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Evaluating Hand Properties of High Counts and High Density Fabrics

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Abstract

Fabric hand is defined as the human tactile sensory response towards fabric, which involves not only physical but also physiological, perceptional and social factors. Fabric hand is one of the most important characteristic of a fabric. This paper discusses the relationship between technical features of high counts and high density fabrics and their hand evaluation. 13 samples of high counts and high density fabrics were selected to be measured by the Kawabata Evaluation System (KES). The range of the mechanical properties of high counts and high density fabrics was given. Using factor analysis with quartimax rotation, 5 factors model was generated. The relationship between the 5 factors and the technical features was shown by using correlation analysis. The study in this paper can offer references for the quality control of high counts and high density fabric design.

Keywords: Fabric Hand Evaluation; KES; Factor Analysis; High Counts and High Density Fabrics

1 Introduction

The phenomenon of the fabric hand is one of the most significant characteristics in determining fabric marketing and in providing the fabric scope of end-uses, performance, and appearance. It is related to basic mechanical properties of fabrics and it expresses some apparent characters and internal quantities. Fabric hand usually means the tactile comfort when someone touches fabrics and it also contains visual sense comfort and audio sense comfort universally [1, 2].

Fabric hand could be evaluated subjectively and objectively. Since fabric hand mainly refers to tactile comfort, people judge fabrics by touching them naturally. However, many studies indicated that the subjective evaluation was not consistent in different countries and different culture [3, 4]. Subjective hand evaluation of the same fabric is usually different. As it is widely recognized that subjective techniques are unable to meet the requirements of a very diverse marketplace or to overcome the loss of expertise in assessing fabrics caused by the retirement of experienced employees. Peirce [5] started to measure fabric hand objectively in the 1920s. He identified fabric bending properties as key component of hand, or more correctly of fabric stiffness, and

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developed a number of tests to measure fabric rigidity in bending. Since the initial work of Peirce, a large number of individual instruments have been developed to measure a number of properties under the low stress conditions consistent with the measurement of hand [6]. The most influential system was the Kawabata Evaluation System (KES) designed by the Hand Evaluation and Standardization Committee (HESC). The first machines of KES was released in Japan in 1972 [7]. Later models, called the KES-FB series, were released in 1978 and were designed to reduce the time required for specimen preparation and testing [8]. By 1984, the system had been adopted in Japan and, to a lesser extent, worldwide. A series of formulas for the prediction of fabric Total Hand Value (THV) were also given by HESC. The KES system was made up by shear/tensile tester, bending tester, compression tester and surface tester, 17 mechanical properties (including fabric weight measured by balance) can be evaluated. This system has been used in extensive fields such as not only objective evaluation of fibers, yarns and fabrics, but also textiles and allied industries, paper industries, etc. [9]. In the 1990s, a new system called Fabric Assurance by Simple Test (FAST) was released in Australia. The concept of the two systems are both based on the determination of the mechanical response of fabrics to low stresses. The reason on designing this system is to enable the appropriate parameters to be measured as quickly as possible with high accuracy and good reproducibility [10]. A new instrument called PhabrOmeter was introduced by N.Pan in 2010, it can measured 7 aspects of fabric hand [3].

The KES was widely used in the world while the formulas given by HESC are scarcely used, it is because the THV predicted by these formulas were based on the subjective evaluation of Japanese scientists. Researchers analysis these mechanical properties measured by KES in different mathematical methods, such as factor analysis, regression analysis and neural network [11-14].

2 Materials and Measurements

2.1 Materials

High counts and high density fabrics were popular among consumers because of their good tactile comfort and silky feel. In order to study the relationship between the technical features and their hand evaluation, 13 samples were selected to be measured by the KES. The technical features of 13 samples were shown in Table 1. These samples were produced by LuThai Group, China and usually used for the production of high-grade shirt.

As shown in Table 1, the samples all belong to high counts and high density fabrics and are all plain woven fabric.

2.2 Measurements

Every sample was placed in a controlled room with a temperature of 20 ± 2 °C, a humidity of $65 \pm 3\%$ for 24 hours and measured for three times by the KES to make sure the consequences were reliable. As the measurement can cause damage to the fabric, we took the order of surface testing, compression testing, bending testing, tensile testing and shearing testing.

