (%)	
	Warp	Weft	Warp	Weft
Cellulose I (Native cellulose)	936.455	520.345	9.670	14.808
Cellulose I from Cellulose III_I	984.976	624.160	30.807	22.807
Cellulose I from Cellulose III_{II}	1046.779	747.519	39.572	27.585
Cellulose II_I	1186.118	845.769	40.919	23.835
Cellulose II from Cellulose III_{II}	1131.859	773.766	45.085	27.308
Cellulose III_I	1100.045	649.123	29.501	23.059
Cellulose III_{II}	1345.963	868.572	42.557	27.445

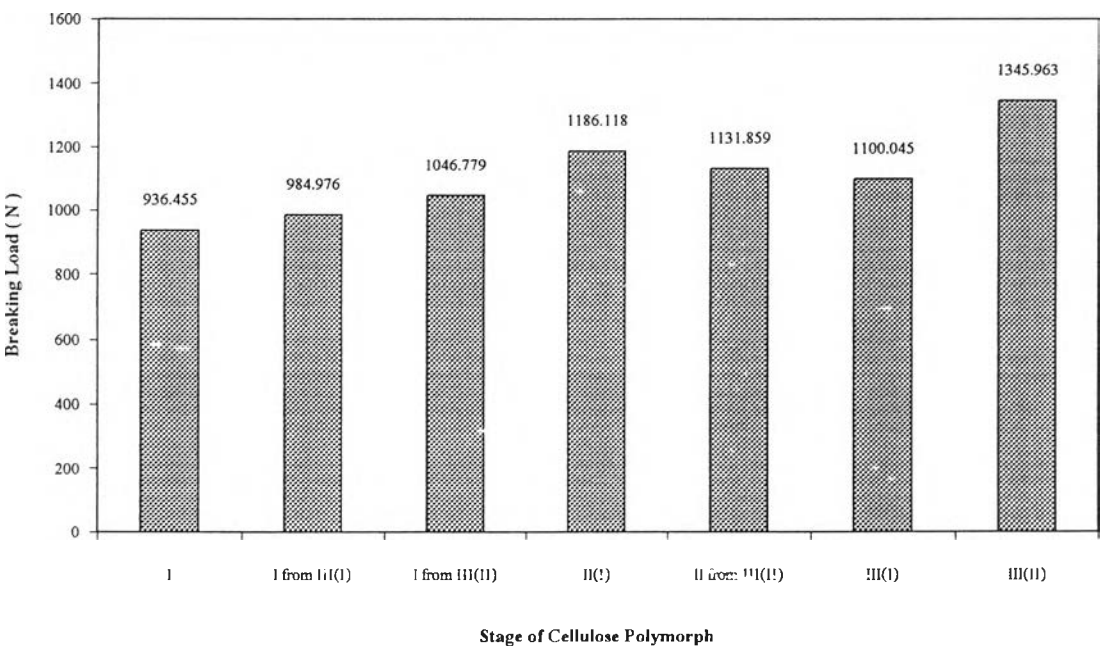

Figure 4.17 Breaking load along warp direction of cotton woven fabric with satin structure at various stages of cellulose polymorphs.

