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Investigation of the Mechanics and Performance of Woven Fabrics Using Objective Evaluation Techniques. Part I: The Relationship Between FAST, KES-F and Cusick's Drape-Meter Parameters

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Abstract
In this study, mechanical and performance analyses of woven fabrics were carried out using objective evaluation techniques. The KES-FB Auto system, the FAST system and Cusick's Drape Meter were used to evaluate the mechanical properties of the fabrics. The shear, bending, extension, and compression parameters were measured using KES-FB and FAST instruments, and the drape coefficient was measured using Cusick's Drape Meter. It was found that the KES-F and FAST systems have a good correlation between each parameter, although they use different measurement principles. Another conclusion obtained from this work concerns the dependence of bending and shear parameters on the fabric drape property. It was found that the drape of a fabric is primarily dependent on the fabric's bending and shear properties.

Key words: *objective evaluation systems, fabric handle, fabric mechanics, KES-F, FAST.*

Introduction

At present, the performance of fabric quality related to mechanical comfort is evaluated by a subjective method called handle judgement. This assessment is made by fabric experts touching the fabric. Fabric handle is defined as the overall aesthetic quality of the fabric perceived [1], which influences consumer priorities and their sense of the usefulness of the product, as well as the marketability of the fabric for retailers. Subjective evaluation of handle has always been used as the fundamental aspect of communication for the development, production, quality control, specification and marketing of textile materials and garments before the development of objective measurement technology for fabric.

The complex concept of fabric handle may be analysed as the interaction between simple attributes of fabric quality such as firmness, fullness, crispness and hardness, smoothness or sleekness [2]. It is also known that fabric handle is related to many characteristics including flexibility, stiffness, compressibility, resilience, extensibility, the surface contour, mass per square meter, surface friction and thermal characteristics [3]. On the other hand, the quality, tailorability and performance characteristics of a fabric are related to its mechanical properties in a low stress region, as well as its surface and dimensional properties. These properties are tensile, shear, bending, compression, surface friction, hygral expansion and relaxation.

As far as traditionally used textile materials are concerned, the comfort of the aesthetic and psychological sense of apparel fabric is an important criterion. The comfort sense of a fabric has various kinds of properties and cannot be determined according to one simple physical parameter. Fabric handle is commonly used to determine the comfort of textile materials.

Objective evaluation is described as the evaluation of the fabric handle, quality and related fabric properties that can be defined as objective properties of the fabric. The basic aim of this measurement is to determine the quantity of the end-use properties of the apparel and fabrics desired.

Major research into the relationship between the mechanical properties of fabric and fabric handle was first conducted by Pierce [4] in 1930. His article "The Handle of Cloth as a Measurable Quality" was the first research on the relation between fabric mechanics and fabric handle. The handle of a fabric was investigated and then converted into numerical values. In the 1970's, S. Kawabata and M. Niwa [5 - 9] started to study fabric mechanics and handle in Japan. They aimed to build a model of the relationship between fabric mechanics and fabric handle. A research committee -The Hand Evaluation and Standardisation Committee (HESC)- was then established in 1972 under the leadership of Mr. S. Kawabata, sponsored by the Textile and Machinery Society of Japan. The research on objective evaluation of fabric handle was accelerated by the foundation of this committee. Efforts of the HESC to seek an objective evaluation of fabric quality and handle, as well as constant studies on the mechanical properties of fabrics in Japan, enabled Kawabata to design the 'Kawabata Evaluation System for Fabrics' (KES-F) [10]. He defined this work as a need for quick and reproducible instrumentation for evaluating fabric handle. In 1973, the first KES-F instruments were introduced to the industry.

These instruments were:
KES-F1: Tensile and Shear Tester
KES-F2: Bending Tester
KES-F3: Compression Tester
KES-F4: Surface-friction and Geometrical roughness Tester

A total of 16 parameters can be obtained from this system.

Table 1. Fabric properties.

