Correlation Analysis between a Modified Ring Method and the FAST System

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ABSTRACT

The original ring method and some of its modified versions were examined with a view to developing a straightforward, universal alternative for use by the textile industry. For this purpose, a total of 42 specimens of commercial woven fabrics differing in composition, weave type and aerial weight were studied by using the FAST method and a modified version of the ring method developed by the authors. Correlation between the results of the two methods was found to depend largely on (a) fabric formability, (b) bending rigidity, and (c) maximum extraction force and the time needed to reach it. Regression equations relating the main variables of the two methods via canonical correlations were developed. The proposed modified version of the ring method allows the easy, inexpensive determination of fabric formability, which was previously possible with the FAST method only.

Keywords: FAST, Ring test, Hand, Low-stress properties, Tailorability, Formability, Canonical relations

INTRODUCTION

Fabric hand can be measured by using direct or indirect methods, which differ in the specific parameters they assess and in the way the phenomenon of hand is interpreted [1]. Thus, indirect methods measure properties such as fabric bending rigidity, roughness or compressibility; and then establish cross-correlations with the results of subjective assessment tests conducted in parallel. The best known, most widely used direct methods are the Kawabata Evaluating System for Fabrics (KES-F) [2] and the Fabric Assurance by Simple Testing (FAST) method [3]. On the other hand, indirect methods use ingenious techniques mimicking the response of humans to fabric feel by assessing quantities such as hand force or hand modulus. The best-known indirect methods include the ring test and the slot method.

The Ring Test and Its Evolution

According to its advocates, the ring test provides a simple, expeditious method accurately mimicking the traditional procedure by which fabrics are passed through a half-closed hand to feel their softness. In fact, this is how the softness of next-to-skin fabrics and their resistance to multiaxial deformation have traditionally been assessed. For example, women in the Middle Ages assessed silk fabrics for softness by passing them through their rings [4].

The ring test involves measuring the force needed to completely pass a circular fabric specimen through a metal ring of specific dimensions. A patent for a test method and a device for measuring hand in fabrics and other flexible materials were filed in the USA in the late 1970s [5]. The method was used to measure the extraction force needed for a fabric specimen to pass through a conical hole of given thickness and diameter. This operational principle was subsequently used to develop a test method the results of which were found to correlate well with subjective hand assessment tests [6] [7]. Also, a detailed interpretation of the force–extraction curve for fabric specimens passed through the ring was reported [8].

Since then, a number of variants of ring shape and diameter have been used. Thus, an INSTRON dynamometer was used to measure the force needed to pass a circular specimen of fabric 25 cm in diameter through a polished metal ring 2 cm wide and 2 cm thick in order to determine the maximum extraction force for various types of fabric; the measured “handle force” was found to be well correlated with KES parameters [4]. This method was also used to assess handle in differently finished fabrics and proved suitable for determining total handle and differences in fabric structure, finish or moisture [9].

A comprehensive study of fabric comfort led to the development of the El Mogahzy–Kilinc method as a substantially improved version of the ring test [10] [11]. The main difference from previous similar methods was that the head used to pass the fabric consisted of a small tube of flexible material ending in an inverted half-cone of the same material. The head was mounted on a digitally controlled low-deformation mechanical analyzer governed via dedicated software [12] [13]. The equipment was used to construct an extraction–time curve (a “hand profile”) for each fabric specimen and calculate the amount of energy required to pass it through the head (the “objective total hand”).

The previous tests, however, provide rather disparate extraction force results owing to the high variability in folding between specimens. New techniques based on the ring test principle but improving on specimen control have been developed since the year 2000 to reduce such variability and efficiently control specimen folding during passage through the ring. To this end, the fabric specimen is passed through a circular hole of variable radius and retained by two disks a variable distance apart [14] [15] [16]. The optimization and application of this test method to woven and knitted fabrics, and also to membranes, has been the subject of much literature [17] [18] [19] [20] [21] [22] [23] [24] [25] [26].

Based on previous research with various types of equipment [27] [28], the USA firm Nu Cybertek, Inc. developed the PhabrOmeter, which affords automatic performance of the ring test on a circular fabric specimen, recording of the extraction–time curve, and processing of the curve to determine new quantities such as the “relative hand value”, “drape index” and “wrinkle recovery rate” [28]. The PhabrOmeter has been successfully used in several applications [30].

