Application of Kawabata evaluation system for the tactile properties of woven silk fabrics in textile industry

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Abstract. Thailand is one of well-known countries for the silk fabric production. However, there are just few studies focusing on tactile properties of silk fabrics. This study collected forty-one machined-woven silk fabrics manufactured in Thailand, Japan, China, Korea, Italy, France, India and USA. The fabrics were classified into 4 groups categorized by the fabric weight according to the “silk fabric” industrial product standard of the Thai Industrial Standards Institute (TISI) 176-2540 (≤ 90 g/m², 91-120 g/m², 121-160 g/m², >160 g/m²). Mechanical properties of the silk fabrics were measured by the Kawabata evaluation system for fabric (KES-F). Correlations between fabric weight groups were analyzed to investigate the relationship among properties. The results showed significant effect of the fabric weight (per unit area) on only compression resilience (RC) and thickness. The thickness was also correlated with the compression properties (WC, RC), the bending rigidity (B) of the warp direction and the surface roughness (SMD). Moreover, the air permeability was associated with the coefficient of friction (MIU), the shearing properties (G, 2HG, 2HG5) and the tensile properties of the weft direction (EM, LT, WT). The total hand value (THV) was calculated by using the Kawabata hand evaluations KN-201-LDY for women’s thin dress fabric. The fabrics with the THV scores above 4 showed high quality for women’s dresses. The principal component analysis (PCA) was conducted to examine the relationship between the mechanical properties and the fabrics. The results showed that the high-quality fabrics were plotted near each other as a group and related to some properties such as the coefficient of friction (MIU), the extensibility (EM), the tensile energy (WT) of the weft direction and the linearity of compression (LC). Finally, the biplot graph of the fabric distribution can be a guideline for a variety of applications. The fabrics for apparels mainly located in the lower-left quadrant while those located in the upper quadrant were appropriate for home textiles.
1. Introduction

Thailand has been famous for producing silk with good quality. Thai silk is recognized as one of the symbols of Thailand by people from many nations especially USA, Japan, European countries and etc. The sensory attraction both visual and tactile influences consumers’ purchase decision. The sensory analysis is one of the methods suitable for assessing the tactile properties of fabrics [1-5]. Kawabata and Niwa developed a reliable instrument named Kawabata’s Hand Evaluation System for Fabric (KES-F) [6,7] with the aim of consuming less time and expenses than when using the sensory analysis. KES-F would conduct the fabric texture measurement, and, the results would be the substitute for human perception. This substitution reliability was confirmed by some research which examined the correlation between the textile perception measured by subjective and objective measurements [3, 8-10]. Since the KES-F had been generally utilized as a measurement in textile, this research studied the relation between the physical and the mechanical properties of silk fabrics by using KES-F and calculating Total hand value [6] in order to identify certain silk fabrics with qualities suitable for apparels or for other applications.

2. Experimental

This study collected 41 machine-woven silk fabrics from various leading sources of production (23 samples from Thailand, 5 samples from Japan, 5 samples from China, 3 samples from Korea, 2 samples from Italy, 1 sample from France, 1 sample from India and 1 sample from USA). The 41 silk fabrics were classified into 4 groups, according to the silk fabric industrial product standard of the Thai Industrial Standards Institute (TISI) 179-2540, which were categorized by the fabric weight per area unit. As shown in Table 1, Group A was consisted of 19 very thin samples (weight per area unit ≤ 90 g/m²). Group B contained 9 thin samples (weight per area unit = 91-120 g/m²). Group C stood for 7 thick samples (weight per area unit = 121-160 g/m²). Group D was of 6 very thick samples (weight per area unit >160 g/m²). The specification of samples is shown in Table 1.

The mechanical properties of fabrics were measured at 20°C and 65% relative humidity by using KES-F (Kato Tech Co., Ltd.). The mechanical properties were as follows. First, the tensile properties were consisted of the fabric extension at 500 N/m width (EM, %), the linearity of load-extension curve (LC), the tensile energy (WT, J/m²) and the tensile resilience (RT, %), which were tested by KES-FB1. Second, the bending properties were consisted of the bending rigidity (B, μNm) and the hysteresis of bending moment (2HB, mN), which were tested by KES-FB2. Third, the shear properties were consisted of the shearing stiffness (G, N/m), the hysteresis of shear force at a shear angle of 0.5° (2HG, N/m) and the hysteresis of shear force at a shear angle of 5° (2HG5, N/m), which were tested by KES-FB1. Fourth, the compression properties were consisted of the linearity of compression-thickness curve (LC), the compression energy (WC, J/m²) and the compression resilience (RC, %), which were tested by KES-FB3. The Last conditions were the surface properties consisted of the coefficient of friction (MIU), the mean deviation of MIU (MMD) and the geometrical roughness (SMD, μm), and tested by KES-FB4. The air permeability was measured by the air permeability tester following the method of ASTM D737. The qmax was measured by KES-F7.