Fabric No.	Material	Yarn Count, Nm - Twist t.p.m. - Linear Density, gr/m		Weave design	Weight, g/cm2
		Warp	Weft		
1	%100 wool	77/2 - 811 - 0.026	78/2 - 812 - 0.026	2/1 twill	165
2	%100 wool	72/2 - 678 - 0.028	38/1 - 706 - 0.026	2/1 twill	165
3	%100 wool	78/2 - 815 - 0.026	78/2 - 833 - 0.026	plain	145
4	%100 wool	80/2 - 813 - 0.025	80/2 - 821 - 0.025	plain	140
5	%100 wool	70/2 - 710 - 0.029	37/1 - 760 - 0.027	plain	160
6	%80 wool %8 polyamid %8 polyester %4 elastan	72/2 - 718 - 0.028	72/2 - 741 - 0.028	plain	170
7	%88 wool %8 polyamid %4 elastan	72/2 - 795 - 0.028	72/2 - 782 - 0.028	plain	180
		72/2 - 742 - 0.028	72/2 - 753 - 0.028	2/2 basket and	
8	%88 wool %8 polyamid %4 elastan	66/4 - 520 - 0.030	66/4 - 474 - 0.030	2/2 filling rib	260
9	%54 polyester %44 wool %2 elastan	80/2 - 854 - 0.025	80/2 - 837 - 0.025	2/1 twill	210
10	%54 polyester %44 wool %2 elastan	100/2 - 934 - 0.020	100/2 - 917 - 0.02	2/1 twill	160
11	%55 polyester %45 wool	82/2 - 900 - 0.024	80/2 - 891 - 0.025	2/1 twill	165
12	%55 polyester %45 wool	80/2 - 814 - 0.025	82/2 - 851 - 0.024	3/1(+2 -1)twill	165
13	%50 polyester %50 wool	56/2 - 690 - 0.036	56/2 - 670 - 0.036	2-2/2-5(+3)twill	320
		70/2 - 750 - 0.029	70/2 - 736 - 0.029		
14	%40 wool %45 polyester %15 linen	56/2 - 600 - 0.036	56/2 - 698 - 0.036	plain	155
		80/2 - 880 - 0.025	80/2 - 891 - 0.025		
15	%40 wool %45 polyester %15 linen	54/2 - 680 - 0.037	57/2 - 663 - 0.035	4/4 basket	200
16	%80 wool %20 polyester	16/1 - 541 - 0.063	16/1 - 534 - 0.063	2/1 twill	250
17	%75 wool %25 mohair	76/2 - 837 - 0.026	38/1 - 765 - 0.026	plain	140
18	%55 polyester %45 wool	80/2 - 912 - 0.025	80/2 - 850 - 0.025	2/1 twill	170
19	%54 polyester %44 wool %2 elastan	80/2 - 867 - 0.025	80/2 - 806 - 0.025	2/1 twill	185
20	%50 polyester %50 wool	46/2 - 602 - 0.043	46/2 - 612 - 0.043	2/2 twill	295
21	%50 polyester %50 wool	67/2 - 866 - 0.030	65/2 - 875 - 0.031	2/1 twill	205

Table 2. Results of tightness factors, the cover factor and weave factor.

Fabric No.	Tightness			Cover factor	Weave factor	
	Russell	Galuszynski	Seyam and El-Shiekh		Warp	Weft
1	0.727	0.686	0.696	0.687	1.500	1.500
2	0.887	0.816	0.849	0.779	1.500	1.500
3	0.756	0.696	0.756	0.614	1.000	1.000
4	0.737	0.678	0.737	0.602	1.000	1.000
5	0.918	0.824	0.918	0.705	1.000	1.000
6	0.777	0.714	0.777	0.625	1.000	1.000
7	0.799	0.735	0.799	0.640	1.000	1.000
8	0.746	0.679	0.709	0.710	2.000	1.250
9	0.745	0.683	0.694	0.686	1.500	1.500
10	0.685	0.645	0.655	0.656	1.500	1.500
11	0.700	0.660	0.670	0.667	1.500	1.500
12	0.690	0.650	0.655	0.675	1.714	1.500
13	0.948	0.909	0.902	0.993	2.750	1.830
14	0.727	0.669	0.727	0.594	1.000	1.000
15	0.584	0.524	0.509	0.716	4.000	4.000
16	0.855	0.806	0.818	0.736	1.500	1.500
17	0.931	0.831	0.931	0.708	1.000	1.000
18	0.677	0.638	0.648	0.649	1.500	1.500
19	0.713	0.672	0.682	0.679	1.500	1.500
20	0.846	0.792	0.786	0.812	2.000	2.000
21	0.785	0.740	0.751	0.725	1.500	1.500

