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Correlation Analysis between the Kawabata System (KES-F) and the UPC Ring Methods of Fabric Analysis

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ABSTRACT

A total of 37 commercial woven fabrics of variable composition, weave type and aerial weight were studied by using the Kawabata Evaluation System for Fabrics (KES-F) and a modified version of the ring method called the "UPC ring method" that was developed by the authors in previous work. The parameters of the KES-F system were correlated with those of the UPC ring method via canonical correlation analysis.

Keywords: KES-F method, UPC ring method, Hand, Low-stress properties, Canonical relations.

INTRODUCTION

Humans perceive reality via their senses and interpret it in accordance with social and cultural patterns that change in space and time. This is why some realities are perceived differently at different places and accepted or rejected depending on the particular time in history. One paradigmatic example of this phenomenon is so-called "hand", which is the subjective perception one acquires by feeling a fabric to assess properties such as stiffness, smoothness, fluffiness or warmth [1]. In addition to touching, the quality of a fabric can be subjectively assessed by seeing, which allows one to judge its appearance in terms of color, brightness or drape, for example. The decision to buy a fabric is eventually dictated by a weighted combination of the previous sensory perceptions in addition to time-related (fashion, culture) and economic (price) considerations.

Geographic differences in fabric hand assessment have presented a problem in this global society where clothing is frequently designed, produced and used at very distant places from one another. In this situation, any attempt at developing objective alternatives to the subjective assessment of fabric properties is certainly welcome. In recent decades, a number of researchers have strived to develop effective equipment and techniques for measuring fabric hand with two types of methods: direct and indirect, which differ mainly in the properties they assess and in the way the concept of hand is interpreted [2].

Indirect methods measure properties such as fabric stiffness, bending resistance, roughness or compressibility and establish cross-correlations with the results of subjective assessments performed in parallel. The two best known and most widely used indirect methods are based on the Kawabata Evaluating System for Fabrics (KES-F) [3] and the Fabric Assurance by Simple Testing (FAST) system [4]. On the other hand, direct methods use creative, ingenious techniques intended to mimic the typical response of humans to fabric feel and quantify specific aspects of their perception which have been designated "hand force" or "hand modulus". Direct methods include the ring test and the slot method [5].

Although the KES-F method was the most widely used to determine fabric hand in the last few decades of the 20th century, the ring method and its variants have regained popularity because these methods assess fabric properties in much the same way as humans do (*i.e.* by passing the fabric through the inside of a half-closed hand) [6-24]. Also, the equipment needed to perform the test is simple, inexpensive and widely available in textile laboratories

The authors recently reported a variant of the ring test called the "UPC ring method" that can be easily implemented with a conventional dynamometer [5]. The results of the FAST test for 37 commercial woven fabrics spanning a broad range of composition and aerial weight were compared with those obtained using the UPC ring method and regression equations based on canonical correlations between the two were developed. Judging by the results, the UPC ring method allows some FAST parameters to be accurately predicted by using a much more simple, universal and economical test method.

In this work, potential relationships between ring method parameters and mechanical properties of the fabrics as measured with the KES-F method, which was devised to assess fabric hand in terms of the amount of energy used in small deformations undergone by fabrics, as opposed the FAST method, which is used to assess tailorability [5] - were investigated.

EXPERIMENTAL

The KES-F method, which was performed in accordance with its specific requirements [2], and the UPC ring method, were applied to a total of 37 commercial drapery, shirt making and lining woven fabrics spanning a wide range of composition, aerial weight (50–447 g/m^2), weave types and densities as broken out in *Table I.*

TABLE I. Composition of the studied fabrics.

Fabric Composition	Number of Specimens
100% Wool	3
Wool and wool blends	6
100% Cotton	5
Cotton and cotton blends	3
Linen and linen blends	5
Polyester/Viscose	4
Polyester/Viscose (lining)	6
100% Polyester (lining)	1
100% Viscose (lining)	2
Acetate and acetate blend (lining)	2

The KES-F parameters LC (compression linearity), WC (compression energy), RC (compression resilience), T_o (thickness at a 0.5 gf/cm^2 pressure) and T_m (thickness at a 50 gf/cm^2 pressure) are conceptually unrelated to the parameters of the UPC ring method, and so is SMD (geometric roughness). Thus, these parameters are excluded from the present study.

