CHAPTER IV

RESULTS AND DISCUSSION

4.1 Inkjet Ink

The inkjet property was investigated for ink viscosity with Brookfield viscometer (model DVIII) at room temperature, spindle # 31, and shear rate at 250 rpm. Table 4.1 shows the viscosity of the cyan, magenta, yellow, and black inks.

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

Inkjet Ink Color	Viscosity (mPa s)
Cyan	2.18
Magenta	2.16
Yellow	2.14
Black	2.34

From Table 4.1, we found that the ink viscosity for each color approximately 2 mPa s conforms to the standard range of requirement for inkjet ink. The printing needs to print more than one pass for achieving the deeper shades because inkjet printer creates tiny drops for the imaging system. So we had to increase the dye concentration in the formulation to eliminate the need for multiple-pass printing. [16]

4.2 Silks Properties

In this study, four types of silk fabrics, non-bleached fabric and without optical brightening agent were investigated.

4.2.1 Description of the silk fabrics

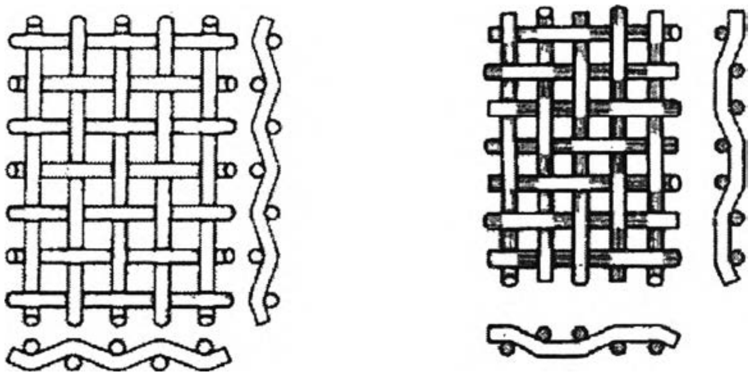
The silk fabrics used were obtained from Thai Silk Co., Ltd. A description of the silk is presented in Table 4.2.

Table 4.2 Description of silk fabrics

Type	Style	Yarn Number (Denier, warp x weft)	Number of yarn per unit length (warp x weft)*
A	plain	104 x 87**	130 x 51
B	twill	102 x 66	140 x 51
C	plain	79 x 67	130 x 70
D	plain	98 x 84	130 x 51

* Count of yarns per inch ** Represents the number of yarns

Silk fabrics A, C and D are the plain weave. Each weft yarn passes alternately over and under each warp yarn, while each warp yarn passes alternately over and under each weft yarn. The warp and weft yarn diameters are generally the same as shown in Figure 4.1(a). The silk B is twill weave that each weft yarn alternately passes over two weft yarns, then under two successive warp yarns and each warp yarn passes alternately over two and under two successive weft yarns, in a staggered arrangement. Twill weave is normally used to allow a heavier yarn diameter than the standard one in association with a given mesh as shown in Figure 4.1(b). [17]



(a) (b)

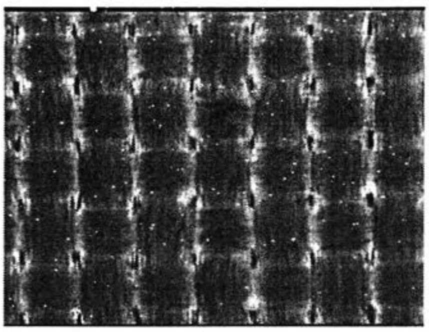
Figure 4.1 Type of weave: (a) plain weave, (b) twill weave

4.2.2 Texture of Silk Fabrics

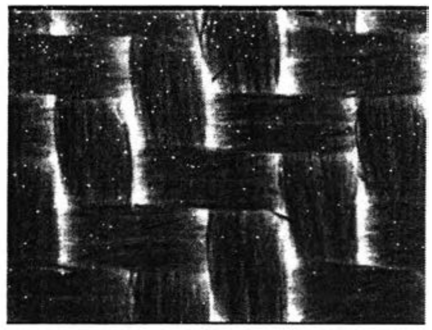
The texture of the non-printed silk fabrics was observed. The transmission images were obtained using an Image Analyzer. It can be seen that the structures of the silk fabrics are shown in Figure 4.2.

As shown in Figures 4.2 (a), (b), (c) and (d), different fabric structures are observed. We saw the number of yarns per inch and their pore size. The twill silk fabric (silk fabric B) has the smoothest surface structure because of the weave method of the twill weave. The twill fabrics, compared to the plain weave, have more pliable drape and hand, wrinkle resistance, resistance to collecting soil and soiling, durability and heavier, tendency to have defined face and back. [18]

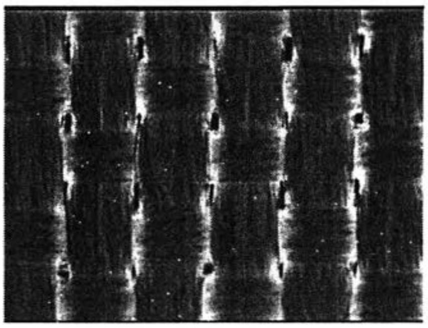
For the same style, the silk fabrics A, C and D were studied for the effect of porosity. The silk fabric C has the smaller pore size than those of the silk fabrics A and D because the silk fabric C contains two yarns weft. The area-to-pore size ratios of the silk fabrics A and D are nearly the same but it is higher than that of the silk fabric C.



(a)



(b)



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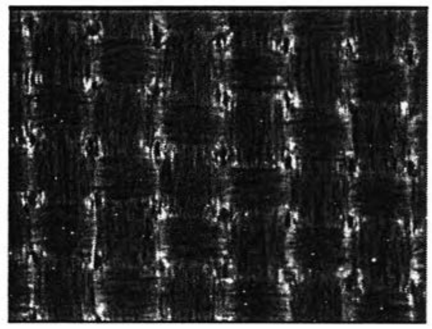


(d)

Figure 4.2 Structural images of the silk fabrics (a) silk type A, (b) silk type B, (c) silk type C, and (d) silk type D

4.2.3 Wicking Behavior of Silk Fabrics

The silk fabrics were tested for the ink absorption by the wicking test. The ink absorption is well known to have a significant influence on print quality.

Table 4.3 Water (W) and 2-Octanol (O) Wicking Rate

Fabric	Fluid	Warp (P) cm	Weft (F) cm	P/F	W/O
A	W	1.7	4.1	0.415	0.578
	O	2.8	3.9	0.718	
B	W	1.85	4.0	0.463	0.728
	O	3.3	5.2	0.635	
C	W	1.75	3.95	0.443	0.776
	O	2.0	3.5	0.571	
D	W	1.15	3.0	0.383	0.567
	O	2.3	3.4	0.676	

These results of fabric wicking behavior are shown in Table 4.3. These data indicate that a wicking anisotropy can exist relative to the warp and weft directions. The weft direction of all silk fabrics can absorb more fluid than that of the warp direction.

The W/O ratio is an index describing the relative ability of the fabric to wick in hydrophobic liquid versus hydrophilic liquid. From Table 4.3, the silk fabrics B and C have the higher W/O ratios; therefore, these fabrics are less hydrophobic than the silk fabrics A and D.

4.2.4 Gloss of Silk Fabrics

The non-printed silk fabrics were evaluated for surface gloss by a gloss meter. The gloss reflects many optical properties such as absorption, transmission, reflection and scattering resulting from the surface characteristics.

The gloss values of silk fabrics A, B, C, and D measured at a 60° specular angle are 3.6, 3.3, 4.0 and 3.8, respectively. The results exhibit that all fabrics have the similar gloss. The matte is the characteristic of silk fabric that affects printed fabric quality.

4.3 MTF of Silk Fabrics

4.3.1 Analyzing Reflection Density

The MTF of the four silk fabrics was measured by the sinusoidal test pattern contact method. The sinusoidal test pattern array contains a set of sinusoidal areas with the spatial frequencies of interest. Each sinusoidal area varies sinusoidally in transmittance. The eight sinusoidal test pattern arrays used for each silk fabric have the spatial frequencies of 0.375, 0.5, 0.75, 1.0, 1.5, 2.0, 2.5 and 3.0 cycles/mm.

