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Mechanical and Surface Properties of Thai Cotton Hand-woven Fabric Made from Hand-spun and Machine-spun Yarns

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Abstract

In some areas in Thailand, women weave fabrics from hand-spun cotton as a cottage industry. Cotton hand-spun yarn has an uneven thickness and low twist that can give a unique appearance to the fabric and is not considered a defect. In this study, we measured the characteristic mechanical and surface properties of 16 Thai fabric samples, and divided them into six groups. The effect of using hand-spun yarn as the weft of a fabric was considered. The Kawabata evaluation system was used to compare the characteristic values with reference values to inform the future direction of hand-spun woven textiles in Thailand. The results show the differences between the characteristic values of warp and weft direction are important for tensile and bending properties and for surface roughness. Using hand-spun yarn in the weft direction of the woven fabric affected the surface irregularity, producing more space between yarns, affecting the air resistance value, which was in the reference range for summer suiting materials, although the thickness was larger. There were large differences between the six groups of fabrics varied in yarn count and cover factor, especially in the bending, shear, and compression properties. All characteristic values compared with the reference values show that most of the Thai handloom-woven fabrics surveyed in this study showed stiffness, crispness, and anti-drape values that were not suitable for suiting. However, Thai hand-loom woven fabrics would be suitable for summer jackets and ladies skirt with anti-drape silhouette for hot summer.

Keywords: Hand-spun yarn; Cotton yarn; Handloom woven fabric; Mechanical properties; Surface properties

Introduction

In rural Thailand, in addition to agriculture, women engage in handloom weaving as a cottage industry. In some areas that produce cotton fabric, the process includes cultivating cotton, hand-spinning, dyeing and then hand-weaving. Cotton hand-spun yarn has uneven thickness and twist that can give a unique appearance to the fabric, which conventional fancy yarn cannot reproduce. The advantage of handloom weaving is that many types of hand-spun yarns can be handled to produce a unique woven fabric. However, the handloom woven fabric must be suitable for the end use.

The fabric quality can be considered from three points of view: the suitability of its physical properties for the end use; the aesthetic appeal of the fabric, which attracts consumers; and how kind the product and process is to humans and the environment. We expected handwoven village fabrics to have different properties and uniqueness from regular, machine-woven fabrics.

In fabric manufacturing, yarn imperfections (neps, thick and thin places) affect fabric weavability and thickness variation [1,2]. Therefore, the causes of yarn imperfections from raw materials and yarn processing, and their prevention have been studied in many countries [3-5]. In synthetic fibers, thick and thin yarns, and irregular cross sections have been used to change the fabric hand. The yarn structure obtained from different spinning systems affects the tactile properties, even if the fabric is produced with the same knitted structure [6]. The imperfections in the fabric surface of hand-spun woven fabric have aesthetic value and are not considered defects or an indication of low-quality. A few studies have examined the hand-spun woven textile design process considering the mechanical and surface properties of the fabric. For example, the quality of shawls made from hand-spun and machine-spun yarns were compared to develop the production process for fine pashmina fibers [7,8].

Textile properties are controlled by a combination of yarn structure and fabric structure to produce an end product that is suitable for its intended use. In this study, fabric samples produced by handloom weaving were collected in Thai villages. The mechanical and surface properties were measured with the Kawabata evaluation system (KES) to obtain the characteristic values. The effect of using hand-spun yarn as the weft yarn on the mechanical and surface properties of the fabric was considered. All characteristic values obtained by KES were compared with the reference values reported in the literature, particularly for high-quality hand and for garment appearance, to guide the future direction of hand-spun woven textiles in Thailand.

Materials and Methods

Samples

Sixteen cotton Thai handloom woven fabrics were collected in Thailand. All warp yarns were spun by a spinning machine. For the weft yarns, either hand-spun or machine-spun imitations of hand-spun cotton yarns were used. All fabrics were woven with a plain structure and finished. They were categorized by their yarn count and the cover factor of weft yarns into six groups (Tables 1 and 2). The warp yarn count was in the range of 23.14 to 34.74 tex, and the weft yarn count was much larger than the warp yarn count (Table 2).