FAST (Fabric assurance by simple testing) was later developed by CSIRO (Australia's *Commonwealth Scientific and Industrial Research Organisation)* as an alternative to the KES-F system to provide the industry with a simple, robust, relatively inexpensive system for objective measurement of the mechanical properties of fabrics. It is mainly used by manufacturers, finishers and garment makers. The FAST system can be used in fabric development, the optimisation of finishing, the evaluation of new technologies (spinning system, finishing machinery), and in buying control for garment makers.

FAST consists of three instruments and a test method to measure, in particular, the properties of wool and wool-blend fabrics related to their making-up properties, as well as the tailoring performance and appearance of tailored garments during wear.

The instruments of the FAST system are;
FAST-1: Compression Meter
FAST-2: Bending Meter
FAST-3: Extensibility meter
FAST-4: It is a test method to measure dimensional stability: relaxation shrinkage and the hygral expansion of fabrics.

Using the FAST system, 14 parameters can be measured and calculated.

The aim of this study was to analyse the mechanical and performance characteristics of wool and wool-blended fabrics using both of the objective evaluation systems, and to search for a reliable relationship between the physical and mechanical properties of the fabrics.

Materials and methods

Twenty one wool (100%) and wool blended woven suiting fabrics, with a fineness which varied from 19.5 to 21.5 micron, were used in this study. The properties of the fabrics used in this study are shown in ***Table 1***. The weave tightness, defined as the ratio of the cloth construction parameters to the corresponding parameters of the reference fabric, the cover factor, which is a number derived from the number of warp (or weft) threads per unit length and the linear density of the yarns, indicating the extent to which the area of a woven fabric is covered by warp (or weft) yarns, and the weave factor, which is defined as the ratio of the thread amount to the interlacing amount, were calculated. The tightness factors were calculated according to Galuszynski [15], Russell [16], Seyam and El-Shiekh [16, 17]. Results of the tightness factors, cover factors and weave factors are given in ***Table 2***. The KES-FB Auto and FAST systems were used to evaluate mechanical properties of the fabrics: the extension, bending rigidity, and shear rigidity. The fabric drape (drape coefficient) was measured using Cusick's Drape meter (***Table 3***).

Table 3. Results of mechanical properties evaluated by FAST, KES-FB and the drape coefficient (evaluated by Cusick's Drape meter).