Also, the KES-F method cannot measure fabric formability, but this parameter can be estimated from its parameters by using the following equation, proposed by the Australian Wool Textile Objective Measurement Executive Committee (AWTOMEC) [25]:

$$F = \frac{B \cdot EI}{49.035} \qquad (1)$$

where F denotes formability, B indicates bending rigidity (gf·cm^2/cm) and EI represents extensibility at 50 gf/cm in the KES-F test. Because formability was determined in correlating the FAST system with the UPC ring method in previous work [5], it was also included here.

Few studies have compared results of the ring test with KES-F measurements. One simply measured the maximum extraction force ($F_{\max}$) of 6 specimens of cotton woven fabrics and related the results to various KES-F parameters [4]. This work compares results on a total of 37 specimens of variable composition, weave type and aerial weight, spanning a much more extensive and representative spectrum of conventional woven fabrics. As in the previous study [5], bending rigidity (B), bending hysteresis (2HB) and aerial weight (W) were found to be closely related to $F_{\max}$ (see *Table II*).

TABLE II. Linear correlation coefficients between $F_{\max}$ as measured in the ring test with each KES-F parameter

Parameter	Grover (1993)	This work
Number of Specimens	6	37
B	0.85	0.72
2HB	0.91	0.78
W	0.98	0.76

The UPC ring method was implemented by using a polished stainless steel ring of 36 mm in inner diameter (d, radius r = d/2) and 4 mm thick firmly attached to an external support also holding a conventional dynamometer. The dynamometer was used to obtain an extraction force–displacement curve for a circular specimen 300 mm in diameter *(Figure 1*). The testing procedure is described in detail elsewhere [5] and was performed in the Department of Textile and Paper Engineering of the Polytechnic University of Catalonia.

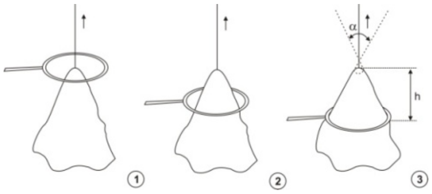

FIGURE 1. Stages of the UPC ring method.

KES-F friction, tensile and shear tests were conducted in the Textile Physics Laboratory of the Department of Textile Engineering of the University of Minho (Guimaraes, Portugal), whereas compression and bending tests were performed in the Textile Physical Parametric Laboratory of the Institute of Textile Research and Industrial Cooperation of Terrassa (UPC, Spain). All tests were done in accordance with the specific requirements of the equipment used as regards number, dimensions and conditioning of specimens, among others [2].

RESULTS AND DISCUSSION

Canonical correlations were used to relate two sets of variables x ($x_1, x_1 \ldots x_p$) and y ($y_1, y_1 \ldots y_q$) in order to find pairs of variables $u_i = a_{i1}x_1 + a_{i2}x_2 \ldots + a_{ip}x_{ip}$ and $v_i = b_{i1}y_1 + b_{i2}y_2 \ldots + b_{ip}y_{ip}$ such that the linear correlation between u_i and v_i would be maximal.

The specific KES-F and UPC-RM parameters examined are shown in *Table III and Table IV*, respectively.

TABLE III. Parameters determined with KES-F method.

Fabric property	Parameter	Symbol	Dimensions
Elongation	Linearity	LT	–
Elongation	Tensile energy	WT	gf·cm^2/cm
Elongation	Resilience	RT	%
Elongation	Extension at 500 gf/cm	EMT	%
Shear	Shear	G	gf/cm·degree
Shear	Hysteresis at $\phi = 0.5$º	2HG	gf/cm
Bending	Bending rigidity	B	gf·cm^2/cm
Bending	Hysteresis	2HB	gf·cm^2/cm
Surface	Friction coefficient	MIU	–
Surface	Mean deviation of	MMD	–
*	Formability	F	–

TABLE IV. Parameters determined with the UPC ring method.