Characterization of physical properties

The physical properties of fabrics were measured at 20 °C and 65% relative humidity by using a KES (KES-FB, Kato Tech Co., Ltd.). The mechanical properties, including tensile, shear, bending,

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Range of weft cover factor*	Range of weft yarn count (tex)		
	S (80–110 tex)	M (140-170 tex)	L (210-250 tex)
Loose (11.0–12.5)	1, 2, 3	7, 8	12, 13
Tight (13.5–15.0)	4, 5, 6	9, 10,11	14, 15, 16

*Cover factor: (threads/inch)/√cotton count.

Table 1: Sample numbers of the six categories.

Group	No.	Yarn	Yarn count (tex)		Yarn density (/cm)		Cover factor	Weight (g/m²)	Thickness (mm)	Air Resistance (kPa.s/m)
		Weft	Warp	Weft	Ends	Picks	Weft			
S-loose	1	Hand-spun	14.50 × 2	85.59	16.95	12.28	11.87	170.0	1.024	0.11
	2	Machine-spun	15.54 × 2	82.02	17.45	12.21	11.56	194.5	1.12	0.22
	3	Hand-spun	15.18 × 2	84.36	12.76	13.03	12.51	174.3	1.078	0.13
S-tight	4	Hand-spun	14.91 × 2	109.36	16.55	13.56	14.82	214.0	1.159	0.24
	5	Machine-spun	14.82 × 2	85.59	13.18	14.97	14.47	240.3	1.262	0.41
	6	Machine-spun	15.58 × 2	84.36	16.97	15.38	14.76	215.3	1.103	0.37
M-loose	7	Hand-spun	16.68 × 2	144.03	19.53	8.97	11.25	216.0	1.612	0.11
	8	Hand-spun	11.95 × 2	159.61	19.72	8.62	11.39	205.3	1.221	0.11
M-tight	9	Machine-spun	14.84 × 2	151.42	14.49	10.82	13.92	234.5	1.275	0.30
	10	Hand-spun	11.57 × 2	168.73	19.22	10.27	13.95	235.3	1.243	0.16
	11	Hand-spun	34.53	168.73	14.91	10.30	13.98	287.5	1.685	0.22
L-loose	12	Machine-spun	26.25	210.91	23.29	7.68	11.66	253.5	1.82	0.18
	13	Hand-spun	30.44	246.06	9.91	7.18	11.77	229.0	2.122	0.12
L-tight	14	Hand-spun	16.36 × 2	203.63	18.94	10.01	14.92	290.3	2.011	0.16
	15	Hand-spun	30.44	246.06	8.94	8.81	14.44	267.0	2.155	0.40
	16	Hand-spun	34.74	236.2, 140.6	16.47	9.84	13.87	259.0	1.819	0.32

Table 2: Sample specifications.

compression, surface properties of the fabrics were measured under the standard measuring conditions [9]. The air resistance was measured by using KES-F8API air permeability tester [10]. The characteristic values and KES testers are listed in Table 3. For hand-spun yarns, yarn thickness variation was observed. Yarn diameter and twist angle were measured in 30-cm-long samples by using a 3D microscope (VR-3000, Keyence).

The primary hand value (HV) was rated to evaluate the suitability of the fabric for men's summer suits and women's medium-thick fabrics, calculated by using the Kawabata hand evaluation equations KN101-S and KN-201-MDY [9]. KN101-S was derived based on fabric mechanical data, mainly for wool materials, and KN-201-MDY includes various materials to construct the predictive equation.

Results and Discussion

Mechanical and surface properties

The difference between the characteristic values of warp and weft direction was profound for tensile and bending properties and surface roughness (SMD). Figure 1 shows the fabric extension at 500 N/m (EM) for both warp (EM1) and weft (EM2) directions for each sample. The EM1 values were two to eight times higher than the EM2 values for all fabrics. For wool fabrics for men's suits, the EM2/EM1 values are between 2 and 3 [11]. EM1 for the S-loose and L-loose groups (Table 1) increased with the increase in weft yarn count, whereas it did not for the M-loose group. When the thick hand-spun yarns were used for the weft direction, the yarn crimp ratio of the warp yarn was higher than that of the weft crimp ratio. The higher crimp of the warp yarn and weft cover factor affected EM1. The high EM1 value for cotton fabrics is usually accompanied by low tensile resilience of warp direction (RT1) as shown in Figure 2.

In Figure 3, the bending rigidity along the warp (B1) and weft (B2) directions are shown. B2 is larger than B1 for all samples, especially for samples with thick weft yarns (sample Nos. 13-15).