According to the 26 mechanical properties provided by the KES instruments, the maximum value, minimum value, mean value and standard deviations of mechanical properties of high

Table 1: Technical features of the 13 samples

Sample code	Yarn Materials	Warp density (D_{warp}) (10 cm^{-1})	Weft density (D_{weft}) (10 cm^{-1})
1	9.7tex C	531	433
2	9.7tex C	591	433
3	9.7tex C	630	433
4	9.7tex C	669	394
5	9.7tex C	709	354
6	9.7tex C	709	472
7	9.7tex C	709	394
8	4.9tex×2 C	709	394
9	8.3tex C	787	394
10	7.3tex C	866	394
11	6.5tex C	866	472
12	7.4tex ×2 C/P(60/40)	551	354
13	7.3tex ×2 C	551	354

counts and high density fabrics were shown in Table 2. The weight of these samples was not included as it is significantly related to the yarn materials.

As the samples selected in this study have a good assessment, Table 2 could be used as a standard range of the mechanical properties of high counts and high density fabrics. If the mechanical properties of a fabric were in this range, it could be regarded as a high quality fabric.

3 Analysis and Discussion

3.1 Factor Analysis Model

Factor analysis is a statistical technique to extract the common factor from a number of variables, the number of variables can be reduced, and the analysis of a difficult question can be conducted more easily. Using factor analysis, the characteristic value, the contribution rate and the cumulative contribution rate were generated and shown in Table 3. 5 factors were selected since the first 5 factors explained 86.883% of all mechanical properties measured by KES. All of the statistical analysis in this paper was carried out by using SPSS (Statistical Product and Service Solutions) 19.0.

In order to explore the relationship between the 26 indexes and the 5 factors, the component matrix was rotated and shown in Table 4. Because the unrotated component matrix cannot provide a clear structure of the latent pattern among the sensory perceptions, Quartimax rotation was used to improve the quality of classification [15]. The rotated component matrix described the proportion of each variable within each component in order to classify the variables. Percentage of variance of each factor to the total variance in the data was used as an indication of the contribution of each factor to overall hand evaluation.

Table 3 and Table 4 showed that the first factor Z1 was mainly determined by 2HB1, B1, RT1, WT1, LT1, LT2, 2HB2, B2, T_m and T_0. As these mechanical properties were directly related to

Table 2: Range of mechanical properties of high counts and high density fabrics

Index	Meanings	Max value	Min value	Mean value	Standard deviations
MIU1	Coefficient of friction	0.122	0.083	0.1022	0.01
MIU2		0.129	0.099	0.1105	0.0098
MMD1	Mean deviation of MIU	0.020	0.010	0.0143	0.003
MMD2		0.0175	0.0099	0.0131	0.002
SMD1	Geometric roughness, μm	3.271	1.404	2.3668	0.6375
SMD2		2.857	1.647	2.2715	0.3896
LC	Linearity	0.284	0.233	0.254	0.0137
WC	Compressional energy, gf $\cdot$ cm/cm^2	0.18	0.111	0.1382	0.0222
RC	Resilience, %	41.87	33.33	37.0438	2.9440
T_0	Thickness at 0.5 gf/cm^2, mm	0.496	0.345	0.4044	0.0479
T_m	Thickness at 50 gf/cm^2, mm	0.257	0.170	0.1983	0.0264
B1	Bending rigidity, gf $\cdot$ cm^2/cm	0.0722	0.0285	0.0469	0.0144
B2		0.0336	0.0185	0.0257	0.0049
2HB1	Hysteresis, gf $\cdot$ cm/cm	0.0551	0.0146	0.0281	0.0125
2HB2		0.023	0.012	0.0167	0.0032
G1	Shear stiffness gf/[cm(degree)]	1.03	0.42	0.7377	0.1737
G2		1.03	0.41	0.6792	0.1693
2HG1	hysteresis of shear force at 0.5 degree, gf/cm	1.16	0.54	0.8185	0.2159
2HG2		1.08	0.38	0.6808	0.2372
2HG51	hysteresis of shear force at 5 degrees, gf/cm	3.32	1.28	2.0908	0.4792
2HG52		3.35	0.83	1.9192	0.6032
LT1	Linearity	0.727	0.599	0.6772	0.0389
LT2		0.842	0.671	0.7668	0.0584
WT1	Tensile energy	16.1	3.68	10.1238	4.4497
WT2		19.63	7.18	12.3031	3.6435
RT1	Resilience, %	71.77	40.45	54.0315	10.3374
RT2		59.73	45.14	52.5938	4.5605

1 means warp, 2 means weft

the bending and flexible characters, Z1 could be named as ‘bending deformation factor’.