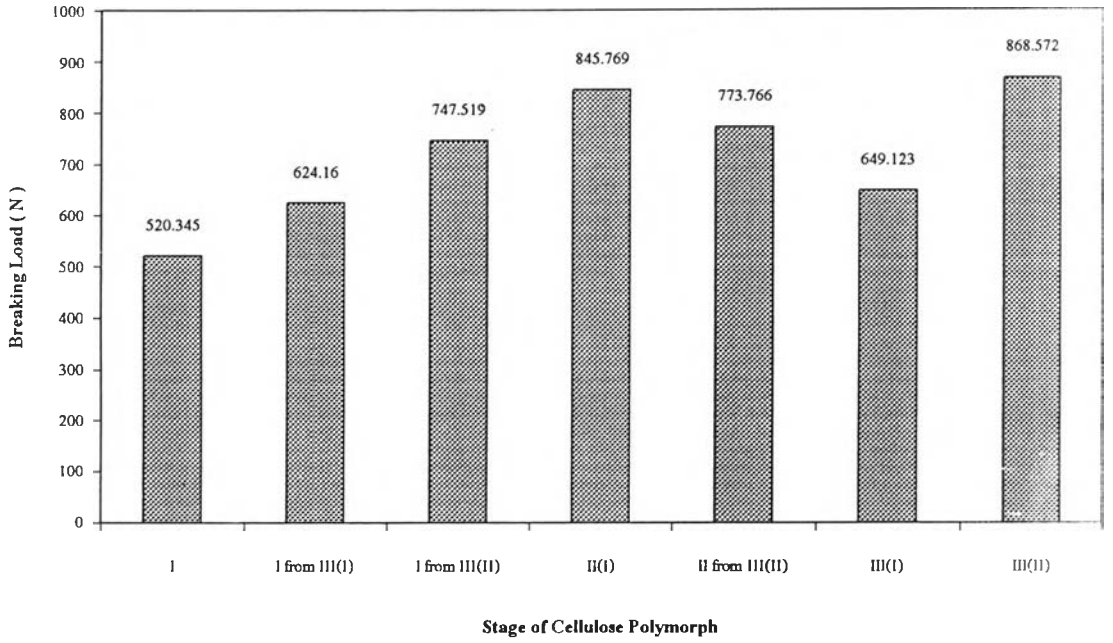

Figure 4.18 Breaking load along weft direction of cotton woven fabric with satin structure at various stages of cellulose polymorphs.

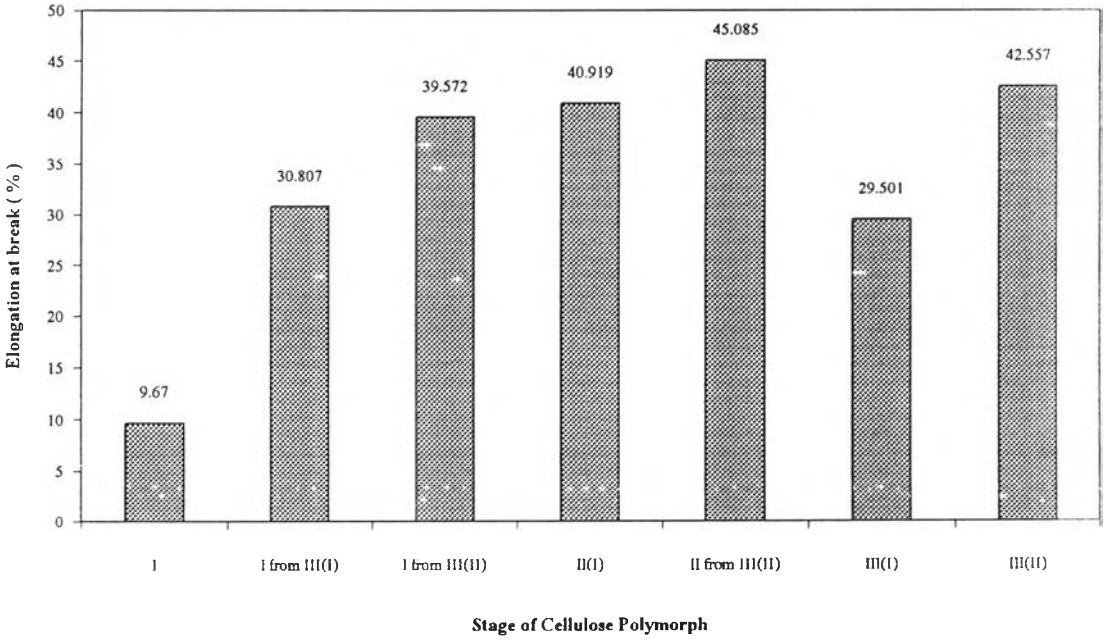

Figure 4.19 Elongation at break along warp direction of cotton woven fabric with satin structure at various stages of cellulose polymorphs.