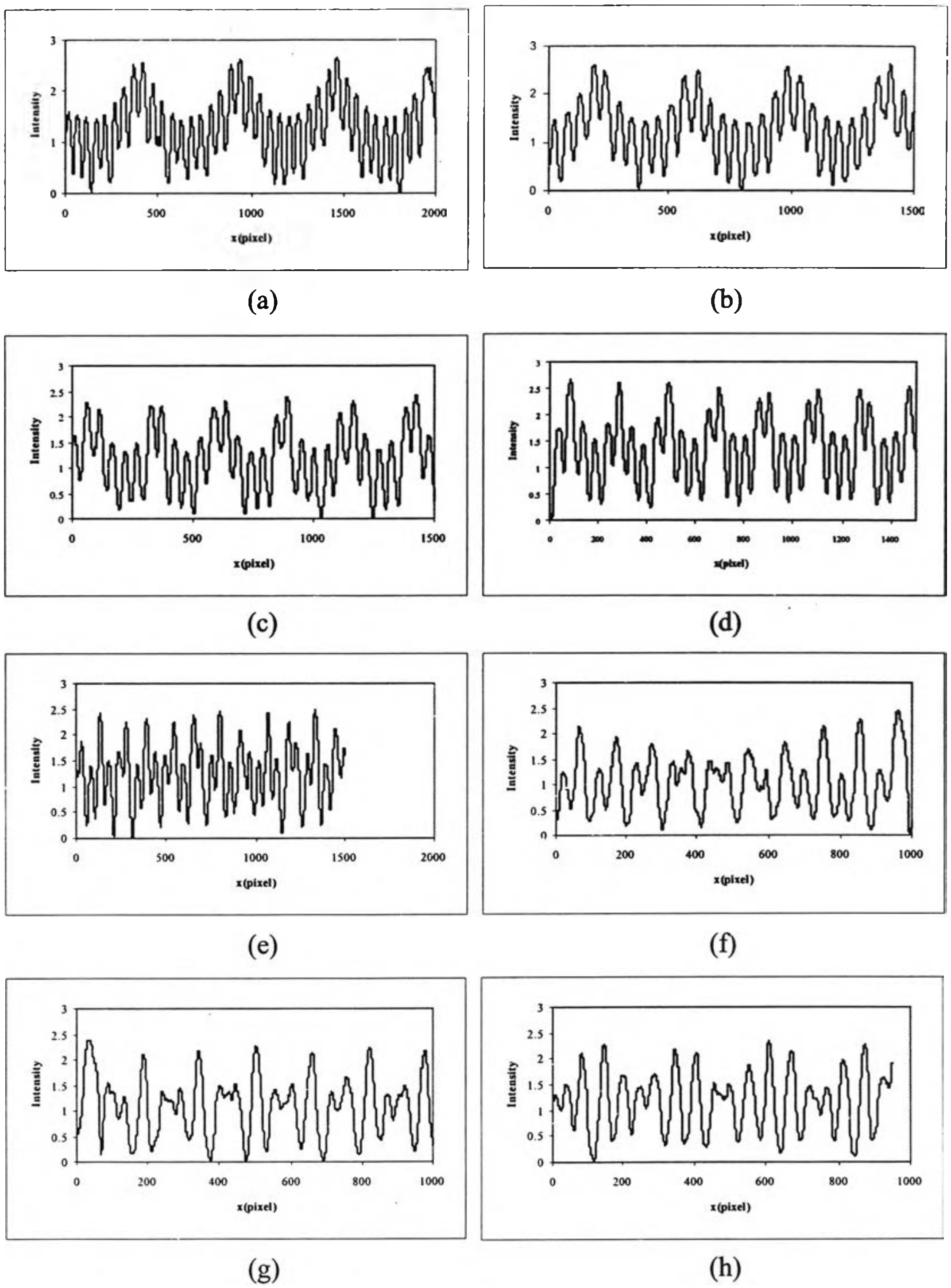


Figure 4.3 Traces of the contacted sinusoidal test pattern for the silk fabric A by the microdensitometer at the different applied spatial frequencies of (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, and (h) 3.0 cycles/mm.

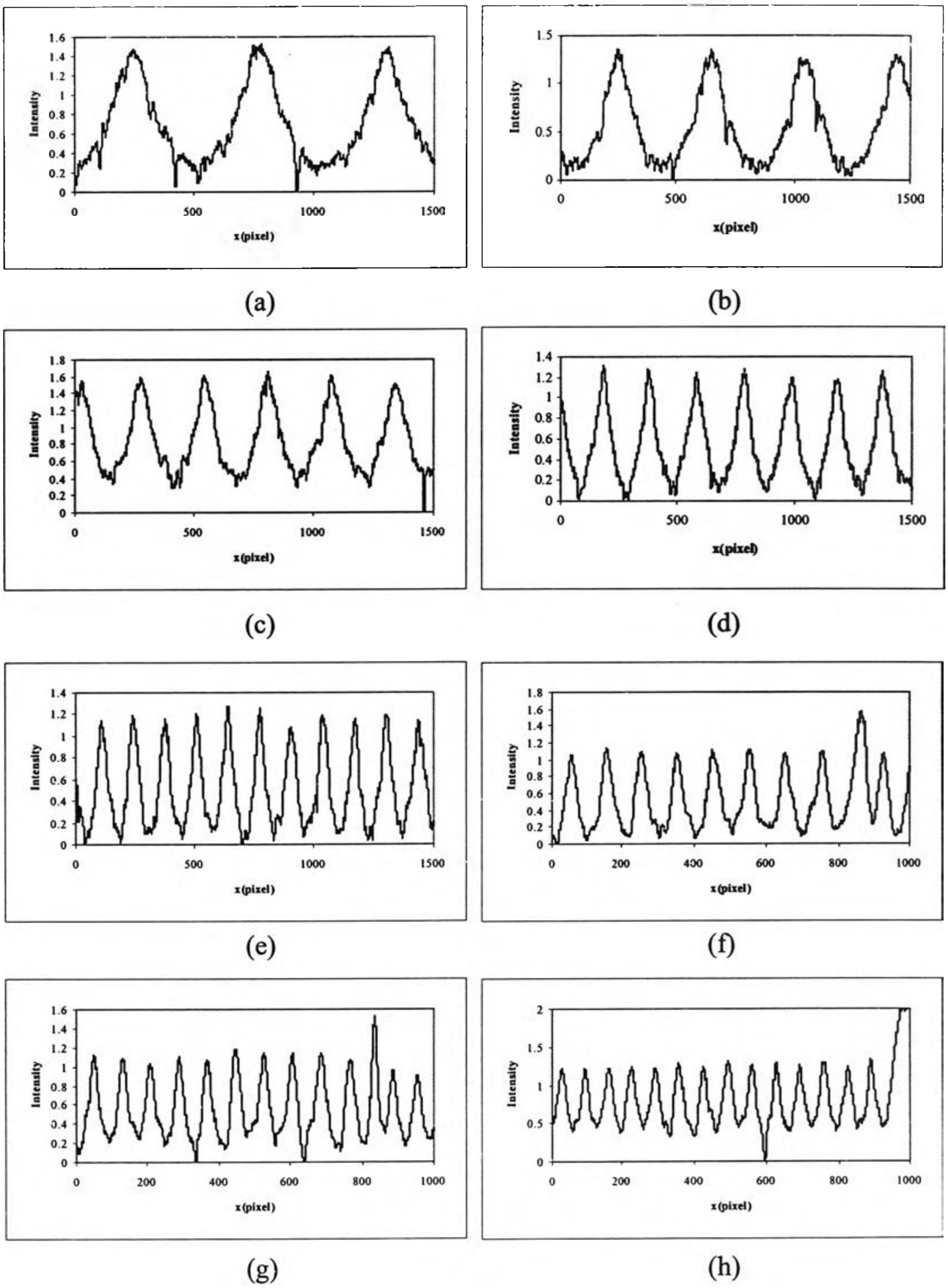


Figure 4.4 Traces of the contacted sinusoidal test pattern for the silk fabric B by the microdensitometer at the different applied spatial frequencies of (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

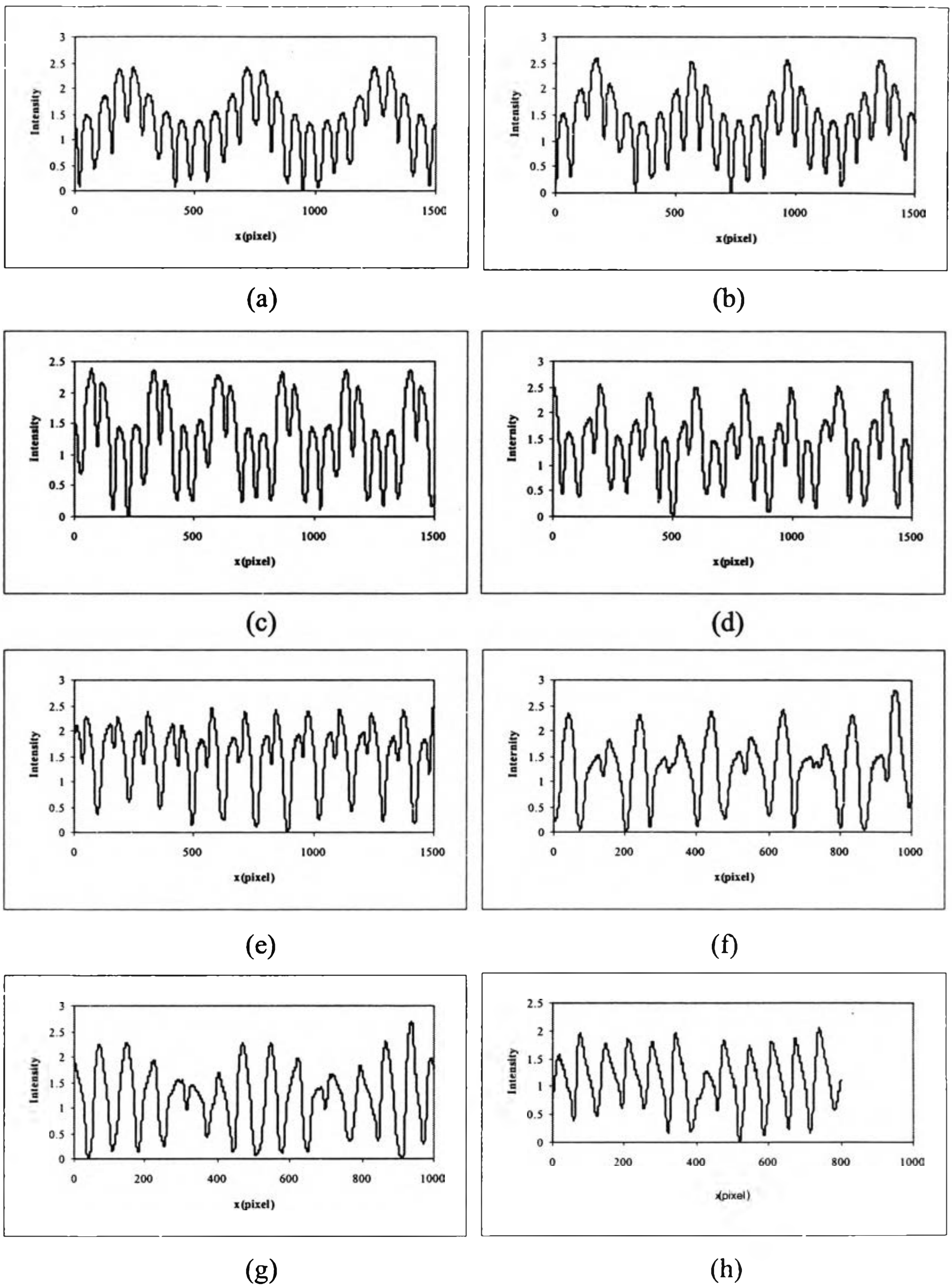
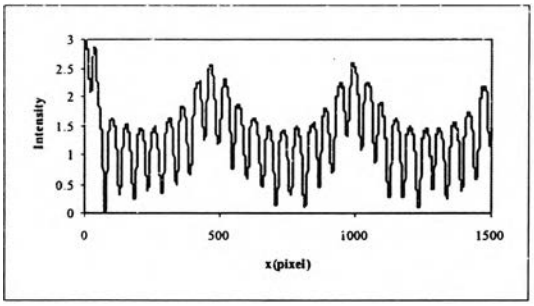
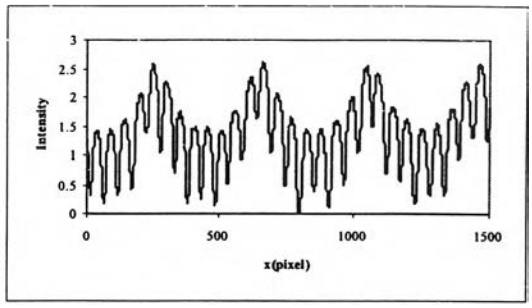
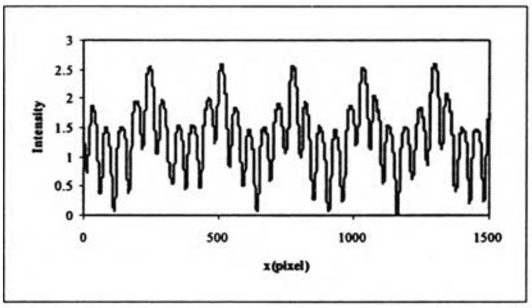