One other similar method determines the force required not to extract, but rather to insert a fabric, paper, or plastic film specimen through a ring or slot. This method is typically used to measure the softness of sanitary paper with the aid of a Handle-O-meter [31] [32] and that of textiles with a Handmeter [33]. The latter, however, has scarcely been used to date.

OBJECTIVES

The primary aim of this work was to simplify the ring test by using a fixed ring diameter and thickness in order to allow the textile industry to readily assess any type of woven fabric with a conventional dynamometer. The ensuing, “UPC ring method” should allow various hand-related properties including fabric tailor ability or drape to be determined without the need for the sophisticated, sluggish, expensive equipment typically needed for these measurements. The method was developed by examining the relationships between mechanical properties of commercial woven fabric specimens as measured with both the FAST method and the proposed modified version of the ring test.

Despite their conceptual complexity, the original ring test and its existing versions require adjusting the measuring conditions (ring material and dimensions) to the particular fabric type or, alternatively, finding reference values for comparison. Also, the measuring head is not always mounted on a conventional dynamometer, so specific equipment and software are often needed.

EXPERIMENTAL

A total of 42 specimens spanning a wide range of commercially woven drapery, shirt making, and lining fabrics differing in type, composition, aerial weight (50–447 m2/g), weave type and density (data not shown) were tested with the FAST method and the proposed (UPC ring) method, as reported in *Table I*.

The FAST test was conducted on equipment at the Textile Physics Laboratory of the Department of Textile and Paper Engineering of the Polytechnical University of Catalonia. Runs were performed in accordance with the equipment specifications as regards number of specimens and their conditioning. Only the FAST-1 (compression), FAST-2 (bending) and FAST-3 (extension) tests were performed since FAST-4 (dimensional stability) was irrelevant to our purpose.

TABLE I. Composition of the studied fabrics.

Composition	Number of specimens
100% Wool	3
Wool and wool blends	8
100% Cotton	5
Cotton and cotton blends	2
Linen and linen blends	4
Polyester/Viscose	4
Polyester/Viscose (Lining)	6
100% Polyester (Lining)	6
100% Viscose (Lining)	2
Acetate and blends (Lining)	2

The measuring head used in the UPC Ring Method was a 4 mm thick stainless steel ring of circular cross-section attached to an external support. The ring was placed under the vertical of the upper jaw of a conventional dynamometer (pre-calibrated position). The fabric specimens used were circles 30 cm in diameter. This diameter was used in order to find a universal dimension allowing passage of a wide variety of commercial fabrics by applying a reasonable amount of force. The ring was made from a rod of circular section in order to minimize potential effects of fabric friction with the ring on specimen extraction force while maximizing those of intrinsic multiaxial deformation in the fabric. Testing revealed that a ring 4 mm thick and 36 mm in inner diameter fulfilled the previous requirements.

In each test run, a specimen was pierced through its geometric center with a rigid metal needle 80 mm long and 2 mm thick. An inverted T-piece was used to retain the specimen at the bottom. The metal needle was held in place by the dynamometer upper jaw (see *Figure 1*, which shows the specimen at the beginning of the test). After the dynamometer was started, the upper jaw was raised at 100 mm/min. The fabric was not yet in contact with the ring, so the extraction–displacement curve had a zero slope; however, as soon as the specimen started to touch the ring (see Image 3 in *Figure 3*), the curve rose with a slope dependent on the particular extraction force applied. The test was finished once the whole specimen had passed through the ring.

The dynamometer recorded the extraction–displacement or extraction–time curve for each specimen in order to determine the time elapsed between the start of the test and the point where the specimen first came into contact with the ring (*Figure 2*). This point in the recording corresponds to the distance *h* in Image 3 of *Figure 3*, which is related to the fabric drape. In addition, the dynamometer allowed calculation of the maximum extraction force and the time needed to reach it.

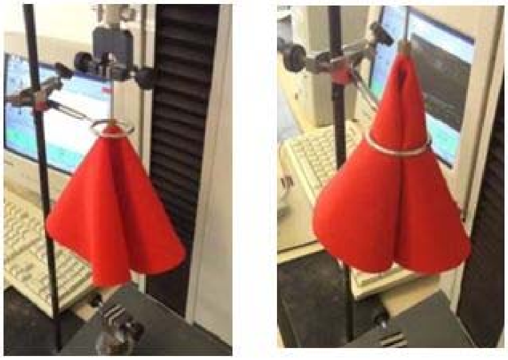

FIGURE 1. Experimental sequence of the UPC ring method. (Left) Start of the test. (Right) During the test.