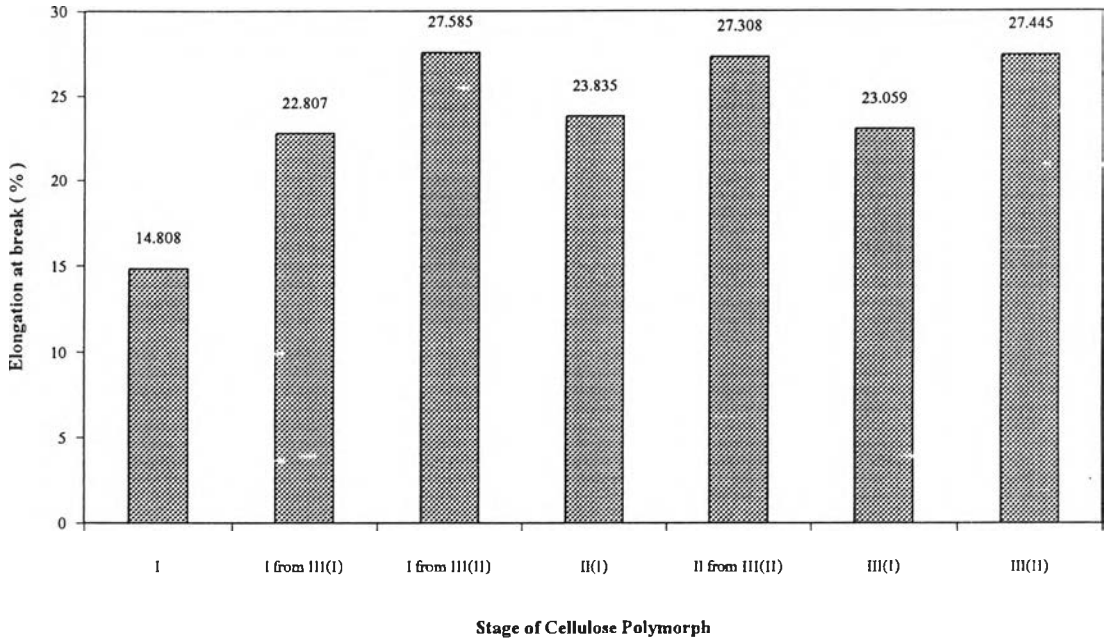

Figure 4.20 Elongation at break along weft direction of cotton woven fabric with satin structure at various stages of cellulose polymorphs.

Results from Tables 4.2 and 4.3 and Figures 4.13-4.20 show that all treated samples have both breaking load and elongation at break higher than those of native cellulose. Caustic soda mercerization and liquid ammonia treatment have caused the woven fabric stronger and more flexible as well as caused the cellulose polymorph transformation. Woven fabrics with cellulose polymorph of cellulose III_{II} obtain the highest breaking load in both warp and weft directions and obtain high elongation at break as well.

Among cellulose I family, cellulose I samples prepared from cellulose III_I or from cellulose III_{II} obtain higher breaking load and elongation at break than the native cellulose I samples. Cellulose I prepared from cellulose III_{II} has higher breaking load and elongation at break than cellulose I prepared from cellulose III_I. For cellulose II family, cellulose II samples prepared from cellulose III_{II} obtain lower breaking load but higher elongation at break than cellulose II_I prepared from mercerizing the original native cellulose with caustic soda. Samples of cellulose II family obtain higher breaking load than samples of cellulose I family. For cellulose III family, cellulose III_{II} prepared from mercerizing the original native

cellulose with caustic soda, then treating with liquid ammonia followed by an ammonia evaporation obtains higher breaking load and elongation at break than the cellulose III_I prepared from treating the original native cellulose with liquid ammonia foilowed by an ammonia evaporation.

It was found that when cotton fabric was treated with either caustic soda or liquid ammonia, the intermolecular hydrogen bonds of the cellulose polymer chains were broken,[23] the conformation of the CH_2OH at carbon 6 changed due to the rotation of the C5-C6 bond,[43] and the polymer chains rearranged themselves to be partly amorphous and partly a new crystal structure of cellulose polymorph. These phenomena bring about fiber swelling in cotton fabric. Fiber treated with caustic soda swells significantly along the cross sectional direction and thus shrinks in fiber length, while fiber treated with liquid ammonia swells equally in every direction.[32] Cotton fibers are staple fibers with natural crimps along fibers length. These crimps help in holding fiber together during yarn spinning process. When these fibers swell due to the treatment mentioned earlier, they increase in size and thus get closer to each other. Each fiber increases in surface area for contacting or interlocking with fibers near by and thus may result in increasing of yarn strength and fabric strength after the caustic soda or liquid ammonia treatment. Swollen fibers are puffy and flexible more than unswollen fibers and this may be caused them to increase in elongation after the treatment.