The results were analyzed by using the correlation analysis with SPSS version 12.0 to see the correlations between the silk fabric weight, the thickness, the air permeability and all the mechanical property values from KES-F. To plot a graph exhibiting the relations between the silk fabric samples and the physical and the mechanical properties, Principal Component Analysis (PCA) was conducted by utilizing the XLSTAT-Sensory statistical software 2017 (Add in soft, New York, USA). After that, Total Hand Value (THV) and the Kawabata hand evaluation KN-201-LDY for women’s thin dress fabric played the role to evaluate propriety of certain silk fabrics which should be made thin dresses for women.

3. Results and discussion

According to the 41 silk fabrics, the qmax and the 5 mechanical properties (the tensile properties, the bending properties, the shear properties, the compression properties and the surface properties) were measured and analyzed by using the correlation analysis to find the correlations between the silk fabric
weight, the thickness and the air permeability. The results revealed that the silk fabric weight was significantly related only to the compression resilience (RC) and the thickness (P<0.05) (with Pearson’s correlation coefficients: \( r = -0.424 \) and -0.386). Moreover, the silk fabric thickness was significantly related to various mechanical properties: WC (0.708), RC (0.613), B-warp (0.600), HB-warp (0.540), SMD-warp (0.705) and SMD-weft (0.580) (P< 0.01). Meanwhile, the air permeability was significantly related to various mechanical properties: LC (0.558), MIU-warp (0.635), G-warp (-0.664), G-weft (-0.659), 2HG-warp (-0.553), 2HG-weft (-0.487), 2HG5-warp (-0.599), 2HG5-weft (-0.572), EM-weft (0.680), LT-warp (-0.604), LT-weft (-0.765), WT-weft (0.670) (P< 0.01).