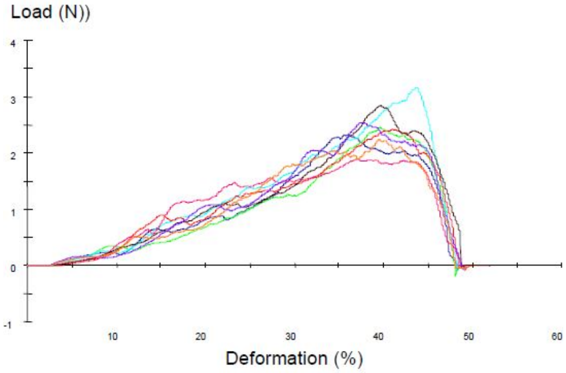

FIGURE 2. Extraction–displacement curve for specimen B2482.

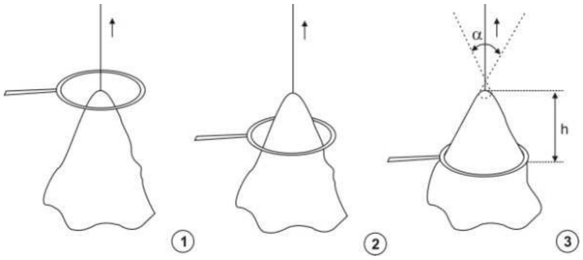

FIGURE 3. Stages of the UPC ring method.

A total of four circular specimens 30 cm in diameter per fabric were examined on both the face and reverse sides. The average value for the 8 tests was used to calculate the following parameters:

a) Maximum extraction force, F_{max} (mN).
b) Time or displacement needed to reach F_{max} (mm).
c) Distance h(mm) between the starting point of the test and that where the specimen first touched the ring (see Image 3 in *Figure 3*).
d) Ratio of h to ring radius (h/r).
e) Contact angle, a(º) (see Image 1 in *Figure 3*).

All tests were performed under standard atmospheric conditions and all specimens were previously conditioned at the Textile Physics Laboratory of the Department of Textile and Paper Engineering of the Polytechnical University of Catalonia (UPC).

RESULTS AND DISCUSSION

The specific parameters determined with the FAST and UPC ring methods are shown in *Table II* and *Table III*, respectively.

Canonical correlation analysis is a descriptive technique allowing the relationships between two sets of variables designated x and y for purely denominative purposes to be explored. The relationships are quantified via canonical variables that are linear combinations of the actual typified variables:

$$u_i = a_{i1}x_1 + a_{i2}x_2 + \quad + a_{ip}x_p \tag{1a}$$

$$v_i = b_{i1}y_1 + b_{i2}y_2 + \ldots + b_{iq}y_q \tag{1b}$$

The coefficients in the previous equations are chosen in a sequential manner: once the most highly correlated values for *u1* and *v1* are found, the (*u2* , *v2*)) pair with the highest correlation not exceeding that of the first —provided the latter variables are uncorrelated to all others— is sought and the procedure repeated until the last pair (*ur* , *vr)* is processed.

The maximization step can be summarized as follows:

Let x be a random vector of dimension p and y one of dimension q.

Let S_{xx} be the variance–covariance matrix for x and S_{yy} that for Y.

Let $U = a'x$ and $V = b'y$ be a linear combination of x and y, respectively.

The correlation between the canonical variables Eq. (2) will be given by

$$r_{u,v} \frac{a'S_{xy}b}{a'S_{xx}a^{1/2}\ b'S_{yy}b^{1/2}} \tag{2}$$

where $r_{u,v}$ is to be maximized under the following constraints Eq. (3a) and Eq. (3b):

$$a\ S_{xx}a = 1 \tag{3a}$$

$$b\ S_{yy}b = 1 \tag{3b}$$

The solution a' can be obtained by calculating the eigenvectors associated to the eigenvalues λ of the characteristic equation for the matrix $S_{xx}^{-1}S_{xy}S_{yy}^{-1}S_{yx}$. Likewise, b' can be obtained by calculating the eigenvectors associated to the eigenvalues of the characteristic equation for $S_{yy}^{-1}S_{yx}S_{xx}^{-1}S_{xy}$. The eigenvalues λ_i(i=1r) are the squares of the correlations between the canonical variables (denoted by R^2) and represent the amounts of variance shared by the two canonical variables.