Fabric type	KES-FB test results				FAST test results				Drape test results
	Extension EM, %	Bending rigidity B, cN.cm^2/cm	Compression energy WC, cN·cm/cm^2	Shear rigidity G, cN/cm·deg	Extension E100, %	Bending Rigidity B, μN·m	Compression surface thickness ST, mm	Shear G, N/m	Drape coefficient
01	2,74	0,059	0,090	0,94	2,60	5,45	0,090	46	0,394
02	2,89	0,068	0,098	0,91	2,55	6,45	0,108	44	0,391
03	2,98	0,046	0,033	1,10	3,05	3,95	0,042	55	0,385
04	3,50	0,046	0,044	1,16	3,50	4,05	0,040	57	0,339
05	6,00	0,057	0,060	0,81	6,20	4,80	0,056	37	0,365
06	8,48	0,044	0,054	0,74	8,70	4,30	0,070	30	0,339
07	9,09	0,050	0,042	1,11	9,30	3,95	0,047	43	0,341
08	9,23	0,086	0,056	1,74	8,50	6,70	0,066	60	0,400
09	12,80	0,057	0,118	0,98	13,85	5,70	0,090	36	0,404
10	7,08	0,036	0,109	0,91	7,55	4,10	0,092	44	0,409
11	1,99	0,051	0,073	0,91	2,05	3,85	0,068	39	0,383
12	2,13	0,048	0,059	1,01	2,10	4,55	0,064	43	0,360
13	1,54	0,244	0,126	1,65	1, 00	15,70	0,095	79	0,529
14	2,22	0,064	0,114	1,04	2,45	6,45	0,104	50	0,511
15	1,87	0,088	0,176	0,50	1,90	7,55	0,152	19	0,478
16	4,27	0,162	0,231	1,51	3,60	11,15	0,203	66	0,509
17	3,24	0,052	0,043	0,97	3,35	4,25	0,045	46	0,427
18	2,97	0,045	0,078	0,67	3,45	3,80	0,057	29	0,342
19	8,16	0,056	0,185	0,98	8,45	5,30	0,162	35	0,449
20	2,29	0,246	0,279	3,14	1,75	36,05	0,218	738	0,748
21	2,08	0,097	0,113	1,73	1,85	9,70	0,110	82	0,497

Results and discussion

Comparison of FAST and KES-FB parameters

The first step of this study was to compare the two objective evaluation systems. As shown in ***Figure 1***, the correlation between FAST and KES-FB values was as high as expected. The correlation coefficients between the two systems were found to be 0.93 for the shear parameter, 0.98 for the compression parameter, 0.99 for the extension parameter and 0.88 for the bending parameter. These values show that FAST and KES-F instruments measure similar values, although they use different measurement principles. As also shown in literature [11, 12], the values show a similarity between previous studies and the present one. Consequently, both the FAST and KES-FB instruments can be used effectively to measure the mechanical properties of fabrics.

Comparison of the drape coefficient, bending and shear properties

Drape is the term used to describe the way a fabric hangs under its own weight. It has an important role in how good a garment looks in use. The draping behaviour required from a fabric will differ widely depending on its end-use. Drape is a very complex attribute of a fabric and is dependent on most of the physical and mechanical properties of a fabric; however, of all of them, it is the bending and shear properties that are the most important, which are known as the primary dependent properties for fabric drape. In view of this it was decided to correlate the drape coefficient with the bending and shear properties from both systems (FAST and KES-F) to validate the correlation of these parameters.

The correlation between the drape coefficient, *FAST* bending and shear properties was high, as can be seen in ***Figure 2***.