4.3.2 Bursting Strength Measurement

All knitted samples were tested for the bursting strength. Results are shown in Table 4.4 and Figure 4.21 for cotton knitted fabric with single jersey structure and yarn count 20/1 and Table 4.5 and Figure 4.22 for cotton knitted fabric with single jersey structure and yarn count 50/1.

Table **4.4** Bursting strength of cotton knitted fabric with single jersey structure and yarn count 20/1 at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	Bursting Strength (kPa.)
Cellulose I (Native Cellulose)	1109.33
Cellulose I from Cellulose III_I	1244.90
Cellulose I from Cellulose III_{II}	1392.60
Cellulose II_I	1305.80
Cellulose II from Cellulose III_{II}	1373.90
Cellulose III_I	1276.90
Cellulose III_{II}	1419.40

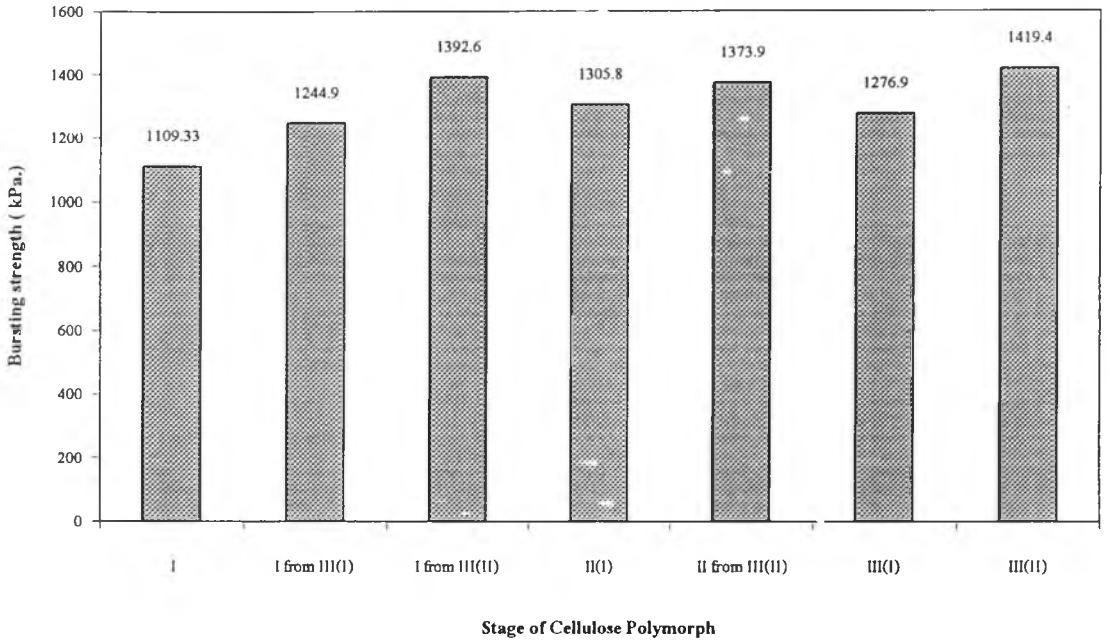

Figure 4.21 Bursting strength of cotton knitted fabric with single jersey structure and yarn count 20/1 at various stages of cellulose polymorphs.

Table 4.5 Bursting strength of cotton knitted fabric with single jersey structure and yarn count 50/1 at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	Bursting Strength (kPa.)
Cellulose I (Native Cellulose)	740.60
Cellulose I from Cellulose III_I	792.20
Cellulose I from Cellulose III_{II}	880.50
Cellulose II_I	844.30
Cellulose II from Cellulose III_{II}	877.70
Cellulose III_I	808.60
Cellulose III_{II}	881.40