SMD of the warp direction (SMD1) is also much larger than that of weft direction (SMD2; Figure 4). When hand-spun yarns were used as the weft yarn with a larger yarn count, the SMD increased more when the sensor moved over thick weft yarns compared with industrial warp yarns.

Fabric surface appearance

When hand-spun yarns are used for fabric, thick and thin parts of the yarn appeared randomly in the fabric surface (Figure 5). Hand-spun yarns inserted in the weft direction were not as even as machine spun warp yarns. This is also why the SMD values for the fabric warp direction were large (Figure 4). For the coefficient of friction (MIU) and mean deviation of MIU (MMD), the difference between the warp and weft directions was small.

Figures 6 and 7 show the distributions of the yarn diameter and twist angle of samples from the six groups, measured by a 3D microscope, respectively. The coefficient of variance(C.V) of these parameters is also shown in figures. Samples No. 13 and 15, which had a higher yarn count, showed more variation in the diameter of thick and thin places than samples No. 1 and 4. However, the distribution of the yarn twist angles did not vary much among samples. The hand spinning process to make these yarns seemed to vary among individuals. Drafting is the part of the spinning process in which a bundle of fiber to be spun is pulled. The more fibers that are drafted, the thicker the yarn will be and vice versa. This is the most important process for controlling the regularity of the yarn thickness. After drafting a certain length, the yarn is held and the other hand turns the wheel to twist the yarn an exact number of times to obtain a consistent twist. Where the yarn is thicker, the twist angle is slightly lower than where the yarn is thinner.

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Properties	Parameters symbol	Characteristic value	Unit	KES machines
Tensile	EM	Fabric extension at 500 N/m width	%	KES-FB1
	LT	Linearity of load-extension curve	-	
	WT	Tensile energy	J/m²	
	RT	Tensile resilience	%	
Bending	B	Bending rigidity	μNm	KES-FB2
	2HB	Hysteresis of bending moment	mN	
Shear	G	Shearing stiffness	N/m	KES-FB1
	2HG	Hysteresis of shear force at a shear angle of 0.5°	N/m	
	2HG5	Hysteresis of shear force at at a shear angle of 5°	N/m	
Compression	LC	Leariry of compression-thickness curve	-	KES-G5
	WC	Compression energy	J/m²	
	RC	Compression resilience	%	
Surface	MIU	Coefficient of friction	-	KES-SE-STP
	MMD	Mean deviation of MIU	-	
	SMD	Geometrical roughness	μm	KES-SE
Air Resistance	R	Air resistance	kPa.s/m	KES-F8-AP1
Construction	T	Fabric thickness at 50 Pa	mm	
	W	Fabric weight per unit area	g/m²	

Table 3: Physical properties of fabrics measured with the KES system

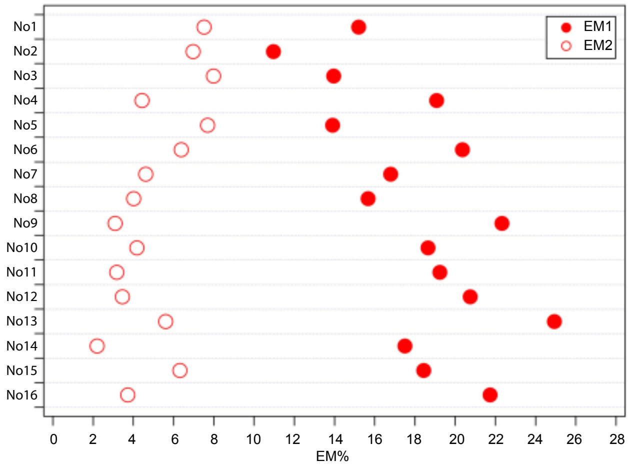

Figure 1: EM1 and EM2 for all samples.

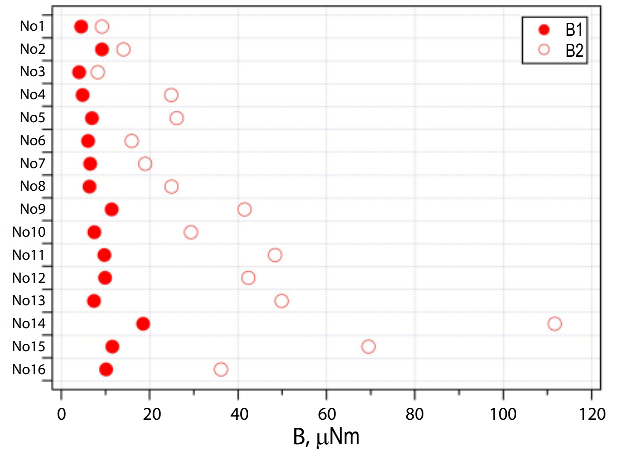

Figure 3: B1 and B2 for all samples.