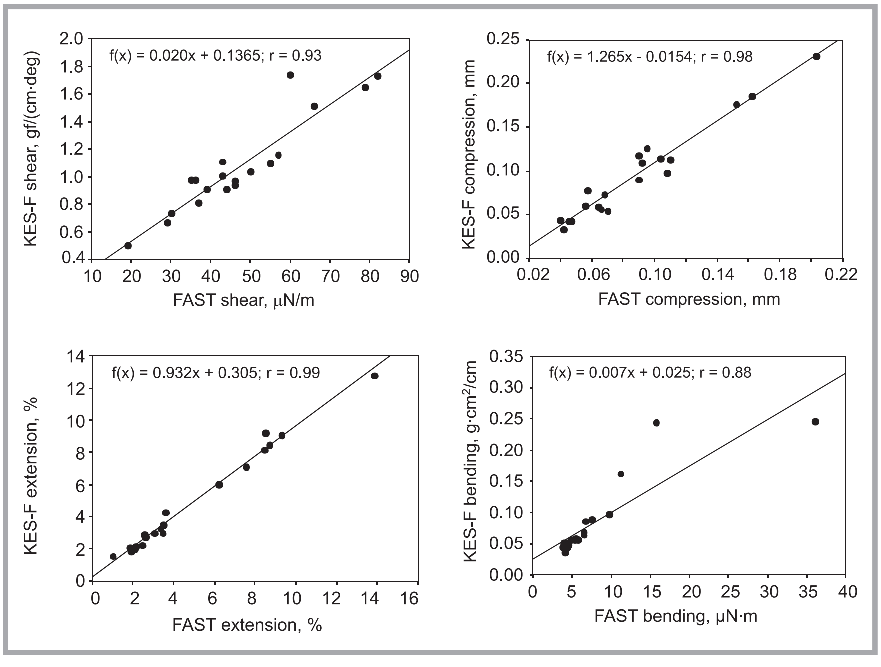

Figure 1. Comparison of KES-FB and FAST parameters.

According to ***Figure 2*** (see page 58), the correlation coefficients are 0.91 between the drape ratio and FAST bending parameter, and 0.80 between the drape ratio and FAST shear parameter. The correlation between the drape ratio and bending is higher than the shear, which is a sign that the bending property is more related to the drape property than the shear.

The correlation between the drape ratio, KES-F bending and shear properties is

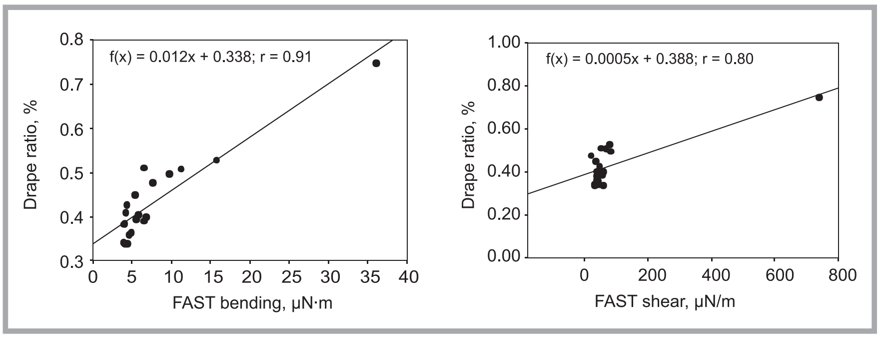

Figure 2. *Comparison between the drape coefficient and FAST bending and shear values.*