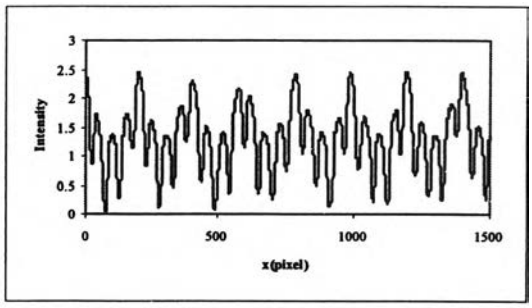
Figure 4.5 Traces of the contacted sinusoidal test pattern for the silk fabric C by the microdensitometer at the different applied spatial frequencies of (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.



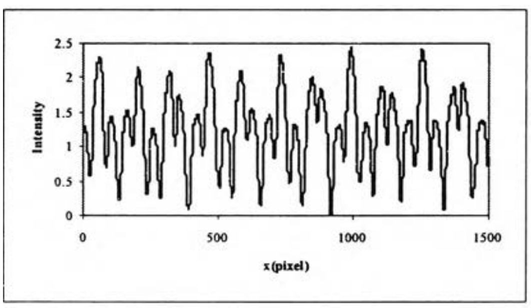


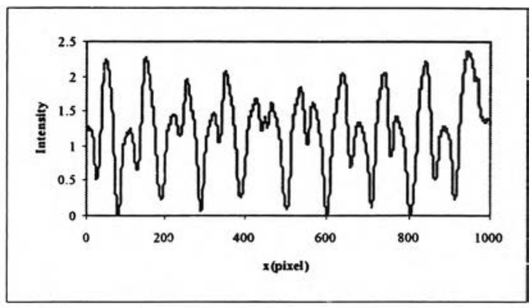
(a) (b)



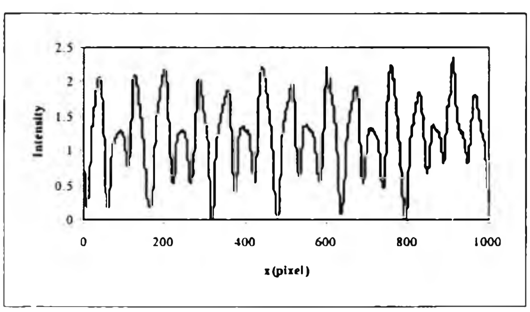


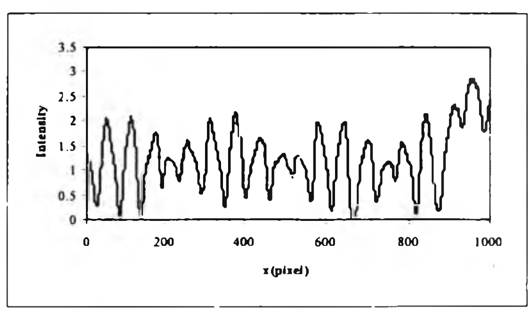
(c) (d)





(e) (f)





(g) (h)

Figure 4.6 Traces of the contacted sinusoidal test pattern for the silk fabric D by the microdensitometer at the different applied spatial frequencies of (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

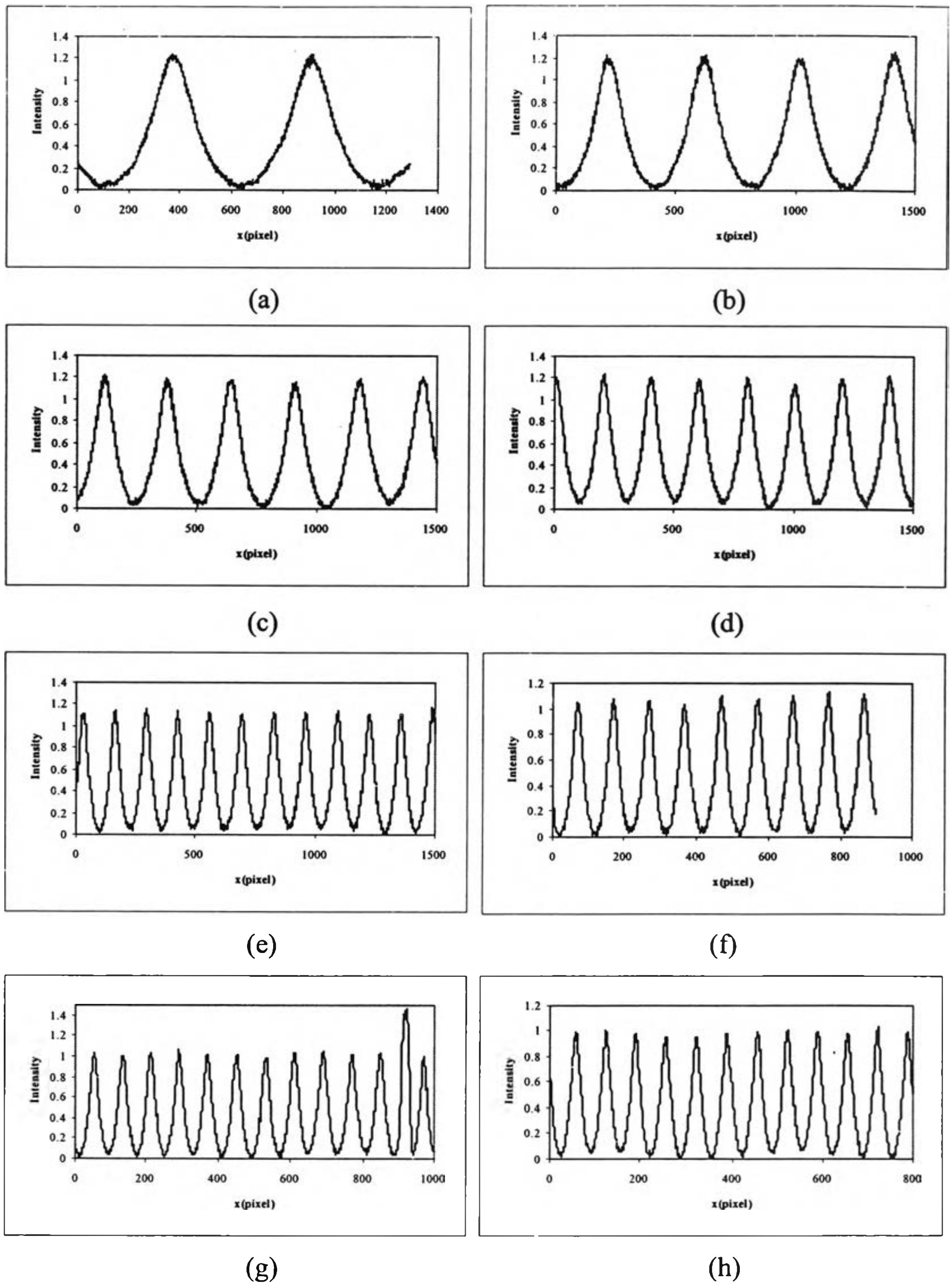
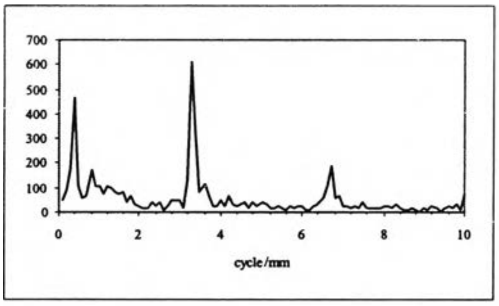


Figure 4.7 Traces of the contacted sinusoidal test pattern for the paper by the microdensitometer at the different applied spatial frequencies of (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

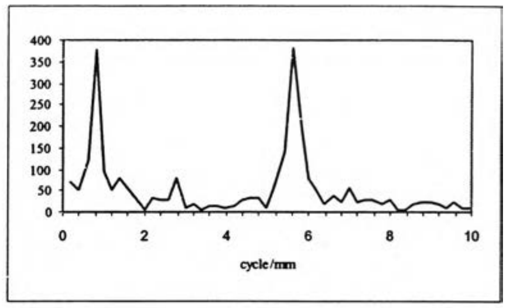
Figures 4.3 to 4.6 show the densities of the sinusoidal test pattern contacted on the silk fabric. Each frequency was normalized to the zero density. Figure 4.7 shows data of the sinusoidal test pattern contacted on an inkjet coated paper. Because the silk fabric has a rough surface, so an inkjet paper was selected as a reference for comparisons with the silk fabric. Each data contain two frequencies of interference. The high frequency is the characteristic of weave and the low frequency is the reflection density of sinusoidal test pattern contacted on the silk. Silks A, C and D have the similar pattern because they are the same plain weave, while the silk B is the twill style.