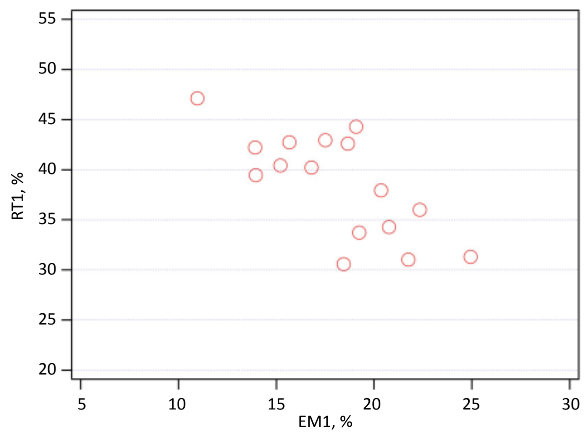

Figure 2: RT1 as a function of EM1.

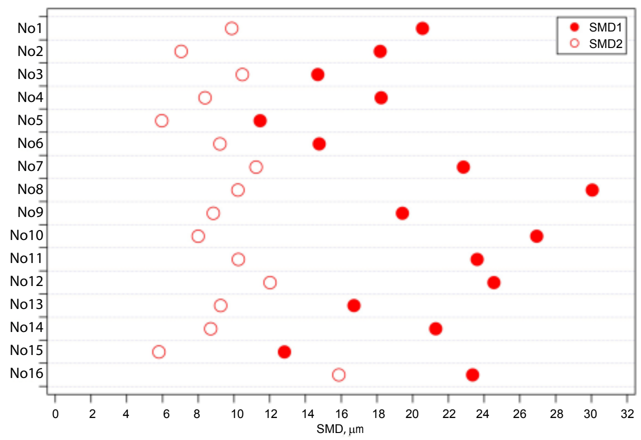

Figure 4: SMD1 and SMD2 for all samples.

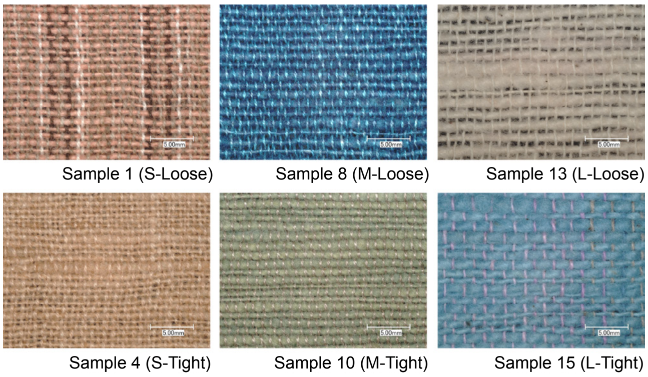

Figure 5: Microscope images of the fabric surface.

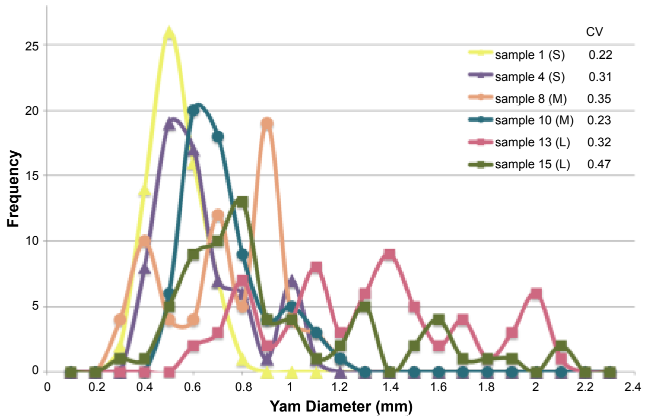

Figure 6: Distribution of yarn diameter measured in 3D microscope images.