Parameter	Symbol	Description
Overall contact height (mm)	h	See image 3 in *Figure 1*
Ring radius to overall contact height ratio (mm)	h/r	Ratio between the two quantities
Contact angle (º)	α	See image 3 in *Figure 1*
Maximum extraction force (mN)	$F_{\max}$	Maximum force needed to extract the specimen from the ring
Distance to maximum force (mm)	$DF_{\max}$	Distance from the starting point of test to that where $F_{\max}$ is reached

TABLE V. Canonical correlation between KES-F and UPC-Ring method variables.

Number	R^2	Canonical correlation	Wilks λ	χ^2	DF	P-Value
1	0.930417	0.964581	0.003076	159.063	55	0.0000
2	0.736429	0.858154	0.044207	85.7687	40	0.0000

TABLE VI. Coefficients of the canonical variables of the KES-F system (first set).

Parameter	Variable	u_1	u_2
LT	x_1	-0.275668	-0.253149
WT	x_2	0.589963	–1.473983
RT	x_3	–0.028412	0.040391
EMT	x_4	–1.048646	2.831690
G	x_5	0.142206	–0.849311
2HG	x_6	–0.131988	0.793724
B	x_7	–0.712974	–0.088643
2HB	x_8	1.017131	0.257431
MIU	x_9	0.011688	0.039558
MMD	x_{10}	0.095028	0.080597
F	x_{11}	0.933481	–1.080727

TABLE VII. Coefficients of the canonical variables of the UPC-Ring method (second set).

Parameter	Variable	v_1	v_2
h	y_1	–1.388328	–4.327195
h/r	y_2	0.458745	0.651474
α	y_3	–1.659443	–5.267203
$F_{\max}$	y_4	0.878925	–0.665361
$DF_{\max}$	y_5	0.036567	1.184612

KES-F parameters were globally denoted by the variables x $\{x_1 \ldots x_{11}\}$ and UPC-RM parameters by y $\{y_1 \ldots y_5\}$; the former were used as independent variables and the latter as dependent variables.

Table V shows the first two canonical correlations obtained and their level of significance.

The coefficients a_{ij} ($i = 1, 2$; $j = 1 \ldots 11$) for the two u variables are listed in *Table VI* and the coefficients b_{ij} ($i = 1, 2$; $j = 1 \ldots 5$) for the two v variables in *Table VII*.

Figure 2 and Figure 3 are plots of the scores between the two sets of variables, x and y, as derived from the first pair of canonical variables (u_1 and v_1) and the second (u_2 and v_2), respectively.

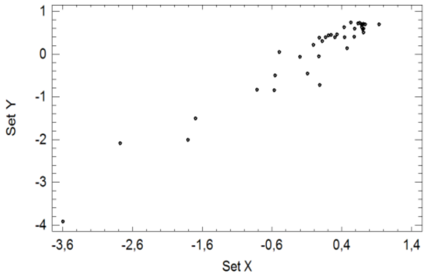

FIGURE 2. Scores between the variables in set x (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, *and x11*) and set y (y_1, y_2, y_3, y_4, *y5*) as obtained from the canonical variables u_1 and v_1.

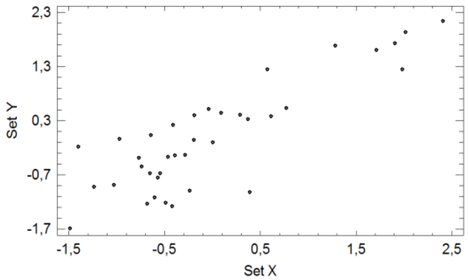

FIGURE 3. Scores between the variables in set x (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, *and x11*) and set y (y_1, y_2, y_3, y_4, *y5*) as obtained from the canonical variables u_2 and v_2.