Considering the plain weave, the spectrum of output complex increases when the spatial frequency of sinusoidal test pattern increases because frequency of the weave is amplitudes of the sine curve interference. For the silk B, the increases in the spatial frequencies of twill weave have a little effect as similar to the result of the paper. The results of these experiments can be explained that each weft yarn typically passes over two and under two warp yarns. The frequencies of twill weave were less than the plain weave. The interference of the amplitude had a little effect on the silk.

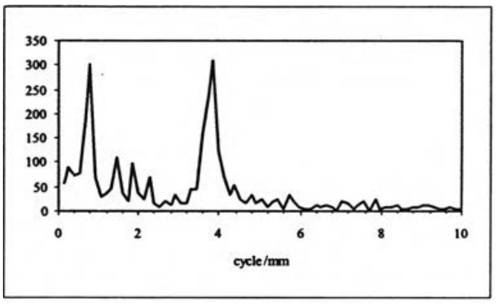
4.3.2 Fast Fourier Transforms (FFT)



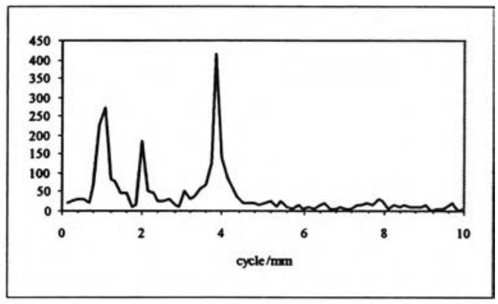
(a)



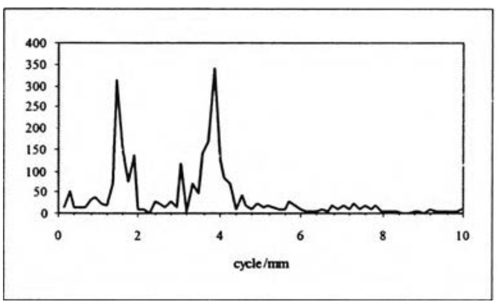
(b)



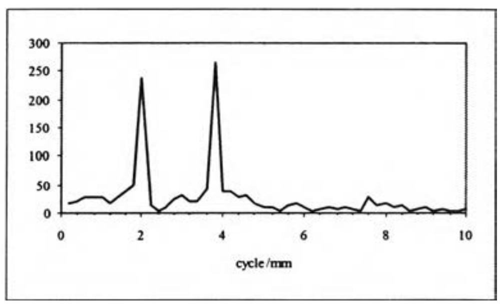
(c)



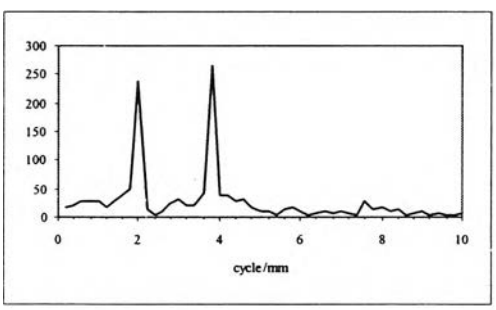
(d)



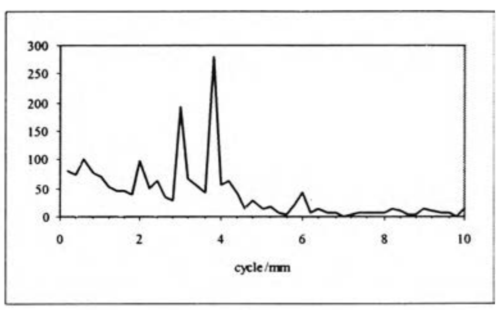
(e)



(f)



(g)



(h)

Figure 4.8 Fourier spectrum of the test pattern on silk A at spatial frequencies (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

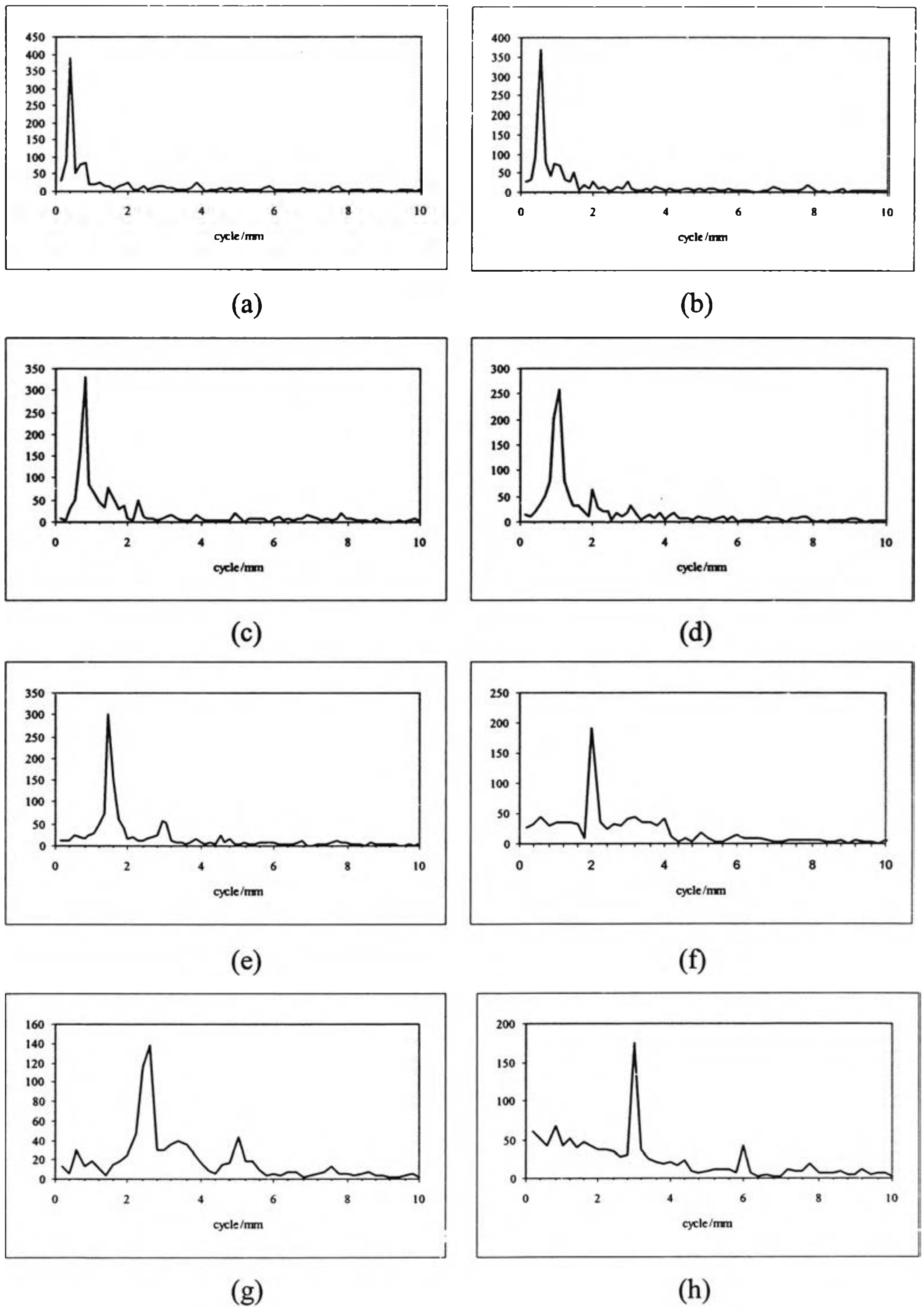


Figure 4.9 Fourier spectrum of the test pattern on silk B at spatial frequencies (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