### Table 1. Sample specifications of four categories of fabric weight

| Fabric Sample | Structure           | Made in  | Export to   | Weight (g/m²) | Thickness (mm) | Air permeability (cms/cm²/s) | THV    |
|---------------|---------------------|----------|-------------|---------------|----------------|-----------------------------|--------|
| A01           | Plain               | Japan    | Japan       | 18.71         | 0.20           | -                           | 3.261  |
| A02           | Plain               | Japan    | Japan       | 25.10         | 0.22           | -                           | 4.021  |
| A03           | Plain               | Japan    | Japan       | 37.41         | 0.11           | 88.73                       | 1.228  |
| A04           | Plain               | China    | USA         | 63.95         | 0.14           | 71.35                       | 3.698  |
| A05           | Plain               | Japan    | Japan       | 65.34         | 0.09           | 8.07                        | 2.709  |
| A06           | Twill 2x1           | Thailand | Japan       | 68.63         | 0.15           | 60.47                       | 4.486  |
| A07           | Plain               | Korea    | USA         | 69.76         | 0.17           | 56.67                       | 4.344  |
| A08           | Satin               | Japan    | Japan       | 69.80         | 0.09           | 56.67                       | 4.529  |
| A09           | Plain               | Thailand | Eastern Europe | 70.82      | 0.13           | 8.37                        | 3.991  |
| A10           | Plain               | China    | USA         | 73.37         | 0.14           | 25.77                       | 3.214  |
| A11           | Plain               | China    | USA         | 74.81         | 0.15           | 34.07                       | 3.452  |
| A12           | Plain               | China    | USA         | 75.07         | 0.16           | 8.03                        | 4.514  |
| A13           | Plain               | Thailand | Eastern Europe | 76.37     | 0.13           | 19.70                       | 3.577  |
| A14           | Plain               | Thailand | Eastern Europe | 78.53     | 0.15           | 7.44                        | 3.719  |
| A15           | Herringbone Twill   | France   | USA         | 79.84         | 0.15           | 8.62                        | 4.406  |
| A16           | Jacquard            | Thailand | Britain     | 80.03         | 0.13           | 49.20                       | 2.592  |
| A17           | Plain               | Korea    | USA         | 82.01         | 0.16           | 2.62                        | 3.594  |
| A18           | Plain               | Thailand | Eastern Europe | 88.16     | 0.14           | 0.93                        | 3.632  |
| A19           | Broken Twill        | Thailand | France      | 90.41         | 0.19           | 7.45                        | 4.147  |
| B01           | Plain               | Thailand | USA         | 94.93         | 0.21           | 8.00                        | 3.679  |
| B02           | Plain               | Thailand | Eastern Europe | 101.71   | 0.17           | 1.97                        | 4.169  |
| B03           | Twill 2x1           | Thailand | France      | 101.87        | 0.20           | 8.46                        | 3.805  |
| B04           | Plain               | Thailand | Eastern Europe | 103.47   | 0.17           | 1.46                        | 4.119  |
| B05           | Plain               | Italy    | USA         | 104.68        | 0.20           | 2.07                        | 2.592  |
| B06           | Plain               | China    | USA         | 104.78        | 0.27           | 66.17                       | 4.145  |
| B07           | Plain               | India    | USA         | 105.58        | 0.20           | 1.94                        | 3.731  |
| B08           | Plain               | Thailand | Eastern Europe | 106.65   | 0.23           | 6.24                        | 3.285  |
| B09           | Plain               | USA      | USA         | 109.18        | 0.20           | 2.24                        | 3.993  |
| C01           | Plain               | Thailand | Britain     | 127.27        | 0.17           | 1.70                        | 2.750  |
| C02           | Twill 2x1           | Thailand | Norway      | 129.37        | 0.32           | 35.97                       | 4.353  |
| C03           | Plain               | Thailand | Eastern Europe | 131.79   | 0.25           | 6.33                        | 2.376  |
| C04           | Twill 2x1           | Thailand | Eastern Europe | 135.30   | 0.23           | 2.00                        | 4.448  |
| C05           | Plain               | Thailand | Eastern Europe | 139.33   | 0.26           | 2.69                        | 2.979  |
| C06           | Twill 2x1           | Thailand | Eastern Europe | 139.80   | 0.24           | 7.76                        | 4.155  |
| C07           | Twill 2x1           | Thailand | Eastern Europe | 142.66   | 0.21           | 1.03                        | 4.580  |
| D01           | Plain               | Korea    | USA         | 173.41        | 0.39           | 57.34                       | 4.135  |
| D02           | Dobby               | Thailand | Hongkong    | 191.44        | 0.38           | 1.58                        | 3.654  |
| D03           | Twill 2x1           | Italy    | USA         | 229.84        | 0.42           | 55.90                       | 4.511  |
| D04           | Dobby               | Thailand | France      | 231.65        | 0.50           | 6.52                        | 3.829  |
| D05           | Plain               | Thailand | Canada      | 267.43        | 0.63           | 7.28                        | 3.993  |
| D06           | Plain               | Thailand | Eastern Europe | 366.95   | 0.79           | 9.07                        | 3.170  |
After analyzing by using Principal Component Analysis (PCA), it was shown in the biplot graph (Figure 1.) that the relations between the silk fabric weight and the mechanical properties were not strong. According to Dimension 2, most of the heaviest silk fabrics in Group C and Group D were plotted on the upper half of the graph, which showed the relations to the thickness, the compression properties, the bending properties and the surface roughness. Dimension 1 represented the silk fabrics with different the tensile properties, the shear possessions and the surface friction. Dimension 3 linked the tensile properties in warp direction and the surface roughness.

After calculating the mechanical property values to find Total Hand Value (THV) for thin dresses for women by using the Kawabata hand evaluation KN-201-LDY for women’s thin dress fabric, it was found that the silk fabrics with good quality (scored above 4) appropriate for being made dresses for women were the silk fabric A02, A06, A07, A08, A12, A15, A19, B02, B04, B06, C02, C04, C06, C07, D01 and D03. These fabrics with good quality were related to the MIU, EM, WT and LC values. Meanwhile, the thick and heavy silk fabrics plotted on the upper part or the right axis were related to the shear properties and suitable for home textiles.

![Figure 1. Biplot graph by using Principal Component Analysis indicating correlations between (A,B) the physical and the mechanical properties and (C,D) silk fabric samples categorized by silk weight.](image)

4. Conclusions
The association between the silk weight and the mechanical properties was not explicit. The thickness and the air permeability correlated with the mechanical properties. The thickness correlated with the compression properties, the bending properties of the warp direction and the surface roughness. The air permeability was associated with the surface friction, the shearing properties and the tensile properties of the weft direction. The mechanical properties can predict the quality of silk fabrics suitable for different usages.

5. References
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