Based on the magnitude of the canonical coefficients a_{ij} and b_{ij} alone, the contribution of the variables x_i to the first variable, u_1, decreased in the sequence $x_4 > x_8 > x_{11} > x_7 > x_2 > \mathrm{x}_1 > x_5 > x_6 > x_{10} > x_9 > x_3$, and that of y_i to v_1 in the sequence $y_1 > y_3 > y_4 > y_2 > y_5$. Similarly, the contribution of x_i to u_2 and that of y_i to v_2 decreased in the following respective sequences: $x_4 > x_2 > x_{11} > x_5 > x_6 > \mathrm{x}_8 > x_5 > x_1 > x_{10} > x_3 > x_9$ and $y_3 > y_1 > y_5 > y_4 > y_2$.

The instability of the coefficients led to reformulation of the canonical variables in terms of their correlations with the original variables x_i and y_i, designated “canonical loads”. *Table VIII* lists the direct and crossed loads for the first two canonical variables.

TABLE VIII. Direct and crossed canonical loads of the first two canonical variables.

Parameter	**Variable**	u_1	u_2	u_3	u_4
LT	x_1	–0.422258	–0.788856	–0.407302	–0.676960*
WT	x_2	0.484201	0.664618	0.467052	0.570345*
RT	x_3	–0.207769	0.129164	–0.200410	0.110843
EMT	x_4	0.492519	0.72688	0.475074	0.623776*
G	x_5	0.163612	0.074792	0.157817	0.064183
2HG	x_6	0.191526	0.082788	0.184742	0.071044
B	x_7	0.811747	–0.173293	0.782996*	–0.148712
2HB	x_8	0.857689	–0.141817	0.827311*	–0.121701
MIU	x_9	0.171402	0.207889	0.165331	0.178401
MMD	x_{10}	–0.000377	–0.339570	–0.000364	–0.291404
F	x_{11}	0.87729	0.22714	–0.846218*	0.194921
h	y_1	–0.435875	0.603489*	–0.451880	0.703241
h/r	y_2	0.543316	-0.509124	0.563266	-0.593278
α	y_3	0.452704	-0.595157	0.469327	-0.693532
F_{max}	y_4	0.952767*	0.070261	0.987751	0.081874
DF_{max}	y_5	0.657047*	0.602040*	0.681173	0.701552

*The asterisks denote the highest crossed canonical loads

The canonical loads were used to calculate redundancies, namely: the total variance for the eleven x variables explained by the five y variables, which was 37.6%, and that for the five y variables explained by the eleven x variables, which was 67.5%.

As can be seen from *Table VIII*, the canonical variables u_1 and u_2 were correlated with variables of essentially identical nature (bending); also v_1 and v_2 were correlated with identical original variables (elongation). Thus, u_1 was highly correlated with F (0.877290), 2HB (0.857689), and B (0.811747), and so was u_2 with LT (0.788856), EMT (0.726880) and WT (0.664618). Also, v_1 was highly correlated with $F_{\max}$ (0.987751) and $DF_{\max}$ (0.681173), and so was v_2 with h (0.703241) and $DF_{\max}$ (0.701552).

Based on the crossed canonical loads, u_1 was highly correlated with $F_{\max}$ (0.952767) and $DF_{\max}$ (0.657047); u_2 with h (0.603489) and $DF_{\max}$ (0.602040); and v_1 with F (0.846218), 2HB (0.827311) and B (0.782996). Finally, v_2 was correlated with LT (–0.676960), EMT (0.623776) and WT (0.570345).

The canonical loads obtained suggest that u_1 can be described in terms of *F, 2HB and B*; v_1 in terms of $F_{\max}$ and $DF_{\max}$; u_2 in terms of LT, EMT and WT; and v_2 in terms of h and $DF_{\max}$. This simplifies the interpretation of the correlations between variables. Thus, the first pair of canonical variables (u_1, v_1) relates KES-F parameters describing bending rigidity — as can be seen from Eq. (1); F also depends on bending — with the energy needed to extract the specimen through the ring in UPC ring method. Similarly, the second pair of canonical variables (u_2, v_2) relates KES-F elongation deformation with the specimen response to transverse compression during the test (h and $DF_{\max}$).