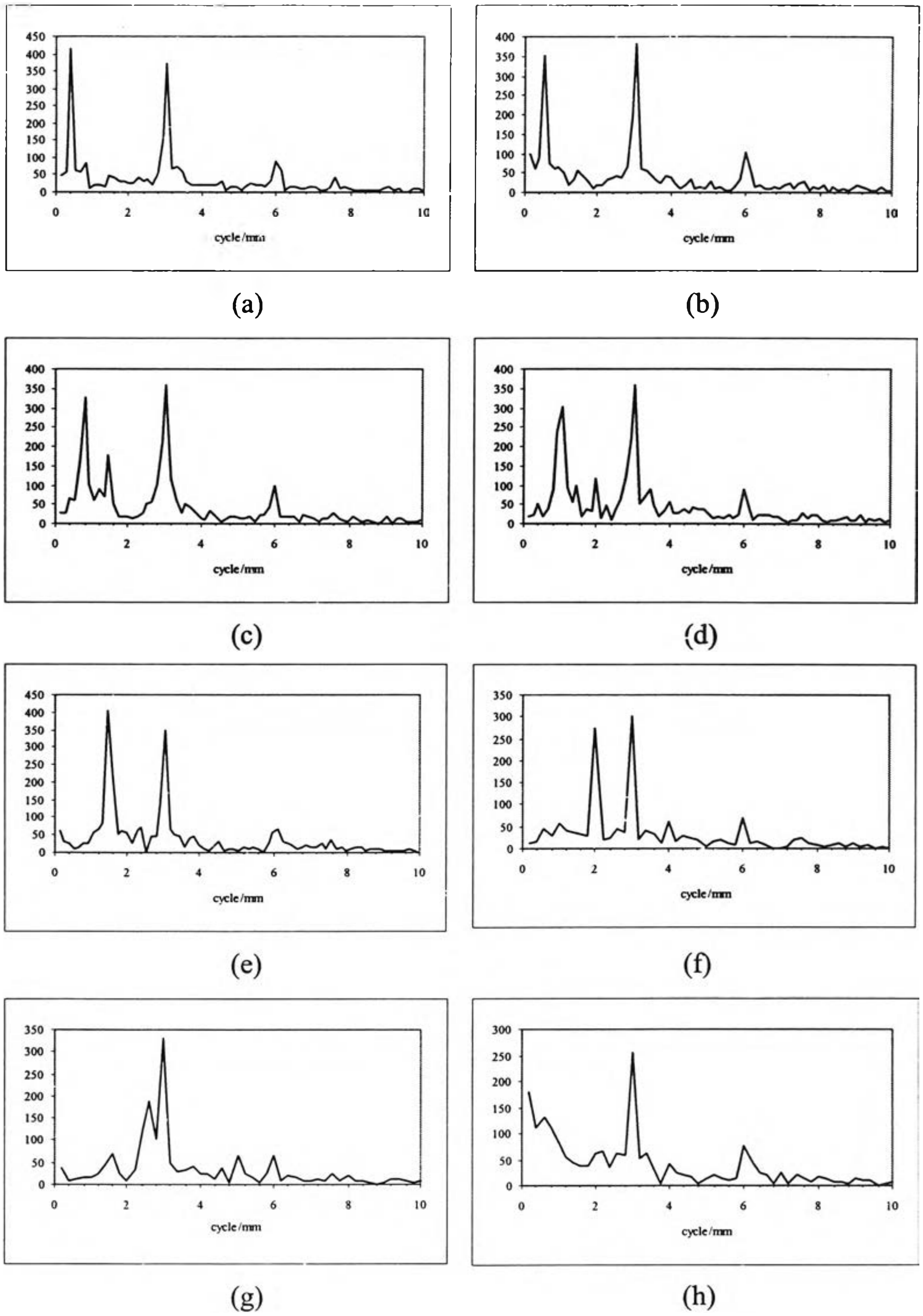
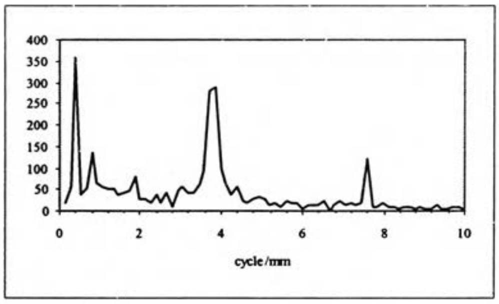
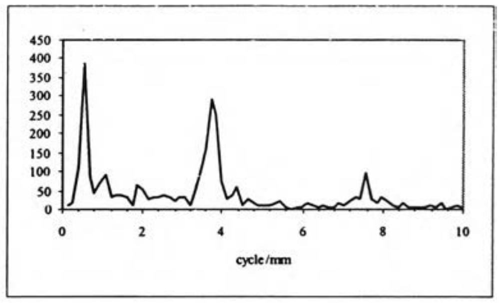


Figure 4.10 Fourier spectrum of the test pattern on silk C at spatial frequencies (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.



(a)



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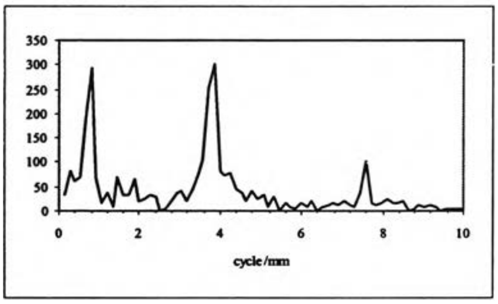

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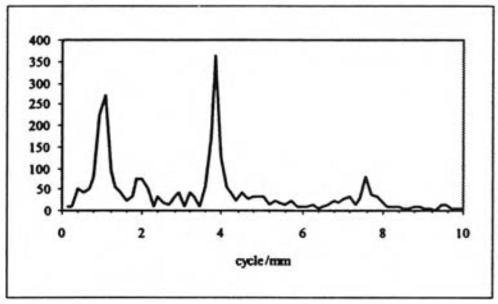
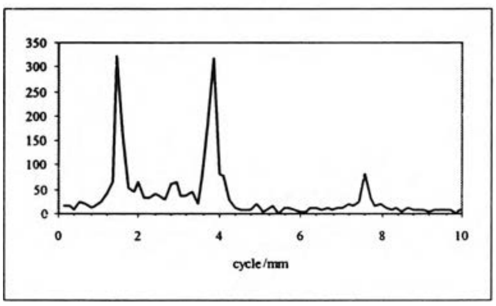
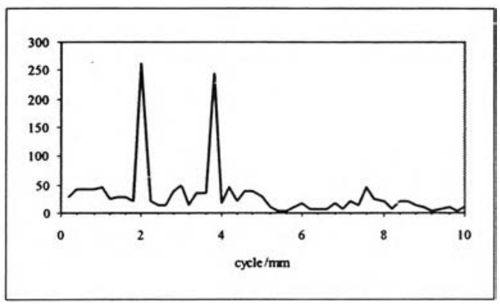


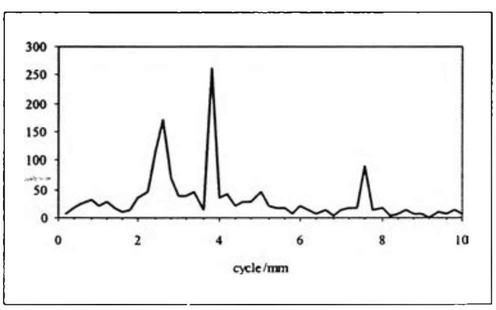
(d)



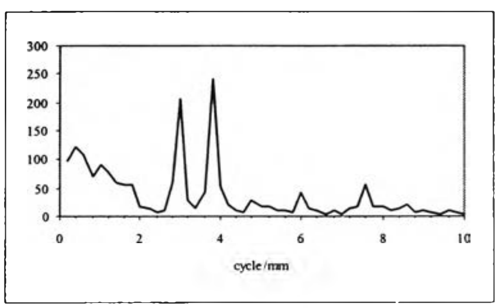
(e)



(f)



(g)



(h)

Figure 4.11 Fourier spectrum of the test pattern on silk D at spatial frequencies (a) 0.375, (b) 0.5, (c) 0.75, (d) 1.0, (e) 1.5, (f) 2.0, (g) 2.5, (h) 3.0 cycles/mm.

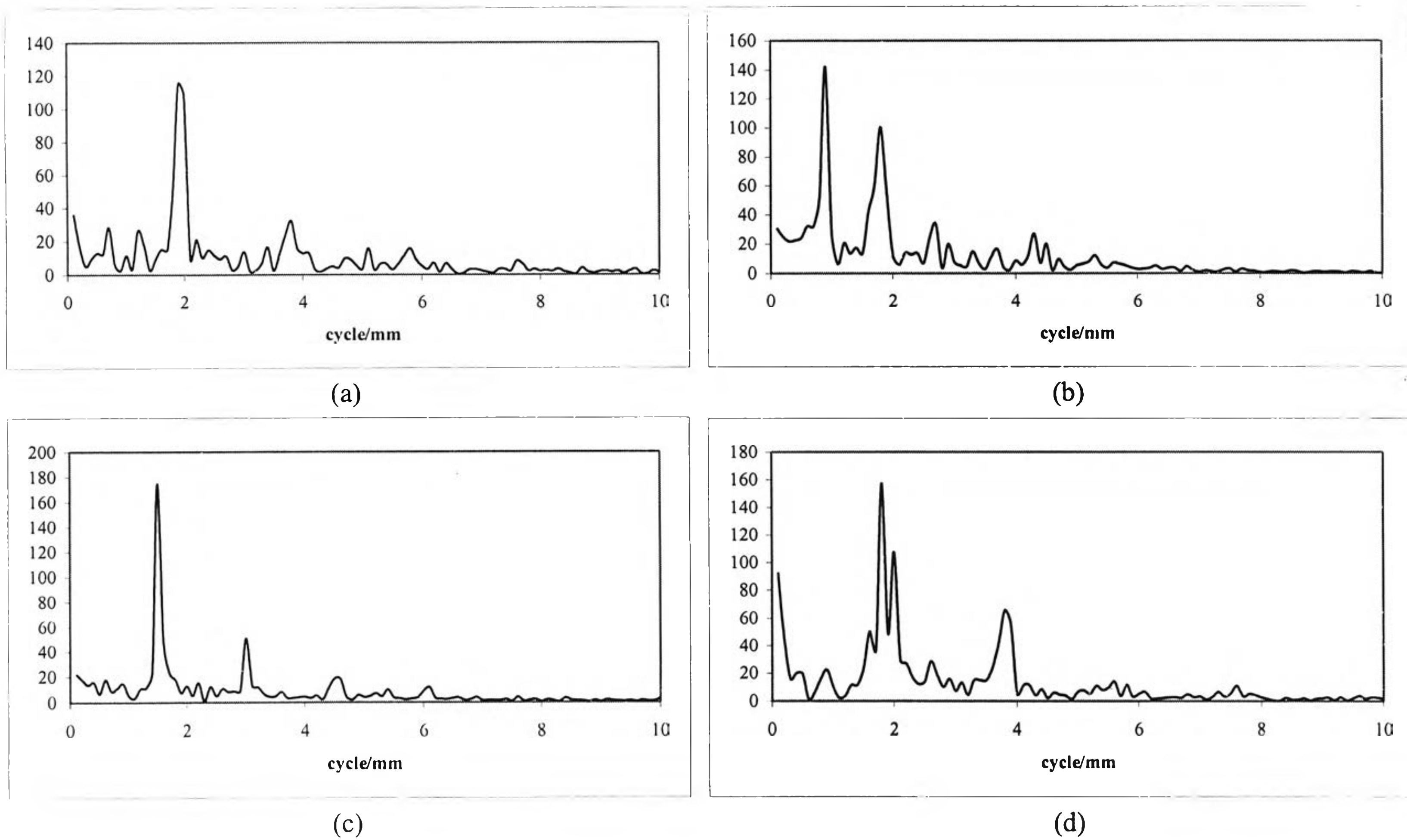
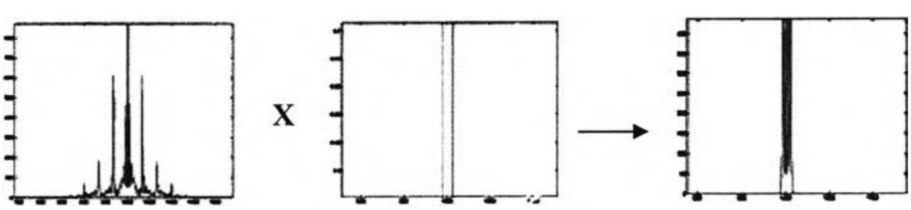


