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A Study on Subjective and Objective Evaluation of the Handle Properties of Shirt Fabrics

Abstract

It is not possible to measure the handle of fabrics, which can be defined as the total senses felt when touching a fabric. Objectively with only one instrument and therefore in many researches concerned with fabric sensorial comfort evaluations were done subjectively without using any instruments. However, various instruments and tools have been developed in order to evaluate fabric handle objectively by means of the related physical and mechanical properties. In this study, in order to evaluate fabric handle of 20 different shirt fabrics objectively, multiple regression analysis was performed, from which both subjective and related objective measurement results were obtained. With an evaluation group consisting of 40 people, the fabrics were evaluated by using bipolar descriptors for the fabric mass per unit area, thickness, bending rigidity, drapeness as well as the thermal absorption of the fabrics were measured, from which 16 different parameters were obtained. By using control fabrics, the most appropriate equation was selected among the 10 different regression equations derived.

Key words: *objective handle, subjective evaluation, woven fabric, regression analysis.*

Introduction

Touching a fabric is the first action that buyers perform in order to evaluate the fabric quality to choose a suitable fabric for garments and to estimate the performance of the fabric for the end use. Fabric handle properties such as softness, stiffness, roughness and drapeability, which are difficult to define in numeric values, are as important as the mechanical properties of fabrics like strength and elongation, which can be measured and defined in numeric values. Since it is impossible to measure fabric handle by using only one instrument objectively, fabric handle, the most common sensorial characteristic, is evaluated by people subjectively. Fingers, containing more than 250 sensors per cm^2, are the most crucial factor when determining fabric quality [1]. However, subjective evaluation of handle makes it difficult to measure and define it. Therefore, over the years various instruments and tools have been developed for objective measurement of fabric handle by many researchers.

Fabric handle is related to the basic mechanical properties of fabrics, especially the initial low-stress region of these properties [2]. Since the sensation is related to the physical properties of the material, physical measurements constitute significant data in terms of objective evaluation. This subject, now often described simply as "Fabric Objective Measurement" (FOM), has become one of the most active areas in textile research [3]. In the FOM context, the works conducted by Kawabata have guided many researchers towards understanding fabric handle and related properties - the so-called sensorial properties. However, the disadvantages of the Kawabata system, such as high costs, difficulties in maintenance and reparation have resulted in conducting studies on improving simpler instruments for the objective evaluation of fabric handle.

Sular searched the handle properties of men suiting fabrics woven with wool and wool blends and found a regression equation for the prediction of fabric handle properties objectively [12].

In a work carried out by Yick et al., using linear regression analysis techniques for shirting materials, shear rigidity, formability, and bending rigidity were found to have significant correlations with fabric handle. Multiple regression analysis was also applied to find a suitable equation which could best describe or predict fabric handle assessments [4].

In the scope of this study, we aimed to define equations for estimating the fabric handle of shirting materials and the relationship between the subjective evaluation values and handle related fabric structural and mechanical properties.

Material and method

The handle properties of 20 different cotton and cotton-polyester shirt fabrics were measured both subjectively and objectively. The structural properties of the fabrics used in the research are given in ***Table 1***.

Table 1. *Structural properties of the fabrics.*

Fabric nr	Mass per unit area	Yarn count, tex		Yarn density (number of yarns per cm)		Fibre composition
		Weft	Warp	Weft	Warp	
1	116	16	12	31	52	CO/PES
2	126	16	15	32	46	CO/PES
3	115	16	12	30	54	CO
4	106	10	10	35	65	CO
5	106	10	10	35	65	CO
6	115	15	12	32	56	CO
7	114	12	12	32	56	CO
8	116	12	11	35	59	CO
9	112	12	12	35	56	CO
10	132	12	8	35	81	CO
11	128	12	12	41	53	CO/PES
12	164	37	37	19	22	CO
13	200	18	19	42	52	CO
14	136	13	10	35	72	CO/PES
15	126	12	11	32	65	CO
16	114	28	15	23	35	CO
17	109	14	16	26	42	CO/PES
18	173	30	30	24	28	CO
19	155	18	26	28	46	CO
20	119	27	22	19	30	CO