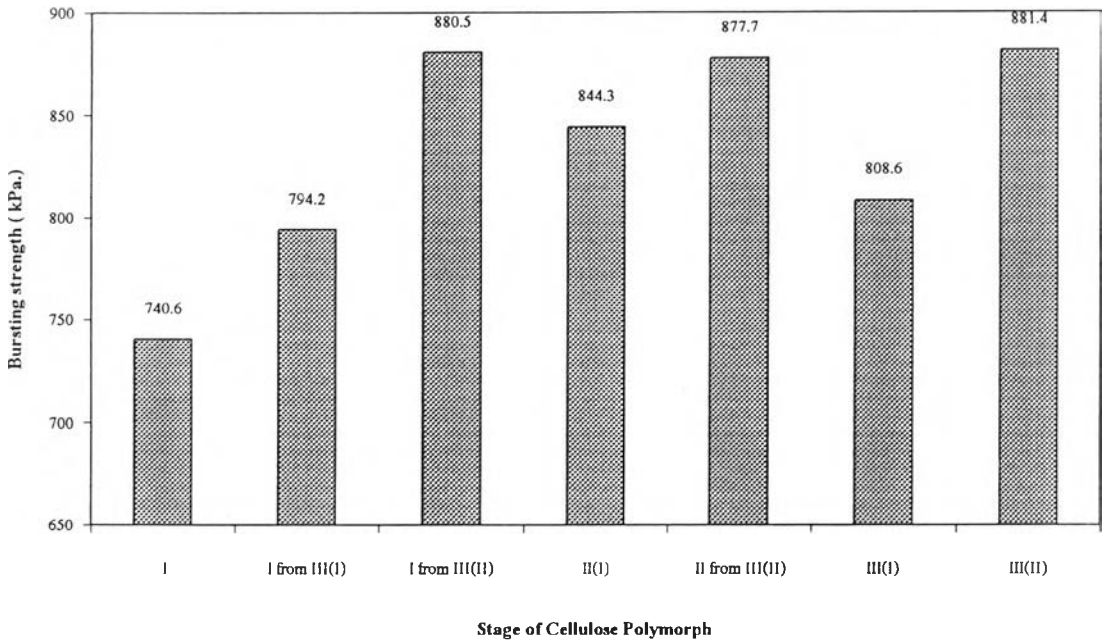

Figure 4.22 Bursting strength of cotton knitted fabric with single jersey structure and yarn count 50/1 at various stages of cellulose polymorphs.

Tables 4.4-4.5 and Figures 4.21-4.22 show that all treated samples have bursting strength higher than those of native cellulose samples. Caustic soda mercerization and liquid ammonia treatment have caused the knitted fabric stronger as well as caused the cellulose polymorph transformation and the reasons for that could have been the same as those explained in section 4.3.1. Both knitted fabrics (yarn counts 20/1 and 50/1) with the cellulose polymorph of cellulose III_{II} obtain the highest bursting strength. Among cellulose I family, cellulose I samples prepared from cellulose III_{I} or cellulose III_{II} obtain higher bursting strength than the original native cellulose I samples. For cellulose II family, cellulose II prepared from cellulose III_{II} obtain higher bursting strength than cellulose II prepared from mercerizing the original native cellulose samples with caustic soda. For cellulose III family, cellulose III_{II} obtain higher bursting strength than cellulose III_{I}. Both knitted fabrics show the same order of bursting strength as follows : Cellulose III_{II} > Cellulose I from Cellulose II_{II} > Cellulose II from Cellulose III_{II} > Cellulose II_{I} > Cellulose III_{I} > Cellulose I from Cellulose III_{I} > Cellulose I (Native Cellulose).

4.4 Dye Absorption Measurement

All native cellulose samples and samples prepared from various treatments were dyed with direct dye "Benzopurpurine 4B" and were measured for dye absorption on samples based on the color strength of dyed samples (K/S). Results are shown in Table 4.6 and Figures 4.23-4.26.

Table 4.6 Color strength of dyed cotton fabrics (knitted and woven) at various stages of cellulose polymorphs.

Stage of Cellulose Polymorph	K / S			
	Knitted, yarn 20/1	Knitted, yarn 50/1	Woven, plain	Woven, satin
Cellulose I (Native Cellulose)	6.149	5.973	7.576	6.051
Cellulose I from Cellulose III_I	9.914	9.400	11.274	10.258
Cellulose I from Cellulose III_{II}	13.614	12.148	12.127	13.204
Cellulose II_I	14.072	13.447	13.427	13.273
Cellulose II from Cellulose III_{II}	15.082	14.048	14.926	14.911
Cellulose III_I	9.722	8.034	11.047	9.737
Cellulose III_{II}	13.922	13.079	12.665	13.236