To determine the effect on fabric appearance of the difference between hand-spun yarn and machine-spun imitations of hand-spun yarn, fabric samples No. 4 and 5 were compared. These two fabrics had a similar weave density and weft cover factor (Table 2). Figure 8 shows weft yarns taken from samples No. 4 and 5. The hand-spun yarn from sample No. 4 showed spindle-shaped thick places. The machine-spun yarn taken from sample No. 5 had a more regular crimp. This result is also consistent with EM1 being larger than EM2 (Figure 1).

3D microscope images of the fabric surface of samples No. 4 and 5 are shown in Figure 9 and photographs of the samples on a light box are shown in Figure 10. Sample No. 4 shows space between the yarns in Figure 9 and has clearer horizontal and vertical organization that corresponds to the thick weft yarns in Figure 10. The air resistance (R) of sample No. 5 is larger than sample No. 4 (Table 2).

Future end-use applications of Thai handloom woven fabrics

The mechanical and surface properties were compared with reference values for men's suit fabric. Kawabata and Niwa developed a data chart to indicate targets for developing fabrics [9]. The mechanical and surface properties of one sample from each of the six groups are plotted in a HESC chart for men's summer suiting in Figure 11. The shaded zone in this chart is the excellent zone in which high-quality fabrics fall [9].

For all fabrics, the properties outside of the excellent zone are tensile resilience (RT), bending hysteresis (2HB), shear hysteresis (2HG), compression energy (WC), mean deviation of MIU (MMD),

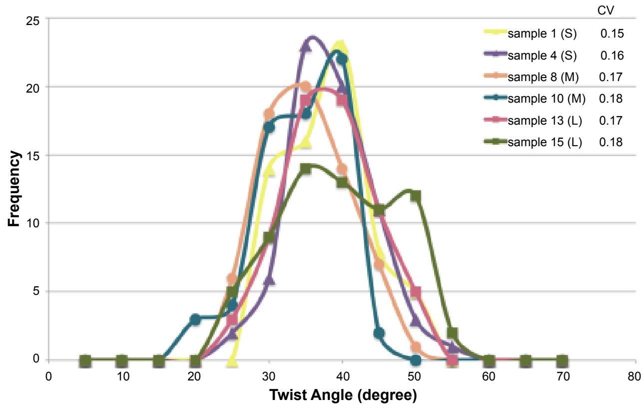

Figure 7: Distribution of yarn twist angle measured in 3D microscope images.

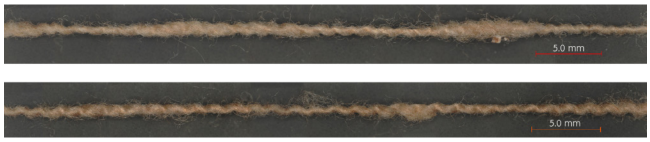

Figure 8: Microscopic images of the hand-spun yarn taken from sample No. 4 (109.3 tex) and the machine-spun yarn taken from sample No. 5 (85.6 tex) using a 3D microscope.

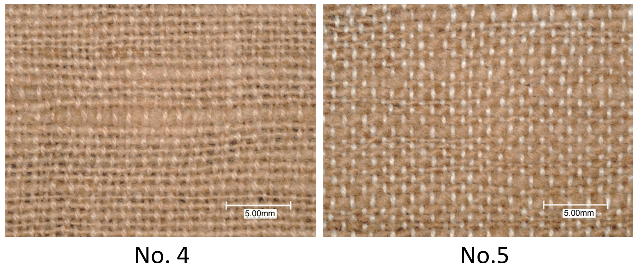

Figure 9: 3D microscope images of samples No. 4 and 5.

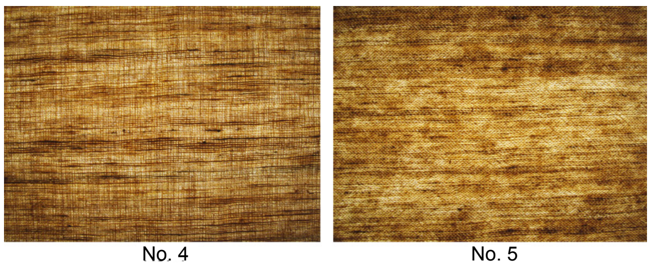

Figure 10: Light box images of samples No. 4 and 5.

and thickness. The Thai cotton handloom woven fabrics surveyed in this study were thick and stiff, which are not suitable properties for suit materials. In Figure 12, the thickness of the fabric samples is plotted against air resistance (R). The mean and standard deviation of reference values for men's summer and winter suiting and women's suiting are also shown [12]. The thickness of Thai handloom woven fabrics is large, although the R values are in the same range as summer suiting materials.