Once the canonical correlation analysis is completed, significantly related variables, whether dependent or independent, can be selected further analysis with exclusion or inclusion of the others.

In this work, we denoted the body of parameters for the FAST and UPC Ring methods by the variables *X {x1, x2… x8}* and *Y {y1, y2… y5}* without specifying whether they were of the dependent or independent type. Table IV shows the first two canonical correlations obtained and their significance.

TABLE II. Parameters determined with the FAST method.

Parameter	Description
Overall formability (F, mm^2)	Capacity of absorbing lengthwise compression
100% warp extensibility (WpE100, %)	Warpwise stretch
100% weft extensibility (WeE100, %)	Weftwise stretch
Bias extensibility (%)	Biaswise stretch
Overall bending rigidity (BR, N·m)	Bending resistance (cantilever method)
Difference in BR between warp and weft (BRWp – BRWe)	Difference between the two quantities
Shearing strength (G, N/m)	Resistance to lateral distortion
Relative compressibility (RC, %)	[(Thickness at 2 gf – Thickness at 100f)/Thickness at 2 gf] × 100

TABLE III. Parameters determined with the UPC ring method.

Parameter	Description
Overall contact height (h, mm)	See Image 3 in *Figure 3*
Ring thickness-to-radius ratio (h/r)	Ratio between the two quantities
Contact angle, (°)	See Image 3 in *Figure 3*
Maximum extraction force (F_{max}, mN)	Maximum force needed to extract the specimen from the ring
Distance to maximum force (DF_{max}, mm)	Distance from the starting point of the test to that where F_{max} is reached

TABLE IV. Canonical correlation between FAST and UPC Ring variables.

Number	R^2	Correlation		^{2}	DF	p
1	0.965308	0.982501	0.003972	187.962	40	0.0000
2	0.705235	0.839782	0.114515	73.679	28	0.0000

TABLE V. Coefficients of the canonical variables of the FAST test (first set).

Parameter	Variable	u_1	u_2
F	X_1	0.590030	–0.055190
WpE100	x_2	–0.107122	0.487352
WeE100	X_3	–0.057508	0.731357
BE	x_4	–0.022615	–0.154711
BR	x_5	0.431553	–0.390179
BRWp – BRWe	x_6	0.097874	0.098644
G	x_7	0.080426	0.114457
RC	x_8	0.099461	0.038823

TABLE VI. Coefficients of the canonical variables of the UPC ring method (first set).

Parameter	Variable	v_1	v_2
h	y_1	0.171664	1.306970
h/r	y_2	0.168913	0.320043
	y_3	0.207683	0.282589
F_{max}	y_4	1.159850	0.309771
DF_{max}	y_5	–0.110071	0.243814

Figure 4 and *Figure 5* are scores plots for the two sets of variables (*x and y*) as obtained from the canonical variables u_1 and v_1, and u_2 and v_2, respectively.

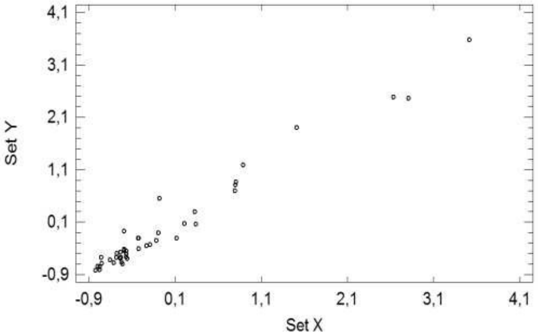

FIGURE 4. Scores between variables in set x (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8) and set y (y_1, y_2, y_3, y_4, y_5) as obtained from the canonical variables u_1 and v_1.

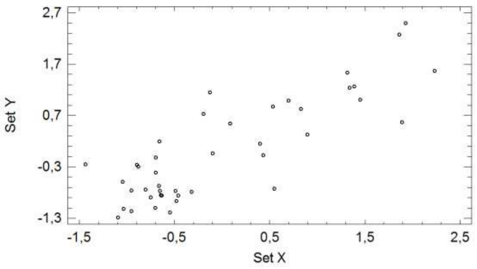

FIGURE 5. Scores between variables in set x (x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8) and set y (y_1, y_2, y_3, y_4, y_5) as obtained from the canonical variables u_2 and v_2.