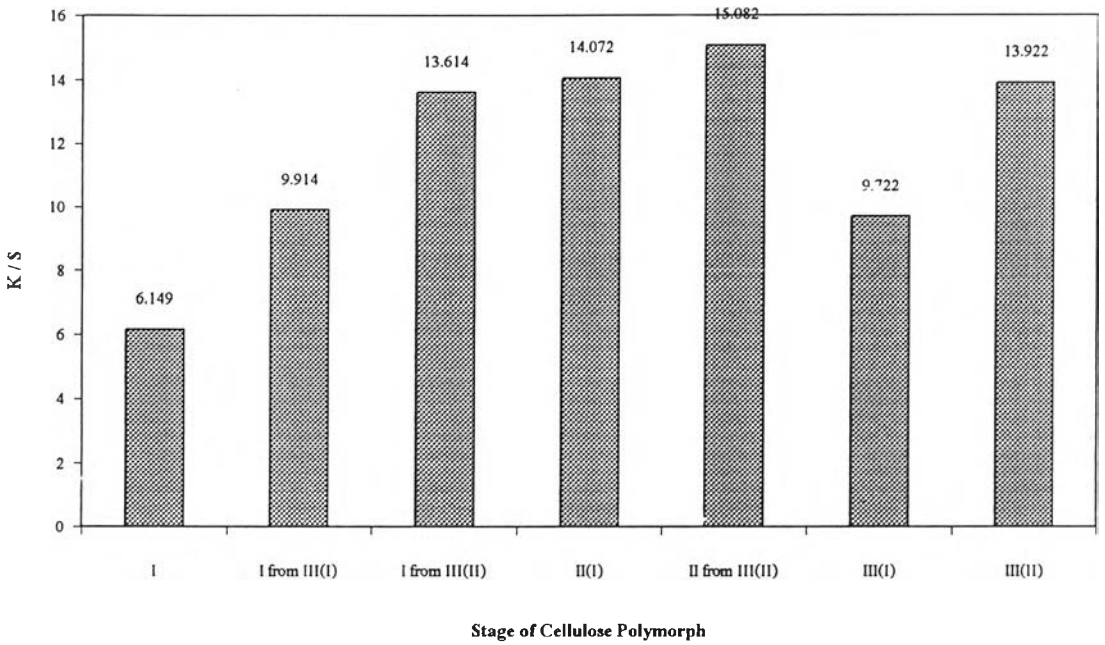

Figure 4.23 Color strength of dyed cotton knitted fabric with single jersey structure and yarn count 20/1 at various stages of cellulose polymorphs.