The second factor Z2 was mainly determined by 2HG51, 2HG1, 2HG2, 2HG51, G1, and MMD2. As these mechanical properties were directly related to the ability to resist shearing deformation, Z2 could be named as ‘shearing deformation factor’.

The third factor Z3 was mainly determined by LC, WC, WT2, and RT2. As these mechanical properties were directly related to the soft and fluffy characters, Z3 could be named as ‘compression resilience factor’.

The fourth factor Z4 was mainly determined by MMD1 and SMD1. As these mechanical properties were directly related to the warp friction and smooth of the surface, Z4 could be named as the ‘surface friction of warp factor’.

Table 3: The characteristic value and variance contribution

Factors	Initial characteristic value			Factors after rotation		
	Characteristic value	Contribution rate %	Cumulative contribution rate %	Characteristic value	Contribution rate %	Cumulative contribution rate %
1	8.999	32.140	32.140	Z1	29.886	29.886
2	8.298	29.635	61.775	Z2	22.710	52.596
3	3.537	12.632	74.407	Z3	15.298	67.893
4	2.517	8.990	83.397	Z4	10.844	78.737
5	1.283	4.581	87.978	Z5	8.146	86.883
6	1.121	4.003	91.981			
7	0.911	3.253	95.234			
8	0.576	2.056	97.290			
9	0.394	1.407	98.697			
10	0.170	0.606	99.303			
11	0.117	0.419	99.722			
12	0.078	0.278	100.000			
13	5.952E-16	2.126E-15	100.000			
14	4.456E-16	1.591E-15	100.000			
15	3.795E-16	1.355E-15	100.000			
16	3.348E-16	1.196E-15	100.000			
17	3.002E-16	1.072E-15	100.000			
18	2.115E-16	7.554E-16	100.000			
19	1.069E-16	3.817E-16	100.000			
20	3.426E-17	1.223E-16	100.000			
21	−8.654E-18	−3.091E-17	100.000			
22	−2.904E-17	−1.037E-16	100.000			
23	−8.455E-17	−3.020E-16	100.000			
24	−1.127E-16	−4.025E-16	100.000			
25	−2.122E-16	−7.580E-16	100.000			
26	−2.378E-16	−8.493E-16	100.000			
27	−3.472E-16	−1.240E-15	100.000			

The fifth factor Z5 was mainly determined by MMD2, SMD2 and MIU2. As these properties were directly related to the weft friction and the smoothness of the surface, Z5 could be named as the 'surface friction of weft factor'.

3.2 The Relationship Between Factors and the Technical Features

By using correlation analysis of the technical features and mechanical properties, the correlation coefficient r was generated. On the basis of r, the high correlation factors (r≥0.8), significant

Table 4: Rotated component matrix

Variables	Component				
	Z1	Z2	Z3	Z4	Z5
2HB1	**0.951**	0.032	−0.202	−0.085	0.062
B1	**0.903**	−0.263	−0.234	0.105	0.070
RT1	**0.890**	−0.339	−0.202	0.005	0.104
WT1	−0.856	0.388	0.228	−0.034	−0.102
LT2	**-0.838**	0.009	−0.193	0.252	−0.183
Tm	**0.823**	0.097	0.028	−0.510	0.141
LT1	**0.816**	0.052	−0.038	0.421	−0.327
2HB2	**0.715**	0.445	0.363	−0.257	0.107
B2	**0.714**	0.211	0.365	−0.063	0.039
T_0	**0.670**	0.273	0.466	−0.401	−0.039
2HG51	−0.099	**0.914**	−0.072	0.019	−0.119
2HG1	0.254	**0.905**	0.194	−0.072	0.088
2HG2	0.199	**0.859**	0.327	−0.120	−0.010
G2	−0.059	**0.842**	0.232	0.127	−0.426
2HG52	−0.196	**0.823**	0.259	−0.164	0.268
G1	−0.028	**0.794**	0.183	0.226	−0.445
MMD2	−0.391	**0.724**	0.103	−0.240	0.136
WC	0.077	0.253	**0.891**	−0.073	−0.157
LC	−0.361	−0.030	**0.842**	−0.024	0.089
WT2	0.304	0.476	**0.753**	−0.020	−0.165
RT2	0.207	−0.482	−0.731	0.078	0.230
RC	0.254	−0.086	−0.726	−0.057	−0.005
SMD1	−0.055	−0.285	−0.161	**0.862**	0.074
MMD1	−0.249	0.170	−0.010	**0.852**	−0.285
MIU2	0.025	0.045	−0.132	−0.446	**0.782**
MIU1	0.501	−0.136	−0.216	0.196	**0.781**
SMD2	0.038	0.261	−0.130	0.331	−0.404