In order to evaluate the handle subjectively, the fabrics were cut into dimensions of 20 × 20 cm. An evaluation committee consisting of 16 men and 24 women at the age of 23 - 60 was chosen from the staff of the Department of Textile Engineering, who have long term experience in the textile industry. Before the subjective evaluation, the aim of the research was explained to the panelists, and each panelist realised the evaluation individually without being influenced. The subjective evaluations were performed in standard atmospheric conditions (20 ± 2 °C and 65% relative humidity). The panelists evaluated the fabrics subjectively in terms of thin-thick, soft-hard, rough-smooth, warm-cool feeling characteristics of the fabric, such as could be defined as primary handle impressions. In order to prevent the effects of colour and design on the evaluation, the fabrics were put in cardboard boxes. The panelists were allowed to see the fabrics only in general handle evaluation.

A grading scale was used in the subjective evaluation of the fabrics. Reference fabrics were chosen according to the objective measurements in order to facilitate the evaluation. The fabrics that had maximum and minimum values in the related objective fabric handle test were chosen as reference.

A ranking scale from 1 to 10 was used in the evaluation of the primary handle of the fabrics, and a grading scale from 1 to 5 was used for the general handle value (SHV). The evaluation scale and duration of the subjective evaluation are given in ***Table 2***.

In order to measure fabric handle objectively in scope of the research, the fabric thickness, compressibility, bending properties, surface smoothness and thermal absorption properties of the fabrics were tested by using various instruments, as shown in ***Table 3***.

A bending rigidity tester with constant angle and a circular bending rigidity tester were used to determine the bending properties of the fabrics. On the bending rigidity tester with constant angle, the strip sample, which measured 2.5 × 15 cm, is held on one side, whereas the other side is allowed to hang down under its own weight. The relation between the length of the overhanging strip, the angle that it bends to and bending rigidity G of the fabric is a complex one, which was solved empirically by Peirce [5, 6]. Bending stiffness measurements were performed on a Shirley stiffness tester according to ISO 4604 [7]. The bending rigidity tester measures the bending resistance in one direction, whereas the circular bending resistance tester, which was developed with the aid of ASTM 4032, measures the bending resistance in multiple directions. In this method the force generated while pushing a fabric specimen through a ring was measured [8].

The thicknesses of the woven fabrics were measured under the pressures of 3 g/cm^2 and 63 g/cm^2. The surface thickness and relative compressibility of the fabrics were calculated according to the following formulas.

- Surface thickness (T) = $T_3 - T_{63}$ in mm.
- Relative compressibility = = $(T_3 - T_{63})/T_3 \times 100$ in %.

Drape properties of the fabrics were determined by using a Cusick drape meter and a Sharp corner drape angle tester, developed by Hes [9]. In the test carried out with the Cusick drape meter, the fabric was bent under its own weight in multi directions. The projection of the fabric over transparent paper is taken by a camera placed over the equipment, and the image is transferred onto a computer. The fabric drape coefficient is calculated automatically by software developed at Ege University. The higher the fabric drape coefficient, the lower the fabric drape and, the stiffer the fabric is.

The principle of the new fabric drape tester developed by Hes is based on the bending of a fabric across a horizontal plate with a 90 degree sharp corner. As an indicator of the fabric drapeability, it provides the sinus of the angle between the fabric edge and horizontal plane. The fabric becomes harder as the drape angle gets smaller [9].

The roughness of the fabric in the research was determined by the inclined plane method. A block of mass m was placed over the inclined plate with the fabric to be tested. The angle of the inclined plate was increased until the block began to slide and the friction force "F" was equal to the parallel component of the block's mass.

$$F = g\ m \sin\theta$$

Normal force N is equal to the component of the mass perpendicular to the inclined plane

$$N = g\ m \cos\theta$$

As the coefficient of friction is $\mu = F/N$, therefore

$$\mu = (g\ m \sin\theta)/(g\ m \cos\theta) = \tan\theta$$

The warm-cool feeling during the first touch of the fabrics was determined by an ALAMBETA instrument. The thermal properties of the textile materials were measured by determining the heat