There are large differences between the six groups of fabric in terms of yarn count and cover factor, and particularly in bending, shear, and compression properties. Thai woven fabrics with a lower yarn

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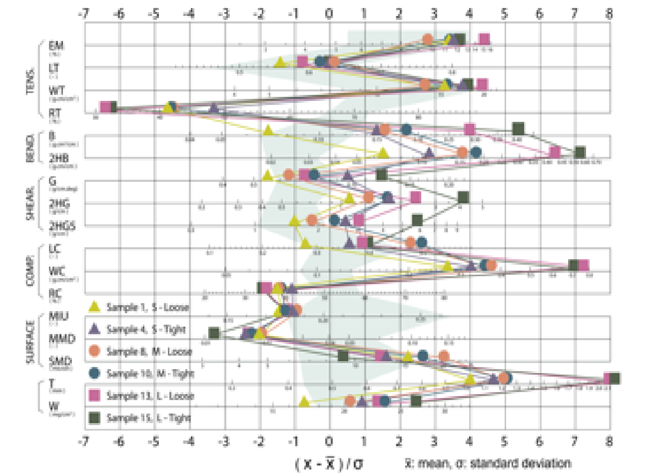

Figure 11: Comparison of mechanical and surface properties of samples from the six groups based on the HESC chart for men's summer suiting. The shaded zone in this chart is the excellent zone in which high-quality fabrics fall.

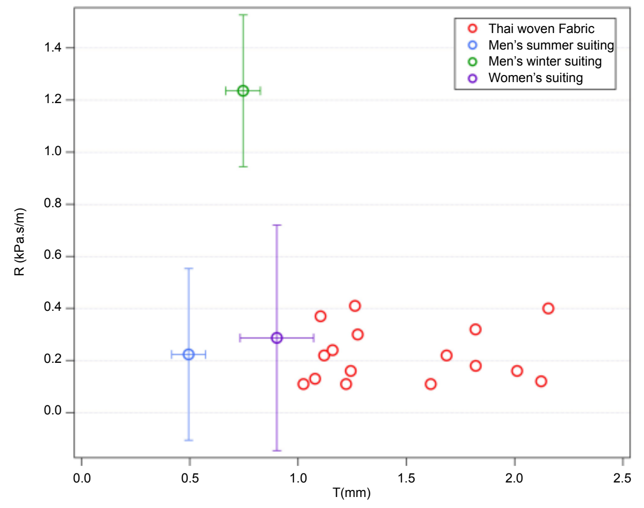

Figure 12: Plot R against fabric thickness.

count and cover factor had a lower bending rigidity (B) and bending hysteresis (2HB), as seen in sample No. 1 (S-loose group) in Figure 11. Thus, woven fabric with a high yarn density and thick hand-spun yarn increased B and 2HB. All fabrics in groups S-loose, M-loose, L-loose (No. 1, 8, and 13) had lower shearing stiffness (G), because the crossing point of the warp and weft moved easily. Compression energy (WC) of all hand-spun woven fabrics had a larger value than that of the high-quality zone of commercial fabrics. The fabrics woven with a larger weft yarn count had higher WC values than fabrics with a smaller yarn count. This was attributed to the thick yarn having a lower twist number, which made the fabric fluffy and soft. However, EM was slightly higher and RT was much lower than the high-quality zone, and thus fiber slippage was possible. This was also because of the properties of cotton fibers. The surface properties MIU and MMD were similar for the six groups.

HV was calculated by using Kawabata hand evaluations KN101-S for men's summer suiting and KN-201-MDY for women's medium-thick fabric. The calculated HVs, such as stiffness (*koshi*), crispness (*shari*), anti-drape (*hari*), fullness (*furukami*), smoothness (*numeri*), and softness (*sofutosa*) are listed in Tables 4 and 5.

HVs of stiffness, crispness, and anti-drape for most of the fabrics were above 5, particularly for the L-tight, L-loose, M-tight fabrics, which mean that the stiffness, crispness, and anti-drape values of these fabrics were too high for men's summer suiting, except for the S-loose fabric. These fabrics had medium stiffness values for women's medium-thick fabric, except L-tight and M-tight fabrics, and L-tight and M-tight fabrics had a low softness, which is not suitable for women's medium-thick fabric.