Extraction method: Principal Component Analysis.

correlation factors ($0.8 \geq r \geq 0.5$) and general correlation factors ($0.5 \geq r \geq 0.2$) were generated and shown in Table 5.

On the basis of Table 4 and Table 5, the relationship between the five factors, mechanical properties and the technical features was generated and shown in Table 6.

Table 5: The relationship between the mechanical properties and the technical features

Index	High correlation		Significant correlation		General correlation	
	Positive	Negative	Positive	Negative	Positive	Negative
MIU1	—	—	—	D_{weft}	Tex	—
MIU2	—	—	—	D_{weft}	Tex	—
MMD1	—	—	—	—	D_{weft}	Tex
MMD2	—	—	—	—	—	D_{warp}
SMD1	—	—	—	—	—	Tex
SMD2	—	—	—	—	—	$D_{warp}D_{weft}$
LC	—	—	—	—	D_{weft}	Tex
WC	—	—	—	D_{warp}	D_{weft}, Tex	—
RC	—	—	—	—	D_{warp}	D_{weft}
T_0	—	—	Tex	D_{warp}	—	—
B1	—	—	Tex	D_{weft}	—	D_{warp}
B2	—	—	Tex	D_{warp}	—	D_{weft}
2HB1	Tex	—	—	D_{warp}, D_{weft}	—	—
2HB2	—	—	—	—	—	—
G1	—	—	—	—	—	D_{warp}
G2	—	—	—	D_{warp}	D_{weft}	—
2HG1	—	—	—	D_{warp}	Tex	—
2HG2	—	—	—	D_{warp}	Tex	—
2HG51	—	—	—	—	—	D_{warp}
2HG52	—	—	—	—	—	D_{warp}
LT1	—	—	Tex	D_{warp}	—	D_{weft}
LT2	—	—	—	—	—	—
WT1	—	—	D_{weft}	Tex	D_{warp}	—
WT2	—	—	—	—	D_{warp}, Tex	—
RT1	—	—	Tex	D_{weft}	—	D_{warp}
RT2	—	—	D_{weft}	—	D_{warp}	—

Table 6: The relationship between factors and the technical features

Factors	Major determinant	Significant correlation	High correlation
Bending deformation factor Z_1	2HB1, B1, RT1, WT1, LT1, LT2, 2HB2, B2, T_0	D_{warp}, D_{weft}	Tex
Shearing deformation factor Z_2	2HG51, 2HG1, 2HG2, 2HG51, G1, MMD2	D_{weft}	
Compression resilience factor Z_3	LC, WC, WT2, RT2	D_{weft}, D_{warp}	
Surface friction of Warp factor Z_4	MMD1, SMD1	D_{warp}	
Surface friction of Weft factor Z_5	MIU2, SMD2	D_{weft}	

4 Conclusions

In this study, 13 samples of high counts and high density fabrics were measured by the KES system. As the samples selected in this study have a good assessment, Table 2 could be used as a standard range of the mechanical properties of high counts and high density fabrics. If the mechanical properties of a fabric were in this range, it could be regarded as a high quality fabric. By using factor analysis, 5 factors model was generated and the cumulative contribution rate of the 5 factors was 86.883% which meant they contained almost all of the information about the samples. The bending deformation factor Z1 had a high correlation with Tex and a significant correlation with Density, and the bending deformation character had a great influence on stiffness of fabric, which means we could change the above three technical features to get a good stiffness when design a new High counts and high density fabrics.The shearing deformation factor Z2 had a significant correlation with D_{weft} which should be taken into consideration when design formation property of a fabric. Density was a significant correlation factor to the factor Z3 and had a great influence on the thickness and fluffiness of fabric. For the surface friction factors Z4 and Z5, there were some technical features beyond discussion in this study such as yarn twist and finishing process.

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