Coefficients a_{ij} and b_{ij} are the standardized weights for each canonical variable and represent their relative contributions to the theoretical (canonical) values. Based on the magnitude of these coefficients alone, the contribution of x to u1 decreases in the sequence $x_1 > x_5 > x_2 > x_8 > x_6 > x_7 > x_3 > x_4$ and that of *y* to v_1 in the sequence $y_4 > y_3 > y_1 > y_2 > y_5$. Similarly, the contribution of x to u_2 and that of *y* to v_2 vary in the following sequences*:* $x_3 > x_2 > x_5 > x_4 > x_7 > x_6 > x_1 > x_8$ and $y_1 > y_2 > y_4 > y_3 > y_5$. However, it is more convenient to describe the canonical variables in terms of their correlations with the original variables, *x* and *y (i.e.*, their canonical loads rather than their coefficients). *Table VII* lists the direct and cross loads of the first two canonical variables.

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

Parameter	Variable	u_1	u_2	v_1	v_2
F	x_1	0.881259	–0.285763	0.865838	–0.239979
WpE100	x_2	0.150031	–0.729277	0.147405	–0.612434
WeE100	x_3	0.315824	–0.828324	0.310298	–0.695612
BE	x_4	–0.211843	–0.095045	–0.208136	–0.079817
BR	x_5	0.945913	0.162302	0.929360	0.136298
BRWp – BRWe	x_6	0.431498	0.246638	0.423948	0.207123
G	x_7	0.183395	–0.113030	0.180186	–0.094920
RC	x_8	0.445191	–0.446294	0.437400	–0.374790
H	y_1	–0.382128	–0.745707	–0.388934	–0.887976
h/r	y_2	0.470257	0.583003	0.478633	0.694230
	y_3	–0.367978	0.246166	–0.374532	0.293131
F_{max}	y_4	0.961459	–0.058774	0.978584	–0.069987
DF_{max}	y_5	0.636485	–0.423163	0.647821	–0.503896

As can be seen from *Table VII*, u_1 was highly correlated with BR (0.945913) and F (0.881259), and so was u_2 with WpE100 (–0.828324) and WeE100 (-.729277). Similarly, v_1 was highly correlated with F_{max} (0.978584) and somewhat less so with DF_{max} (0.6478211). Finally, v_2 was highly correlated with *h* (–0.887976) and less markedly so with the *h/r* (0.694230). These results suggest that the canonical variable u_1 explains “shaping” in the studied materials, u_2 extensibility, and v_1 and v_2 “handle” and “drape” in the ring method.

Also, based on the canonical cross-loads of *Table VII*, u_1 was highly correlated with F_{max} (0.961439) and also, to a lesser extent, with DF_{max} (0.636485); and so was u_2 with *h* (–0.745707) and the *h/r* (0.58303).Similarly, v_1 was highly correlated with BR (0.929360) and F (0.865838), and v_2 with WpE100 (–0.695612) and WeE100 (–0.612434).

The previous canonical loads were used to calculate the corresponding redundancies. The total variance in the eight x variables explained by five *y* variables was 41.4% and that in the five y variables explained by the eight *x* variables was 59.4%.

Based on these loads, u_1 can seemingly be described in terms of *F* and BR, and v_1 in terms of F_{max} and DF_{max} Eq. (4a) and Eq. (4b). Subsequent analysis of the *x* (*F*, BR) and *y* (F_{max}, DF_{max}) groups yielded the following pair of variables with a canonical correlation coefficient of 0.954315 and a redundancy of 78.5% for *x* and 70.4% for *y*:

$$u_1 = 0.58301 \cdot F + 0.492647 \cdot \mathrm{BR} \qquad (4a)$$

$$v_1 = 0.981225 \cdot F_{max} + 0.0256056 \cdot \mathrm{D}F_{max} \qquad (4b)$$

Figure 6 is a plot of scores between the canonical variables.