One of the end-use application for Thai handloom woven fabrics could be casual summer jackets. In this case, weft yarn count must be in the range of 80-170 tex and with low cover factor to satisfy the clothing requirement. The other application is used for lady's dress and skirts. Niwa reported the silhouette design for lady's garments based on the fabric mechanical properties which concerns fabric weight and bending properties [13,14]. We think Thai handloom woven fabrics has the bending properties to generate the silhouette like an anti-drape (hari-type) to forms a skirt with space between fabrics and the body.

Group	Sample No.	Koshi (Stiffness)	Shari (Crispness)	Hari (Anti-drape)	Fukurami (Fullness and softness)
S-loose	1	2.95	5.30	3.52	4.84
	2	5.04	5.99	5.51	5.12
	3	2.17	4.15	2.85	5.81
S-tight	4	6.06	6.63	6.46	4.69
	5	5.65	4.96	5.49	5.12
	6	4.80	5.51	4.93	4.72
M-loose	7	4.55	6.33	5.58	5.00
	8	5.63	7.58	6.52	4.54
M-tight	9	8.30	7.81	8.78	3.76
	10	6.53	7.67	7.37	4.78
	11	8.67	8.48	10.17	4.79
L-loose	12	7.40	7.65	8.69	4.67
	13	7.54	6.55	8.91	4.97
L-tight	14	11.54	9.33	12.80	3.78
	15	9.20	6.27	10.54	5.11
	16	8.12	7.99	8.29	4.75

Table 4: HV calculated by Kawabata hand evaluation KN101-S to characterize the fabrics for men's summer suiting.

In making the garment construction, the warp and weft directions of fabric had better to be considered because of their large different extensibility of fabric.

Conclusion

The mechanical and surface properties of Thai hand-woven fabrics made from hand-spun and machine-spun cotton yarns were investigated. For all fabrics, the warp yarns were machine spun and the weft yarns were hand-spun. The difference between the fabric characteristic values of the warp and weft directions was large for tensile and bending properties and surface roughness (SMD) measured by the KES system.

Using hand-spun yarn in the weft direction of the woven fabric affected the surface irregularity, producing more space between yarns and clear horizontal and vertical lines in the fabrics corresponding to the thick weft yarn compared with machine-spun imitations of hand-spun yarn.

Group	Sample No.	Koshi (Stiffness)	Numeri (Smoothness)	Fukurami (Fullness and softness)	Sofutosa (Softness)
S-loose	1	4.10	5.22	5.32	4.46
	2	5.31	6.00	6.16	4.84
	3	3.82	6.69	6.47	6.21
S-tight	4	5.69	4.87	5.48	3.59
	5	5.88	5.94	6.39	4.56
	6	5.16	5.68	5.98	4.43
M-loose	7	4.70	5.27	6.05	4.71
	8	5.24	4.69	5.19	4.05
M-tight	9	6.49	3.98	5.19	2.71
	10	5.65	4.74	5.25	4.00
	11	6.43	4.74	6.00	3.73
L-loose	12	5.78	5.10	6.26	4.37
	13	5.49	5.87	7.23	5.03
L-tight	14	7.88	3.70	5.87	1.59
	15	6.51	6.30	7.53	4.91
	16	6.43	5.04	6.19	3.12

Table 5: HV calculated by Kawabata hand evaluation KN-201-MDY to characterize the fabrics for women's medium-thick fabric.

The air resistance (R) values were similar to reference values for summer suiting materials even though the handwoven fabrics were thicker. There were large differences between the six groups of fabrics varied in the yarn count and cover factor, particularly in the bending, shear and compression properties. The fabrics with thinner yarn and looser weave had lower bending rigidity (B) and shearing stiffness (G) values. The tensile resilience (RT), bending hysteresis (2HB), shear hysteresis (2HG), compression energy (WC), mean deviation of MIU (MMD), and thickness of all the hand-spun woven fabrics were outside the excellent zone of commercial fabrics. Primary hand values (HV) of stiffness, crispness, and anti-drape were too high for most of the fabrics, and they are not suitable for suits. However, Thai hand-loom woven fabrics would be suitable for summer jackets and ladies skirt with anti-drape silhouette.

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