Figure 4.12 Fourier spectra of the reflectance of (a) silk A, (b) silk B, (c) silk C, and (d) silk D

The FFT can analyze and separate the signals of the filtering data. Figures 4.8 to 4.12 illustrate the analyzed data of the reflection by the FFT technique. Figures 4.8(a) to 4.8(h) illustrate the spectrum of signals at the peaks approximately at 0.375, 0.5, 0.75, 1.0, 1.5, 2.0, 2.5, and 3.0 cycles/mm. They have the similar frequency of sinusoidal test pattern. Each figure has the peak appeared at about 4 cycles/mm. Figure 4.12(a) shows the characterization of weave of silk A. It has a peak displayed at 4 cycles/mm as well, since this peak is the characteristic frequency of the silk fabric. As expected, Figure 4.8(b) does not have the peak shown at 4 cycles/mm but the peak was shifted to 5.7 cycles/mm. This case may be caused by the direction of the silk fabric on the trace. Figures 4.9 to 4.11 give the similar results with silk A in that each spectrum of the signal shows the peak of spatial frequency of the sinusoidal test pattern. This peak does not exist in the FFT of the silk fabric (Figures 4.12(a)-(d)).

We realized the importance of the peaks at the low frequency side; thus, the low-pass filtering technique is well suited to calculation. The noise should be eliminated from the measurement for this step of experiment. The figure 4.13 shows resulting of low pass filter.



Frequency Domain   Low-pass filter   Low frequency

Figure 4.13 Resulting of low-pass filter

A filter was used to cut off all high frequency components of the Fourier transform spectrum at a distance greater than a specified distance D_0 from the origin of the transform, the form of this filter is thus given by the following expression:

$$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \le D_0 \\ 0 & \text{if } D(u,v) \ge D_0 \end{cases} \tag{4.1}$$

where D_0 is any specified non-negative quantity, and D(u, v) is the distance from point (u, v) to the center of the frequency rectangle.

The cut off frequency was forwardly transformed. The results of applying low-pass filters are exactly the reflection density of silk fabric by taking the inverse Fourier Transform of the product *H(u, v)*. The all steps can be short concluding in figure 4.14.

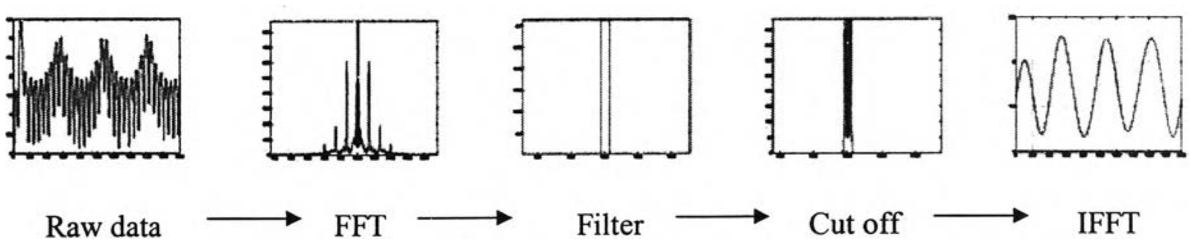


Figure 4.14 Steps of low-pass filter

4.3.3 CTF of Silks Fabric

The Contrast Transfer Function (CTF) can be calculated from this reflection density. The contrast c(ω) is given by the difference in the maximum and minimum intensities as shown in Table 4.4.

Table 4.4 CTF of the four silk fabrics.

Spatial Frequencies	CTF (C_{ω}/C_0)			
	Silk A	**Silk B**	**Silk C**	**Silk D**
0.375	1	1	1	1
0.5	0.9751	0.9192	0.9418	0.9764
0.75	0.9438	0.8938	0.8890	0.7909
1.0	0.8107	0.8468	0.7650	0.8843
1.5	0.7931	0.8129	0.7145	0.8306
2.0	0.7492	0.7097	0.6882	0.8177
2.5	0.5239	0.6717	0.6637	0.6965
3.0	0.4782	0.4946	0.4939	0.6390

4.3.4 MTF of the Silk Fabrics

Finally, the MTF of silk fabrics can be obtained by the CTF given in Eq.3.3 as shown in Table 4.5.

Table 4.5 MTF of the four silk fabrics.

Spatial Frequencies	MTF(2CTF_{silk}-1)			
	Silk A	Silk B	Silk C	Silk D
0.375	1	1	1	1
0.5	0.9502	0.8384	0.8836	0.9528
0.75	0.8876	0.7876	0.7780	0.5818
1.0	0.6214	0.6928	0.5300	0.7686
1.5	0.5826	0.6258	0.4308	0.6612
2.0	0.4984	0.4149	0.3764	0.6354
2.5	0.0478	0.3434	0.3274	0.3930
3.0	-0.0437	-0.0108	-0.0122	0.2780

The data of Table 4.6 were plotted in the MTF curve. In other words, the coefficient d was calculated by:

$$MTF_{(\varpi)} = \frac{1}{\left[1+(2\pi d\varpi)^2\right]^{\frac{3}{2}}} \tag{4.2}$$

Figures 4.13 to 4.16 were plotted to compare the MTF of each spatial frequency. The coefficient d was calculated to be 0.0783, 0.0712, 0.0873, and 0.0604 for the silks A, B, C and D. respectively.

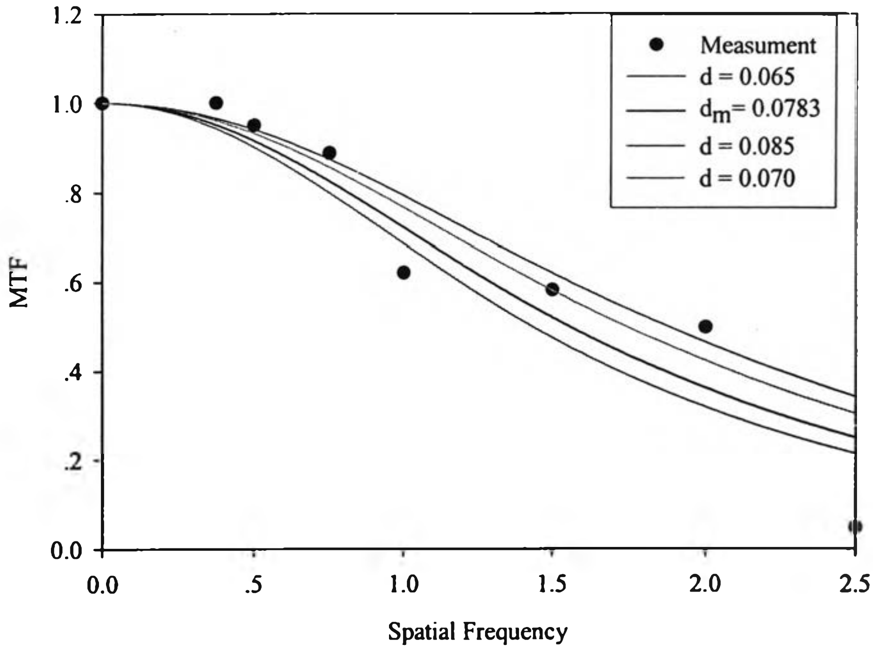


Figure 4.13 The MTF of silk fabric A.

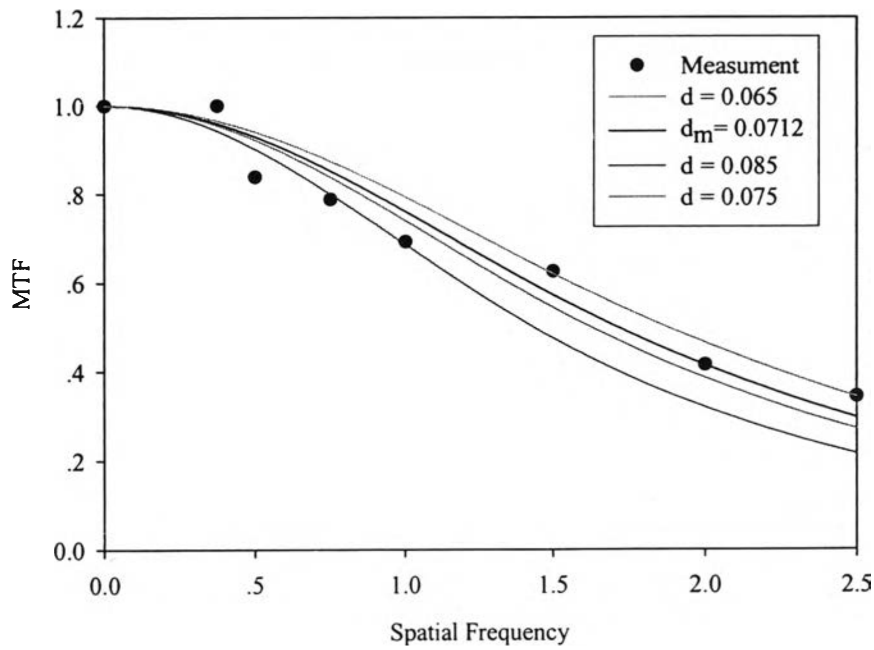
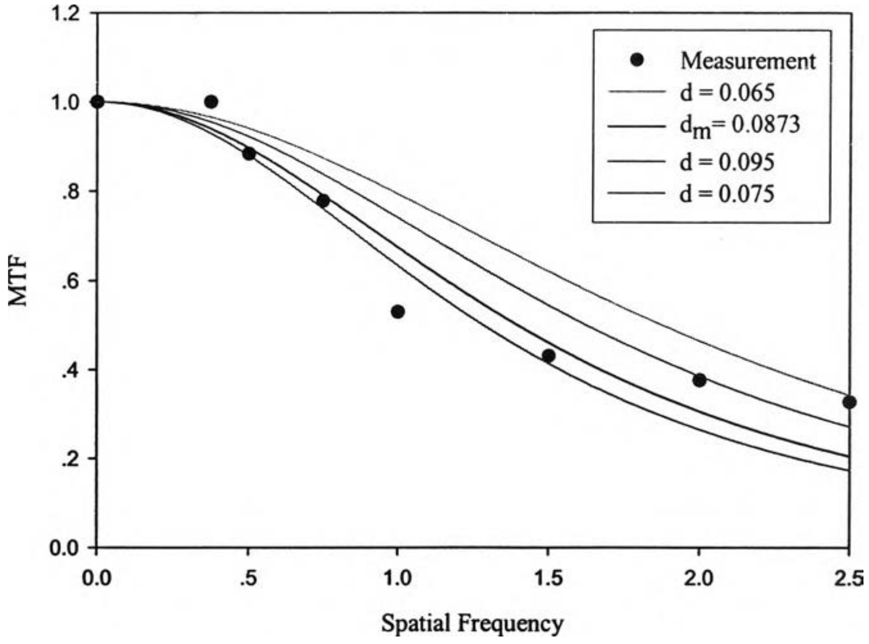


Figure 4.14 The MTF of silk fabric B.