Based on these loads, u_2 can be described in terms of WpE100 and WeE100 Eq. (5a) and Eq. (5b), and so can v_2 in terms of *h* and the *h/r*. Subsequent analysis of the *x* (WpE100, WeE100) and *y* (*h, h/r*) groups yielded the following pair of variables with a canonical correlation coefficient of 0.640159 and a redundancy of 29.7% for *x* and 21.9% for *y*:

$$u_2 = 0.570394 \cdot \text{WpE100} + 0.604879 \cdot \text{WeE100} \tag{5a}$$

$$v_2 = 1.888027 \cdot h + 1.1343 \cdot (h/r) \tag{5b}$$

Figure 7 is a plot of scores between the canonical variables.

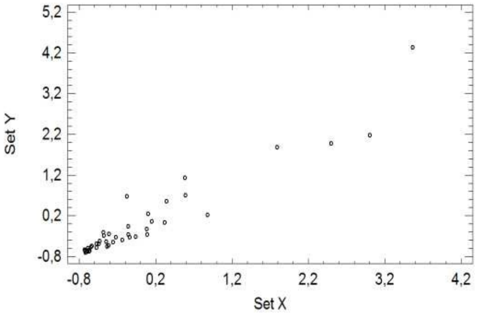

FIGURE 6. Scores between variables in set x (x_1,x_5) and set y (y_4,y_5) as obtained from the canonical variables u_1 and v_1.

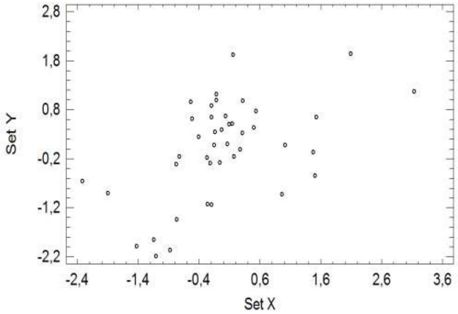

FIGURE 7. Scores between variables in set x(x_1,x_5) and set y (y_4,y_5) as obtained from the canonical variables u_2 and v_2.

Eq. (4a), Eq. (4b), Eq. (5a) and Eq. (5b) describe the relationships between the body of parameters of the FAST method and that of the UPC Ring method. Although these equations can be used for prediction, it is more practical to use regressions on the original variables instead for this purpose.

For predictions, the variables of the FAST method are ranked as dependent variables (*y*) and those of the UPC ring method as independent variables (*x*). This is so because the UPC Ring method is more universal in scope (it only requires a dynamometer, which is usually available in textile laboratories, for implementation), so it affords easier control of its variables and their use to predict FAST variables.

Regressing the FAST variable *F* and the UPC Ring variables F_{max} and DF_{max} required transforming *F* in order to correct for deviations from the linear model hypothesis. We used the Box–Cox power transformation for this purpose. The λ value minimizing the sum of residual squares of the model fitted with Y^2 was 0.313.

Previously, the origin of *F* was displaced by 0.03122, which was the point where this parameter started to exceed 0. The regression Eq. (6) for the resulting response variable was

$$F^* = -0.517111 + 0.000108106 \cdot F_{max} + 0.0345987 \cdot \text{D}F_{max} \tag{6}$$

Table VIII shows the results of the analysis of the coefficients of Eq. (3) and *Table IX* that of the variance of the regression. The corrected coefficient of determination was 90.757%.

The FAST variable BR was regressed on the UPC Ring variables F_{max} and DF_{max} by using the Box–Cox transformation with λ = 0.021. The resulting regression Eq. (7) was:

$$\text{BR}^* = 1.027274 + 0.00000958131 \cdot F_{max} - 0.000965294 \cdot \text{D}F_{max} \tag{7}$$

Table X shows the analysis of the coefficients of Eq. (7) and *Table XI* those of the regression variance. The corrected coefficient of determination was 66.7893%.

The FAST variable WpE100 was regressed on the UPC Ring variables *h* and *h/r* by using the Box–Cox transformation with λ= 0.068. The resulting Eq. (8) was:

$$\text{WpE100}^* = 0.654607 + 0.032523 \cdot h + 0.0478099 \cdot (h/r) \tag{8}$$

Table XII shows the analysis of the coefficients of Eq. (8) and *Table XIII* those of the regression variance. The corrected coefficient of determination was 28.940%.