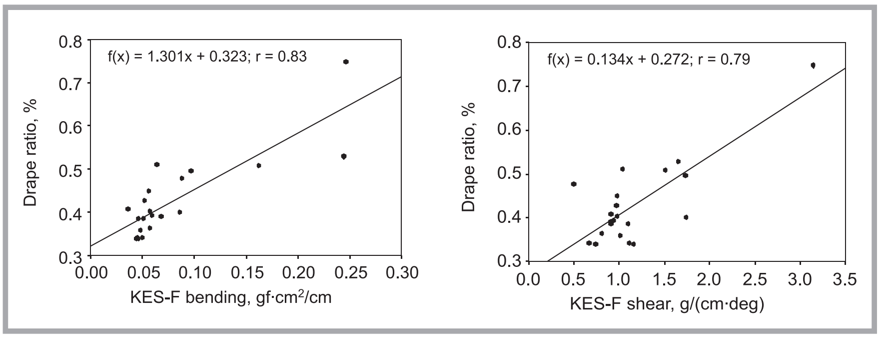

Figure 3. *Comparison between the drape ratio, KES-F bending and shear values.*

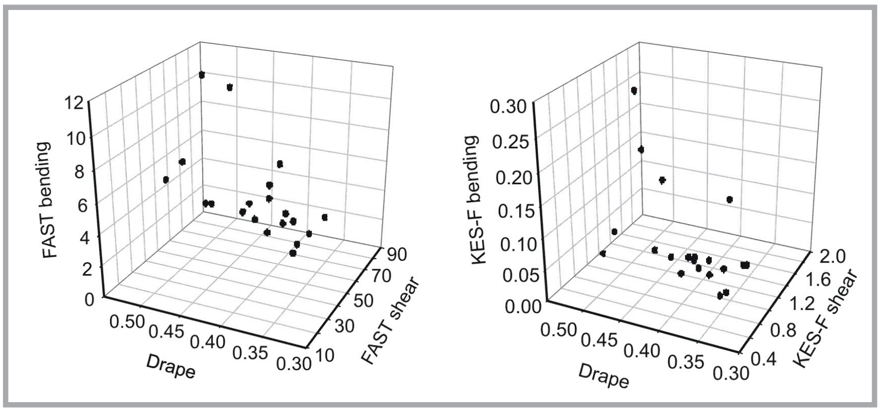

Figure 4. *Relationship between the bending and shear Properties measured and the FAST, KES-FB and drape coefficients.*

also high, as shown in ***Figure 3***. According to ***Figure 3***, the correlation coefficients are 0.83 between the drape ratio and KES-F bending parameter, and 0.79 between the drape ratio and KES-F shear parameter.

The correlation coefficients are very similar for both comparisons of the drape with FAST and KES-F bending and shear parameters. It is once again shown that the fabric drape property is mostly related to fabric shear and bending properties. On the other hand, drape is a very complex attribute and is not only dependent on bending and shear parameters but also on other properties of fabrics; however, their effects are not as high as the bending and shear, which is why the correlation coefficients are nowhere near 100%. Chen [13] also studied drape in which the drape coefficient was correlated with mechanical properties, and a correlation was found within the range of 60 to 95 percent for ten fabric samples. In the present study, the correlations found are in the same range as the literature.

In the study, the drape ratio is also expressed by bending and shear properties, with both the FAST and KES-FB results and the tightness factor of Seyam and Galuszynski. The multi regression formulas derived are shown below:

$$\text{Drape} = K_b \times 0.866 + K_s \times 0.602 \times 10^{-1} + 0.288 \; (r = 0.862) \quad (1)$$

$$\text{Drape} = K_b \times 1.059 + K_s \times 0.604 \times 10^{-1} + - T_g \times 0.251 + 0.452 \; (r = 0.883) \quad (2)$$

$$\text{Drape} = K_b \times 0.940 + K_s \times 0.625 + - T_s \times 0.170 + 0.407 \; (r = 0.879) \quad (3)$$

$$\text{Drape} = F_b \times 0.948 \times 10^{-2} + F_s \times 0.812 \times 10^{-4} + 0.357 \; (r = 0.824) \quad (4)$$

$$\text{Drape} = F_b \times 1.145 \times 10^{-3} + - F_s \times 0.324 \times 10^{-4} + T_g \times 0.181 + 0.223 \; (r = 0.838) \quad (5)$$

$$\text{Drape} = F_b \times 1.039 \times 10^{-3} + F_s \times 0.345 \times 10^{-4} + T_s \times 0.066 \times 10^{-1} + 0.306 \; (r = 0.827) \quad (6)$$

where;

K_b - KES-F bending value
K_s - KES-F shear value
F_b - FAST bending value
F_s - FAST shear value
T_g - Tightness of Galuszynski
T_s - Tightness of Seyam

Conclusions

In this research, the mechanical properties of wool and wool blended fabric were measured using objective evaluation systems. The relationship between the KES-FB and FAST systems and that between the drape ratio and the bending and shear properties measured by the FAST and KES-FB systems were investigated. The following conclusions can be drawn from the findings of these investigations:

It was found that the KES-FB and FAST systems have a good correlation between each parameter, although they use different measurement principles.

A high correlation was obtained between drape-shear and drape-bending parameters. It is once again seen that these are the primary parameters that effect drape.

According to the statistical analyses, a high correlation was also obtained between multi regression models of drape-shear-bending and the additional tightness factor. The coefficients in the models were also found to be significant.

Since the textile industry is still searching for a reliable method to end discussions between fabric manufactures and consumers over quality, it seems that objective evaluation systems like KES-FB and FAST will continue to be used and will have an important role in the future as today.

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