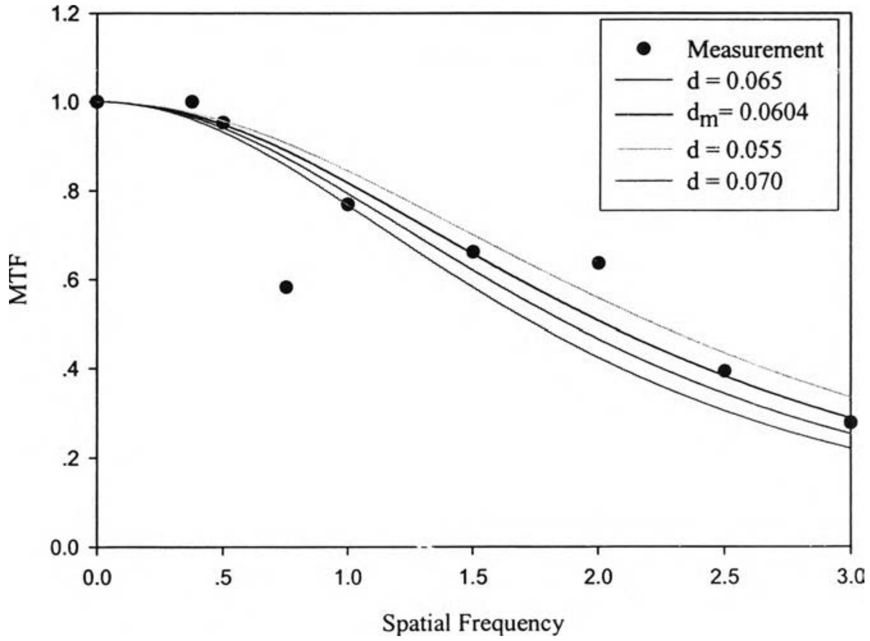


Figure 4.16 The MTF of silk fabric D.

From the result of MTF, Silk A, B, C, and D are 0.0738, 0.0712, 0.0873, and 0.0604 respectively. Silk D has the smallest d value, i.e. it has a good quality in sharpness because the light scattering in this silk fabric is lowest.

The result indicated that the measurement of MTF of silk fabric using contact sinusoidal method can be used to find the PSF of silk fabrics, however only 45/0 degree is measured. The 45° beam of the microdensitometer is made annular to minimize the effects of any texture pattern that might be embossed on the sample surface. [19] Unfortunately, 45° beam have effect to shadows because the rough surface of silk fabrics but we assumed to noise.

4.4 Point Spread Function Model (PSF)

Normally, the d value is the coefficient of the empirical function of MTF, which corresponds to the Point Spread Function (PSF) [10]:

$$h(r) = \frac{1}{2\pi k^2} e^{\frac{-r}{k}} \tag{4.2}$$

From MTF data at 4.3 can be calculated to PSF that shown in the figure 4.17.

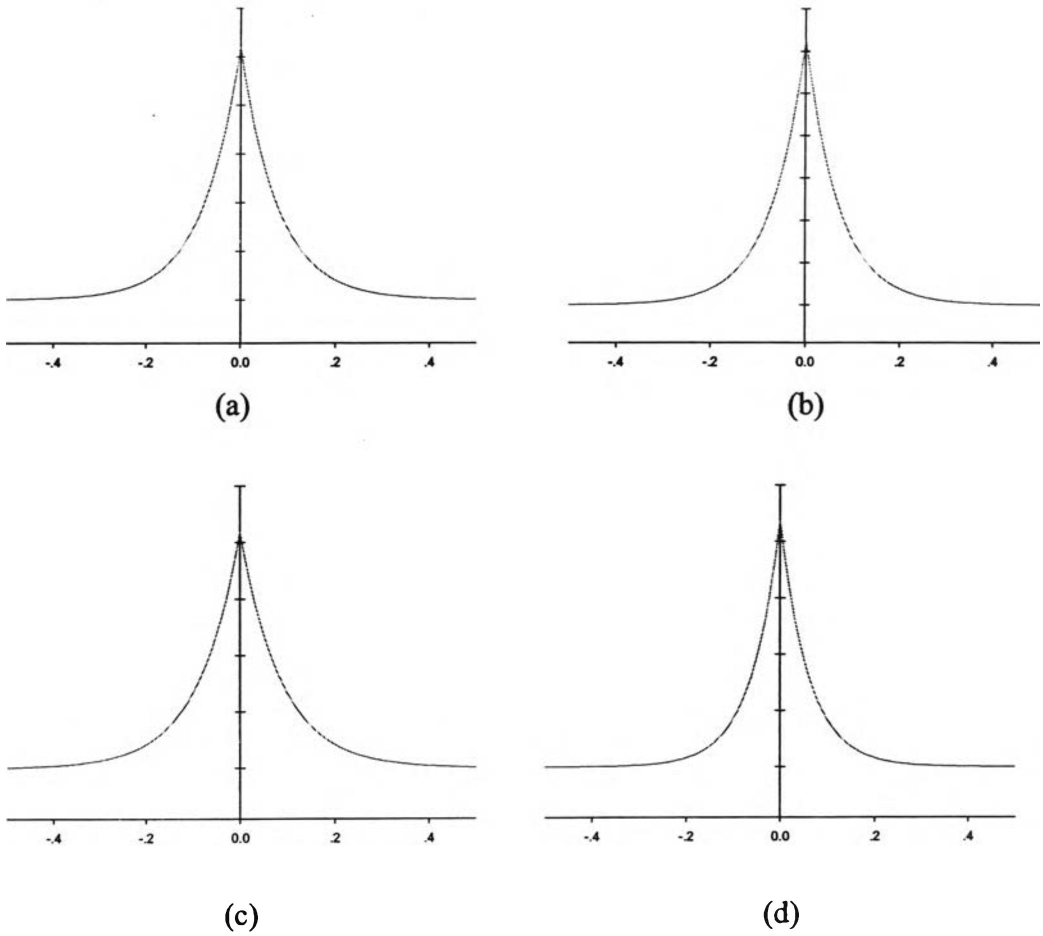


Figure 4.17 Point Spread Function of Silk Fabrics (a) Silk A, (b) Silk B, (c) Silk C and (d) Silk D.

The PSF describes light scattering in silk that could be explained by the diagram in Figure 4.18.

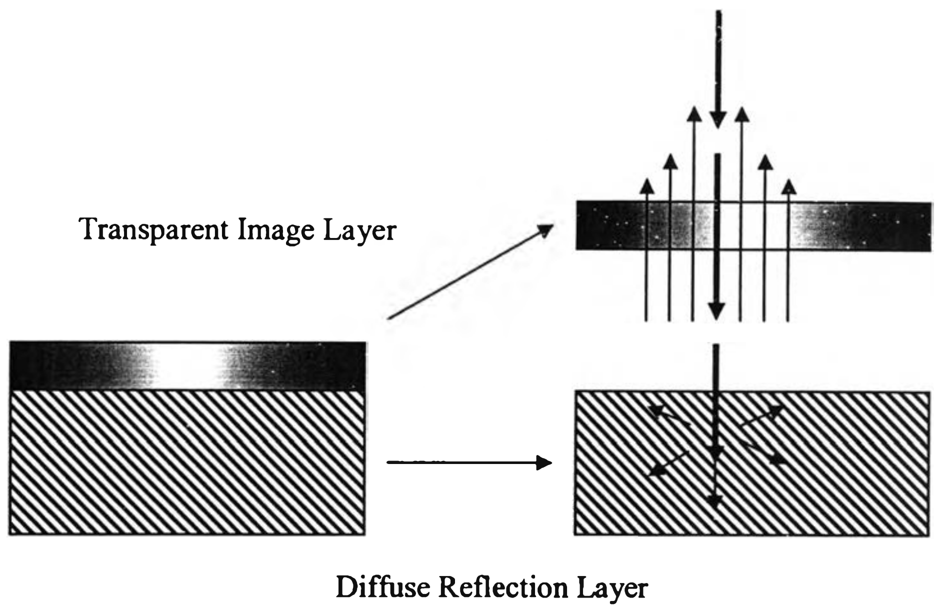


Figure 4.18 Diagram of reflection image model

As shown in Figure 4.18, the light projected to the transparent image layer was absorbed and transmitted to the layer. The light is then scattered in the diffuse reflection layer, which is the silk in the present case. This phenomenon is represented as the MTF of the diffuse reflection layer. Finally, the scattered and reflected light in the diffuse reflection layer is absorbed in the transparent image layer again.

It means the light scatting of the silk D has the smallest that it has a good quality on sharpness more than the other.