Table 2. *Evaluation scale for the primary and general handle values of the fabrics.*

Handle impressions evaluated subjectively	Ranking scale	Evaluation period, second
Thinness-thickness	1...... ....5.................10 Thin Thick	15
Softness-stiffness	1.....................5.................10 Soft Stiff	15
Roughness-smoothness	1......................5.................10 Smooth Rough	15
Warm-cool feeling	1..................... 5.................10 Warm Cool	15
General handle	1......................3.....................5 Poor average excellent	20

Table 3. *Objectively measured parameters; * according to the measurement device available.*

Property	Parameter	Unit
Fabric mass per unit area	Area mass	g/m^2
Thickness	Thickness under the pressures of 3 cN/cm^2, 63 cN/cm^2 (*)	mm
Compressibility	Surface thickness Relative compression	mm %
Bending	Circular bending rigidity Bending length – warp and weft directions Bending rigidity – warp and weft directions, general	cN mm mg·cm
Drape	Drape coefficient Drape angle	% °
Friction	Static friction coefficient	-
Thermal	Thermal absorption	W·m^{-2}·s$^{1/2}$·K^{-1}

flow passing through the fabrics placed between two plates at a temperature of 33 ºC and 23 ºC. Thermal absorption values are related to fabric surface properties and give an idea about the warm-cool feeling during the first touch of fabrics. After the first contact between the skin and fabric, a cold feeling is felt when the fabric is cooler than the skin, and heat transfer occurs from the body to the fabric. This parameter is a good indicator of variable thermal feelings when a garment is worn. Fabrics having low thermal absorption values give a warmer feeling.

Thermal absorption is calculated by the following formula [10]:

$$b = \sqrt{\lambda \cdot p \cdot c} \quad \text{in } W \cdot m^{-2} \cdot s^{1/2} \cdot K^{-1}$$

λ = thermal conductivity in W/(m K),
p =fabric density in kg/m^3,
c =specific heat of fabric in J/(kg K).

Results and discussion

Subjective evaluation of fabric handle

In order to investigate the relationship between primary handle properties and values determined by handle related objective tests, the handle properties of the fabrics were first evaluated subjectively. The mean values and standard deviations of the primary and general handle evaluations of 40 panelists are given in ***Table 4***.

As can be seen from ***Table 4***, due to the fact that the handle of the fabrics were chosen differently on purpose, the ratings of 20 fabrics are quite different from each other in all subjective evaluations.

In order to determine the consistency of the primary and general handle evaluations of the 40 panelists, Kendall coefficients were calculated. Consistency coefficients (W) of the subjective evaluations are given in ***Table 5***.

The higher and statistically significant W values mean that agreement among the panelists is higher than it would be by coincidence. The highest consistency coefficient is determined for the general handle, which could be explained by the smaller ranking of general handle evaluation compared to primary handle evaluation, whereas the lowest coefficient is determined for the warm-cool feeling. As it is known that warm-cool feeling evaluation is quite difficult for panelists, this was an expected result. In order to determine the relationship between the subjective evaluation values using the results of the 40 panelists, correlation coefficients were calculated. As is shown in ***Table 6***, the highest correlation is calculated between the smoothness and roughness evaluations.

When the fabric is thicker and stiffer, the handle of the fabric worsens, and with the decrease in the roughness of the fabric and with the increment in cool feeling, the handle of the fabric is evaluated as being better.

Before composing an equation for the estimation of the fabric handle by using the objective test results, an equation was formulated with subjective primary handle values. The contribution shares of four primary handle components of general handle were determined by considering the correlation coefficients between each handle component and the general handle value, which are as follows: 40% softness-stiffness, 35% roughness-smoothness, 25% thinness-thickness, and 5% warm-cool feeling. The subjective handle (CHV) equation calculated is given below, where softness - stiffness is abbreviated as "S"/S, roughness - smoothness as "R"/R, thinness - thick-

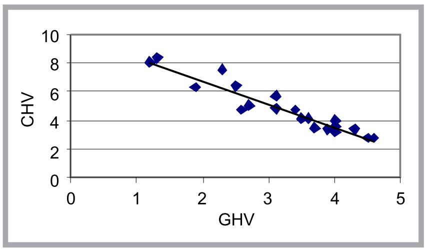

Figure 1. *Correlation between the general handle (SHV) and calculated handle values (CHV).*