The FAST variable WeE100 was regressed on the UPC Ring variables *h* and *h/r* by using the Box–Cox transformation with λ = 0.033. The ensuing Eq. (9) was:

$$\text{WeE100}^{*} = 1.02499 + 0.00593136 \cdot h \qquad (9)$$

Table XIV shows results of the analysis of the coefficients of Eq. (9) and *Table XV* those of the regression variance. The corrected coefficient of determination was 23.4335%.

TABLE VIII. Analysis of the coefficients of Eq. (4a) and Eq. (4b).

Parameter	**Estimate**	**Standard error**	**T**	**p**
Constant	–0.517111	0.336351	–1.537410	0.1323
F_{max}	0.000108	0.000025	4.272500	0.0001
DF_{max}	0.034598	0.010779	3.209550	0.0027

TABLE IX. Analysis of the variance of F^{*} vs F_{max} and $DF_{max.}$

Source	**Sum of squares**	**DF**	**Mean square**	**F-ratio**	**p**
Model	3.81359	2	1.90679	51.46	0.0000
Residual	1.44497	39	0.037050		
Total	5.25856	41			

TABLE X. Analysis of the coefficients of Eq. (7).

Parameter	**Estimate**	**Standard error**	**T**	**p**
Constant	1.07274	0.0170364	62.9674	0.0000
F_{max}	0.000009	0.000001	7.47603	0.0000
DF_{max}	–0.000965	0.000546	–1.7679	0.0849

TABLE XI. Analysis of the variance of BR^{*} vs F_{max} and $DF_{max.}$

Source	**Sum of squares**	**DF**	**Mean square**	**F-ratio**	**p**
Model	0.008027	2	0.004013	42.23	0.0000
Residual	0.003707	39	0.000095		
Total	0.011734	41			

TABLE XII. Analysis of the coefficients of Eq. (8).

Parameter	**Estimate**	**Standard error**	**T**	**p**
Constant	0.654607	0.112311	5.82853	0.0000
h	0.032523	0.008405	3.86925	0.0004
h/r	0.047809	0.018149	2.63427	0.0120

TABLE XIII. Analysis of the variance of $WpE100^{*}$ vs h and h/r.

Source	**Sum of squares**	**DF**	**Mean square**	**F-ratio**	**p**
Model	0.0860188	2	0.043009	9.35	0.0005
Residual	0.179416	39	0.004600		
Total	0.265435	41			

TABLE XIV. Analysis of the coefficients of Eq. (9).

Parameter	**Estimate**	**Standard error**	**T**	**P**
Intercept	1.02499	0.012892	79.5011	0.0000
Slope	–0.005931	0.001611	–3.68079	0.0007

TABLE XV. Analysis of the variance of $WeE100^{*}$ vs h.

Source	**Sum of squares**	**DF**	**Mean square**	**F-ratio**	**p**
Model	0.011962	1	0.011962	13.55	0.0007
Residual	0.035316	40	0.000882		
Total	0.047278	41			

CONCLUSIONS

The exploratory study conducted in this work allowed us to relate the FAST test to the proposed UPC Ring method by correlating their parameters. The results obtained here afford the following conclusions:

- Fabric formability (*F*), bending rigidity (BR), maximum extraction force (F_{max}) and the times needed to reach it (DF_{max}) are the individual parameters most markedly contributing to correlation between the FAST and UPC ring methods. The canonical correlation between these variables is 0.95.
- Full (100%) extensibility (WpE and WeE), the distance between the specimen position at the start of the test and the point where it touches the ring (*h*), and the ratio of *h* to the ring radius (*h/r*) exhibit a canonical correlation of 0.64.
- The previous correlations account for the facts that the three-dimensional molding of fabrics is correlated with their handle, and so is extensibility with drape.
- Based on the regression equations between the main FAST and UPC Ring variables as identified from their canonical correlations, F_{max} and DF_{max} explain 95.75% of the variance in fabric formability (*F*) and 66.79% of that in bending rigidity (BR). Also, *h* and the *h/r* explain 28.94% of the variance in 100% warp extensibility (WpE) and 23.43% of that in 100% weft extensibility (WeE).
- The UPC Ring method provides a more universal alternative to the determination of some FAST parameters in a more simple economical than the FAST method itself. Thus, the proposed method allows the determination of such an important property as fabric formability (F), which could only be assessed with the FAST method before.

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