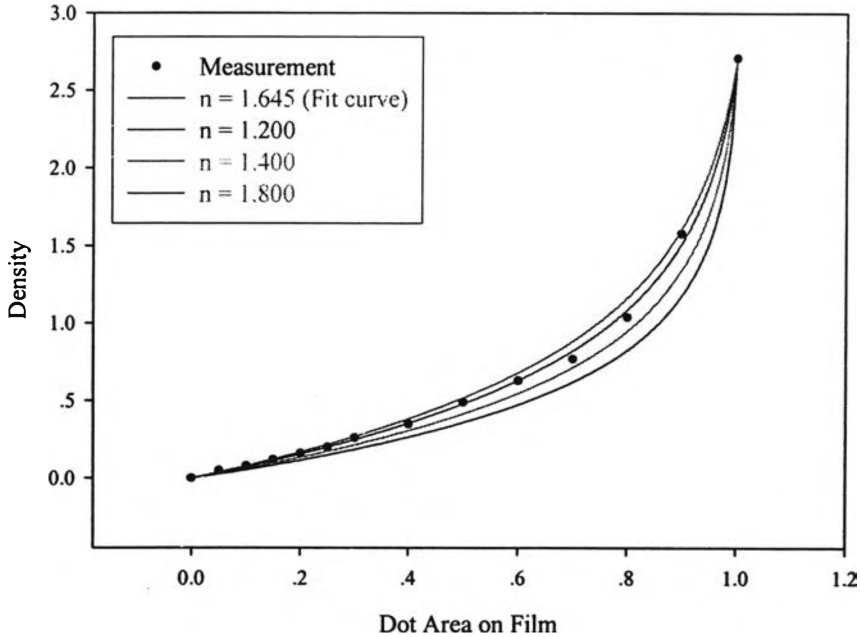
4.5 Measurement of n-value from the Yule-Nielsen Effect

To confirm the experimental result, the film with the dot areas from 0 to 100 % was contacted on the four silks for measuring the fabric dot gains. The densities measured are shown in Table 4.6.

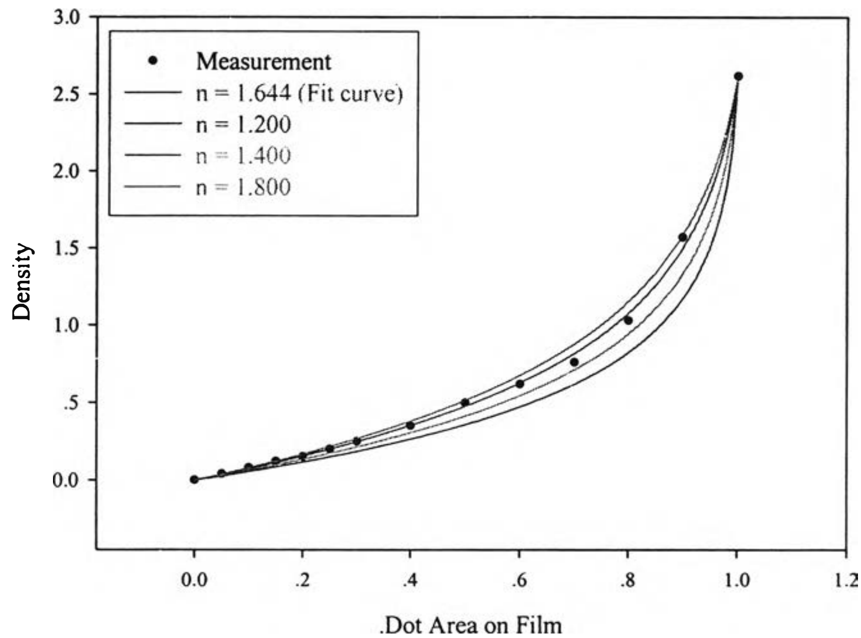
Table 4.6 Densities of the film and the contacted film on the four silk fabrics.

Dot area	Film	A	B	C	D
0	1.06	1.57	1.68	1.79	1.63
5	1.10	1.62	1.72	1.84	1.68
10	1.13	1.65	1.76	1.87	1.71
15	1.16	1.69	1.80	1.90	1.74
20	1.20	1.73	1.83	1.95	1.78
25	1.24	1.77	1.88	1.99	1.82
30	1.29	1.83	1.93	2.05	1.88
40	1.38	1.92	2.03	2.16	1.97
50	1.51	2.06	2.18	2.30	2.12
60	1.64	2.20	2.30	2.42	2.25
70	1.79	2.34	2.44	2.57	2.39
80	2.06	2.61	2.71	2.83	2.67
90	2.61	3.15	3.25	3.37	3.21
100	4.60	4.28	4.30	4.34	4.32

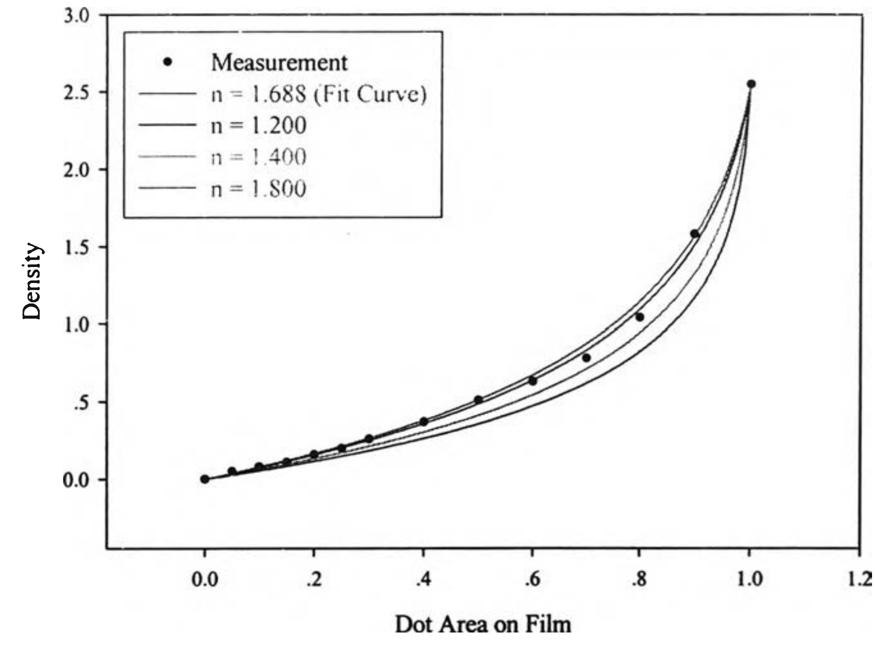
The values presented are the average of the three measurements.


Measurement
n = 1.645 (Fit curve)
n = 1.200
n = 1.400
n = 1.800
Density
Dot Area on Film
3.0
2.5
2.0
1.5
1.0
.5
0.0
0.0
.2
.4
.6
.8
1.0
1.2

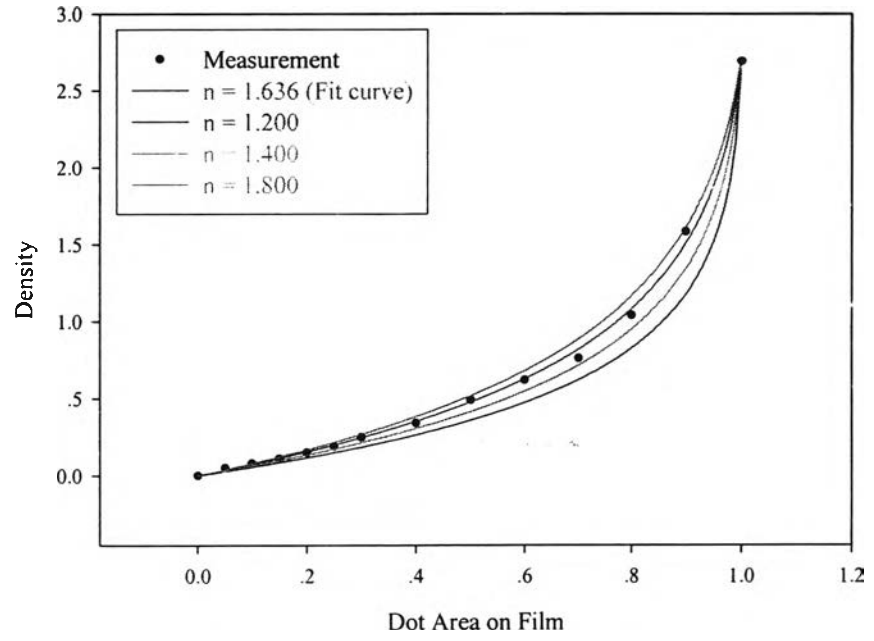
(a)


Measurement
n = 1.644 (Fit curve)
n = 1.200
n = 1.400
n = 1.800
Density
.Dot Area on Film
3.0
2.5
2.0
1.5
1.0
.5
0.0
0.0
.2
.4
.6
.8
1.0
1.2

(b)



(c)



(d)

Figure 4.18 The relationships between dot area on the film and the density of contacted film on silk (a) silk A (b) silk B (c) silk C (d) silk D calculated by Yule-Nielsen equation

This data were transferred to the normalized value that was later plotted between the dot area on the film and the density of the contacted film on silk. Yule-Nielsen result was compared with the experiment result. The n-factors obtained by the following equation of Yule-Nielsen model were adjusted to fit the experimental curve.

$$D = -n\log\left\{1 - A\left[1 - 10^{-D_s/n}\right]\right\}$$

Normally, Yule-Nielsen model shows the relationship of scattering of light. Light that enters the silk fabric scatters before it strikes the observer's eye. The n-value of Yule-Nielsen equation relates with light scattering that was assumed to be the sharpness of printed fabrics.

From Figures 4.18, n-values of silk A, B, C and D were 1.645, 1.644, 1.688 and 1.636, respectively. Silk C gives the highest n-value, which indicates that light scattering is higher than other silks. In other words, the lowest n-value denotes the good sharpness of substrate; so silk D is sharper than the silks B, A, and C, respectively.