Table 4. *Subjective evaluation results of 20 fabrics.*

Fabric nr	Thinness-Thickness		Softness-Stiffness		Roughness-Smoothness		Warm-Cool Feeling		Subjective General Handle	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
1	4.1	1.455	4.1	1.127	5.9	1.586	6.1	2.185	3.4	0.874
2	3.6	1.193	3.5	1.094	4.9	1.781	6.5	2.141	3.6	0.967
3	3.3	1.386	3.1	1.116	3.5	1.154	6.4	2.634	3.9	0.736
4	2.5	1.192	2.7	0.992	2.4	0.849	7.1	2.658	4.6	0.616
5	2.5	1.050	2.7	1.067	2.4	0.879	6.7	2.866	4.5	0.664
6	3.7	1.223	4.0	1.068	3.9	1.107	6.6	2.091	4.0	0.873
7	3.4	1.455	3.2	1.149	3.1	1.201	6.4	2.638	4.3	0.775
8	3.1	1.083	3.3	1.240	3.9	1.225	6.6	2.579	4.0	0.943
9	3.5	1.261	3.6	1.328	5.1	1.679	6.4	2.121	3.5	1.022
10	3.6	1.612	2.9	1.657	2.8	1.092	6.6	2.342	4.0	0.933
11	5.0	1.305	4.8	1.339	7.5	1.785	5.9	2.142	3.1	1.205
12	7.9	1.039	3.2	1.733	4.8	1.993	3.9	2.369	3.1	1.266
13	7.1	1.640	5.9	1.691	6.1	1.981	6.4	1.975	1.9	0.839
14	5.3	1.445	4.9	1.364	4.8	1.572	6.1	2.304	2.7	1.157
15	3.3	1.299	3.5	1.288	3.1	1.345	7.0	2.585	3.7	1.077
16	4.1	1.350	4.5	1.213	5.4	1.297	5.8	2.074	2.6	1.334
17	6.7	1.465	8.0	1.439	8.1	1.779	5.3	1.853	2.3	1.235
18	6.7	1.369	6.3	1.121	6.4	1.368	5.4	1.911	2.5	1.140
19	8.7	1.214	8.3	1.102	7.6	1.537	5.0	1.819	1.2	0.406
20	7.2	1.746	8.9	1.001	9.0	1.558	5.1	1.802	1.3	0.685
max	8.7	1.746	8.9	1.733	9.0	1.993	7.1	2.866	4.6	1.334
min	2.5	1.039	2.7	0.992	2.4	0.849	3.9	1.802	1.2	0.406

Table 5. *Kendall consistency coefficients; *significant according to α = 0.01.*

	Thinness-Thickness	Softness-Stiffness	Roughness-Smoothness	Warm-Cool Feeling	Subjective General Handle
Kendall consistency coefficient (W)	0.633*	0.680*	0.631*	0.466*	0.737*

Table 6. *Spearman correlation coefficients among the subjective evaluation results; *Correlation coefficients are significant at α = 0.01.*

	Thinness-Thickness	Softness-Stiffness	Roughness-Smoothness	Warm-Cool Feeling	Subjective General Handle
Thinness-Thickness	1				
Softness-Stiffness	0.793*	1			
Roughness-Smoothness	0.810*	0.919*	1		
Warm-Cool Feeling	0.869*	0.692*	0.804*	1	
General Handle	-0.896*	-0.905*	-0.901*	0.828*	1

Table 7. Objectively measured parameters of the test fabrics.