Further analysis of the x and y variables most markedly contributing to u_1 (F, 2HB, B) and v_1 ($F_{\max}$, $DF_{\max}$), respectively, led to the following pair of variables, with a canonical correlation coefficient of 0.947326 and a respective redundancy of 61.6 and 72.7%:

$$u_1 = -1.107356 \cdot \mathrm{B} + 1.36464 \cdot 2\mathrm{HB} + 0.798744 \cdot \mathrm{F} \qquad (2a)$$

$$v_1 = 0.893167 \cdot F_{\max} + 0.139709 \cdot DF_{\max} \qquad (2b)$$

Figure 4 is a plot of scores between the sets of variables x and y as derived from the canonical variables u_1 and v_1.

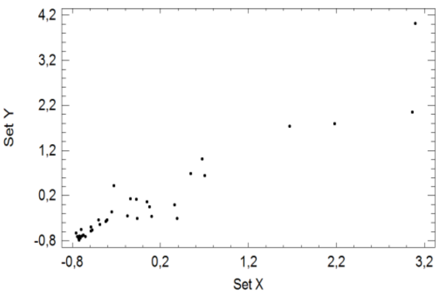

FIGURE 4. Scores between the variables in set *x* (x_7, x_8, *and x11*) and set *y* (y_4, y_5) as obtained from the canonical variables u_1 and v_1.

Similarly, further analysis of the *x* and *y* variables most markedly contributing to u_2 (LT, WT, EMT) and v_2 (h, $DF_{\max}$), respectively, provided the following pair of variables with a canonical correlation coefficient of 0.839869, and a respective redundancy of 57.7 and 38.1%:

$$u_2 = -0.488116\cdot \mathrm{LT} - 1.091624\cdot \mathrm{WT} + 1.604548\cdot \mathrm{EMT} \quad (3a)$$

$$v_2 = 0.335165\cdot h + 0.905795\cdot DF_{\max} \quad (3b)$$

Figure 5 is a plot of scores between the sets of variables *x* and *y* as derived from the canonical variables u_2 and v_2.

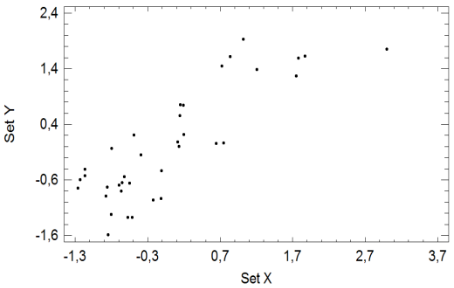

FIGURE 5. Scores between the variables in set *x* (x_1, x_2, x_4,) and set *y* (y_1, y_5) as obtained from the canonical variables u_2 and v_2.

The canonical variable u_1 (a linear combination of B, 2HB and F) was found to be correlated with v_1 (a linear combination of $F_{\max}$ and $D_{\max}$), and so was u_2 (a linear combination of LT, WT and EMT) with v_2 (a linear combination of h and $DF_{\max}$). Also, each KES parameter in variable u_1 was linearly related to the parameters in variable v_1 of the UPC ring method via least-squares fitting. Although the regression equations obtained were significant ($p < 0.05$), their coefficients of determination (R^2) were all less than 0.70. Therefore, these empirical equations are not useful in practice to predict KES parameters from ring-method parameters.

CONCLUSION

In this work, mechanical properties of 37 commercial fabric specimens were assessed by using two objective evaluation systems: KES-F and the UPC ring method.

Two canonical variables correlate with P = 0.0000 the KES-F parameters with the UPC ring method parameters with a coefficient of 0.96 and 0.85. A simplification of the previous correlations allows the relationships between the two methods to be approximated as follows: the variables defining bending deformation (parameters B, 2HB and F) are related to the amount of energy needed to extract the specimen and the distance it travels through the ring ($F_{\max}$ and $DF_{\max}$) in the UPC ring method; also, elongation deformation (parameters LT, WT and EMT) in KES-F is related to parameters explaining the morphology of the specimen during the test.

The results of this research, together with those of a previous paper (5), testify to the effectiveness of the UPC Ring method as an industrially attractive alternative to classical systems for objective assessment of fabrics.

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