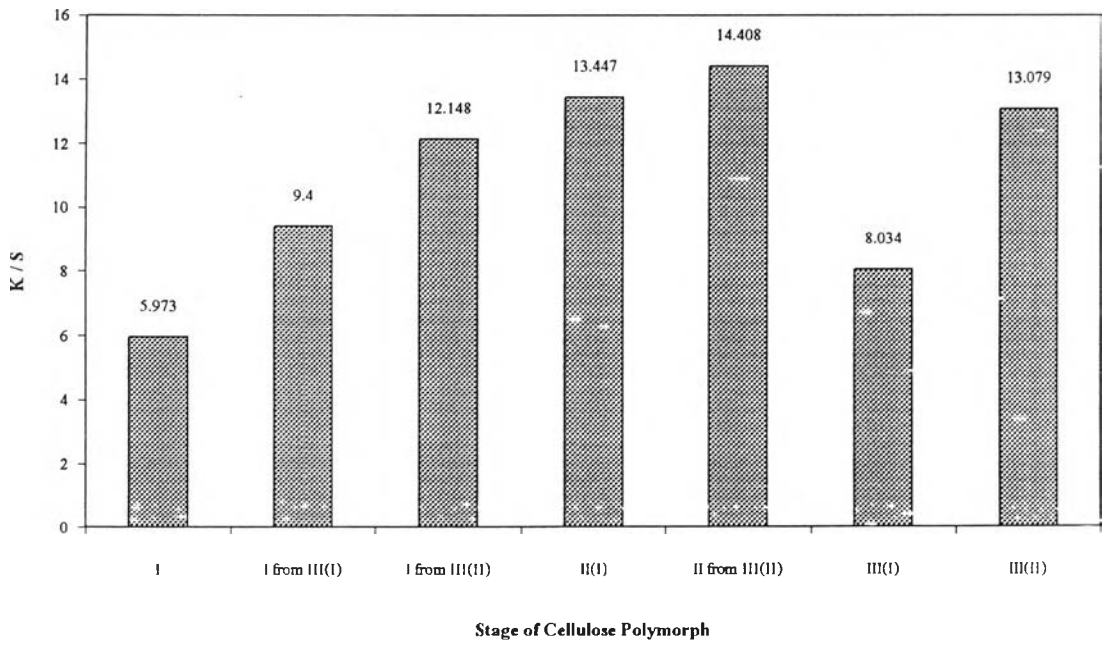

Figure 4.24 Color strength of dyed cotton knitted fabric with single jersey structure and yarn count 50/1 at various stages of cellulose polymorphs.

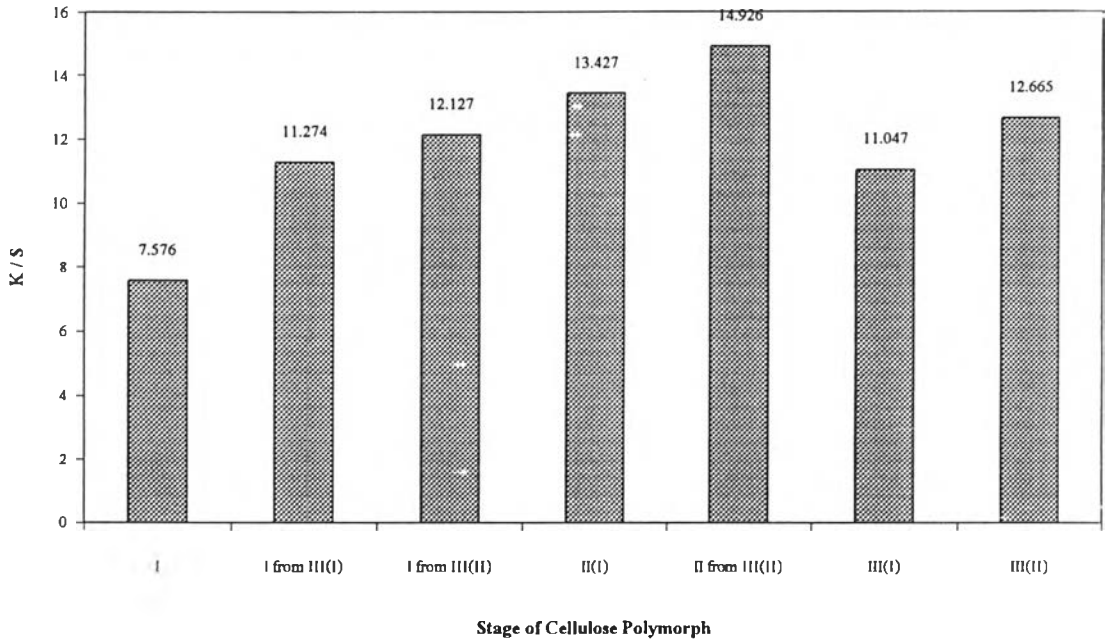

Figure 4.25 Color strength of dyed cotton woven fabric with plain structure at various stages of cellulose polymorphs.