Fabric Nr	Mass per unit area, g/m²	Thickness, mm (3 g/cm²)	Thickness, mm (63 g/cm²)	Surface thickness, mm	Relative compressibility, %	Circular bending rigidity, cN	Bending length -weft, cm	Bending length -warp, cm	Bending rigidity-weft, mg·cm	Bending rigidity-warp, mg·cm	General bending rigidity, mg·cm	Drape coefficient	Drape angle, °	Static friction coefficient	Thermal absorbsion, Ws$^{1/2}$/m^{2}K
1	.16	0.247	0.185	0.062	25.00	7.80	0.896	1.475	8.422	37.29	17.72	35.71	64.45	0.291	168
2	126	0.238	0.180	0.058	24.48	8.50	0.854	1.408	8.004	35.30	16.81	38.71	66.08	0.305	165
3	115	0.200	0.137	0.063	31.67	8.67	0.955	1.475	10.023	36.92	19.24	36.34	66.31	0.296	179
4	106	0.165	0.107	0.058	35.35	7.17	0.867	1.383	6.913	28.10	13.94	28.70	65.97	0.267	191
5	106	0.173	0.120	0.053	30.77	7.67	0.838	1.421	6.481	30.48	14.06	37.29	68.29	0.285	174
6	115	0.195	0.135	0.060	30.77	7.58	1.025	1.483	12.399	37.53	21.57	41.54	65.77	0.264	181
7	114	0.198	0.143	0.055	27.73	8.58	1.013	1.458	11.844	35.35	20.46	37.70	66.79	0.295	182
8	116	0.230	0.163	0.067	28.99	7.67	0.992	1.350	11.346	28.56	18.00	31.82	65.21	0.299	162
9	112	0.217	0.150	0.067	30.77	8.08	1.029	1.308	12.214	25.14	17.53	35.76	66.93	0.297	157
10	132	0.270	0.208	0.062	22.84	8.3	0.958	1.404	11.627	36.72	20.66	31.83	61.74	0.305	168
11	128	0.302	0.232	0.070	23.20	7.92	0.871	1.367	8.461	32.68	16.63	35.81	57.55	0.323	157
12	164	0.697	0.533	0.163	23.45	42.75	1.204	1.529	28.637	58.77	41.03	30.57	72.09	0.353	110
13	200	0.373	0.300	0.073	19.64	89.00	1.068	1.346	24.497	48.80	34.58	48.32	57.15	0.373	189
14	136	0.257	0.193	0.063	24.68	52.00	1.196	1.504	23.484	48.20	33.64	49.69	56.41	0.304	186
15	126	0.227	0.163	0.063	27.94	8..50	1.021	1.604	13.413	52.07	26.43	33.24	67.77	0.288	167
16	114	0.250	0.182	0.068	27.33	7..30	1.217	1.271	20.550	23.40	21.93	38.34	61.40	0.309	159
17	109	0.290	0.218	0.072	24.71	183.6	1.242	2.942	20.884	279.0	76.34	67.26	44.00	0.297	147
18	173	0.417	0.327	0.090	21.60	71.08	1.263	1.517	34.922	60.36	45.91	52.81	60.39	0.307	166
19	155	0.398	0.310	0.088	22.18	341.0	1.371	2.763	39.971	327.1	114.35	67.40	49.09	0.321	150
20	119	0.408	0.320	0.088	21.63	169.2	1.396	2.746	32.390	246.6	89.39	63.30	40.45	0.323	133
X	129	0.288	0.215	0.072	26.23	52.6	1.0637	1.638	17.324	75.43	34.01	42.11	61.19	0.305	164
S	25	0.123	0.101	0.024	4.159	86.34	0.173	0.516	10.203	91.54	27.75	12.048	8.345	0.025	19.6
min	106	0.165	0.107	0.053	19.64	7.170	0.838	1.271	6.481	23.40	13.94	28.7	40.45	0.264	110
max	200	0.697	0.533	0.163	35.35	341.1	1.396	2.942	39.971	327.1	114.35	67.4	72.09	0.373	191

ness as "T"/*T* and warm - cool feeling as "WC"/*WC*.

$$CHV = 0.4 \times S + 0.35 \times R + 0.25 \times T + 0.05 \times WC$$

Subjective handle values of the 20 fabrics were calculated using this equation. The correlation between the subjective general handle values (*SHV*) that were given by the panelists and the calculated handle value is (r = -0,955) significant for $\alpha = 0.01$ significance level. The scatter plot between the general handle value and calculated handle value is given in ***Figure 1***.