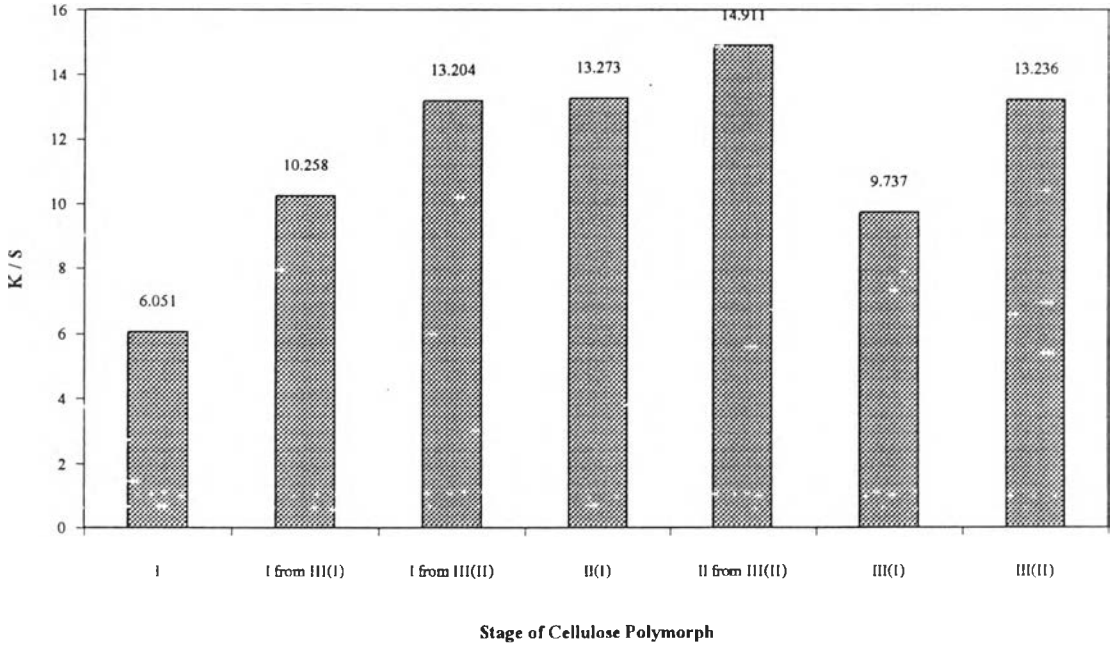

Figure 4.26 Color strength of dyed cotton woven fabric with satin structure at various stages of cellulose polymorphs.

Results from Table 4.6 and Figures 4.23-4.26 show that after dyeing all treated samples contain color strength or dye absorption higher than those of native cellulose I samples. Caustic soda mercerization and liquid ammonia treatment have caused the cellulosic fabric to absorb more dyestuffs during dyeing. All four fabrics show the same order of color strength as follows : Cellulose II from Cellulose III_{II} > Cellulose II_{I} > Cellulose III_{II} > Cellulose I from Cellulose III_{II} > Cellulose I from Cellulose III_{I} > Cellulose III_{I} > Cellulose I (native cellulose)

For cellulose I family, cellulose I samples prepared from cellulose III_{I} or from cellulose III_{II} obtain higher color strength than the native cellulose I samples. For cellulose II family, cellulose II prepared from cellulose III_{II} obtain slightly higher color strength than cellulose II_{I} prepared from mercerizing the original native cellulose with caustic soda. For cellulose III family, most cellulose III_{II} prepared from mercerizing the original native cellulose with caustic soda, then treated with liquid ammonia followed by an ammonia evaporation obtain higher color strength than cellulose III_{I} prepared from treating the original native cellulose with liquid ammonia and followed by an ammonia evaporation. Among all stages of cellulose polymorphs, cellulose II from cellulose III_{II} (prepared from mercerizing the original native cellulose with caustic soda, then treating with liquid ammonia followed by an ammonia evaporation and finally mercerizing again with caustic soda) obtain the highest color strength or absorb the highest amount of dyes when compared with other stages of cellulose polymorphs.

Samples of cellulose II family or the samples that have passed the transformation to cellulose II obtain approximately the same dyeability but they are able to absorb more dyes than other samples. This means that transformation to cellulose II increases the dyeability of the cellulose sample more than transformation to other stages of cellulose polymorphs. When cellulose sample was mercerized with caustic soda, its polymer chains in the crystalline parts rearrange and transform its cellulose polymorph to cellulose II polymorph. Some crystalline parts lose their orientation and turn into amorphous to function as a dye absorbing portion. These phenomena significantly bring about fiber swelling in the cross

sectional direction and thus shrink in fiber length. Transformation to cellulose II may have increased the fiber swelling and the amorphous portions in the sample more than the transformation to other cellulose polymorphs. Results from this measurement also indicate that pretreatment of cellulose to various stages of cellulose polymorphs helps to increase the dyeability of the cellulose sample.

The overall results in this Chapter have indicated that transformation among cellulose polymorphs I, II, and III are possible by caustic soda mercerization or liquid ammonia treatment. With these two treatments, cellulose can transform its polymorph to other polymorphs as many times as possible with very low damage at the molecular level. In addition, these transformations improve the strength and dyeability of the cellulosic fabrics.