Objective evaluation of fabric handle

In the scope of the present work, in order to determine the fabric handle by means of the mechanical and structural properties of the fabrics, 15 different characteristics of the 20 shirting fabrics were measured and the average values of the features determined are presented in ***Table 7***.

Spearman correlation coefficients between the subjective evaluations and objective test results were calculated and are given in ***Table 8***.

As shown in ***Table 8***, there is a significant correlation between each of the fabric properties measured and general handle, except the bending length in the warp direction. Although the correlations between the subjective thickness evaluation and each of the properties are statistically important, the highest correlations are observed between the thickness and compressibility measurements. The correlation coefficient between the subjective roughness evaluation and the static friction coefficient is 0.6, which is statistically significant. Thermal absorption and warm-cool feeling, which can be defined as the first impression when touching a fabric, also have a statistically important correlation.

Multiple linear regression analysis was applied in order to estimate the fabric handle objectively. In this analysis the

*Table 8. Spearman correlation coefficients between the subjective evaluations and objective test results; *Correlation coefficients are significant at α = 0.01.*

Parameters	Subjective general handle	Subjecitve Thinness-Thickness	Subjective Softness-Stiffness	Subjective Roughness-Smoothness	Subjective Warm-Cool Feeling
Mass per unit area	-0.537*	0.645*	0.402	0.36	-0.391
Thickness (3 g/cm²)	-0.838*	0.893*	0.666*	0.7*	-0.805*
Thickness (63 g/cm²)	-0.829*	0.896*	0.668*	0.7*	-0.800*
Surface thickness	-0.831*	0.787*	0.671*	0.7*	-0.783*
Relative compression	0.745*	-0.815*	-0.643*	-0.7*	0.612*
Circular bending rigidity	-0.706*	0.695*	0.595*	0.6*	-0.628*
Bending length-weft	-0.778*	0.753*	0.741*	0.6*	-0.721*
Bending length-warp	-0.352	0.445*	0.370	0.27	-0.421
Bending rigidity-weft	-0.779*	0.798*	0.709*	0.58	-0.685*
Bending rigidity-warp	-0.621*	0.710*	0.590*	0.5*	-0.541*
General bending rigidity	0.756*	0.781*	0.687*	0.6*	-0.665*
Drape coefficient	-0.672*	0.592*	0.783*	0.6*	-0.510*
Drape angle	0.716*	-0.635*	-0.814*	-0.7*	0.510*
Static friction coefficient	-0.736*	0.748*	0.515*	0.6*	-0.682*
Thermal absorbsion	0.524*	-0.486*	-0.405	-0.6*	0.655*

subjective general handle value (*SHV*) was evaluated as a dependent variable (*y*), and other objective test values were evaluated as independent variables (*x*). The contributions of some independent variables may not be that important in the regression equations, and in this case it is possible to decide whether independent variables (*k*) are necessary or not in the regression equations by using the Stepwise method. If a similar successful regression equation was formulated with fewer independent variables, their contribution would be less important and therefore be omitted. The method of checking whether the contribution (*p*) of independent variables to the equation is statistically important or not, is first to calculate the regression equation with all variables and to find the determination coefficient (R^2_k),second to calculate a new regression equation with (k - p) independent variables by omitting (p) variables, and finally to calculate the determination coefficients of the new equation (R^2_p) [11].

In the present work, a regression equation consisting of all independent variables is calculated first, and then new regression equations are formulated by the Stepwise method using parameters that contribute to the equations more than others. Coefficients of the independent variables and related adjusted regression R^2 values are given in ***Table 9***.

After investigating the coefficients of the variables in the equations, it was determined that the coefficients of the first model are not statistically important, whereas the others are. The regression determination coefficient of the 5th model, consisting of bending rigidity in the weft direction, drape angle and static friction coefficient, is the highest at 91.9%.

Graphics indicating the relationship between the estimated handle values (*EHV*) and subjective handle values (*SHV*) are given in ***Figure 2***.

When the graphics indicating the relation between the real subjective handle values (*SHV*) and estimated handle values (*EHV*) are examined, it can be seen that the best fabric handle estimation was performed with the 5th model. However, as the 2nd model consists of different objective test measurements that affect fabric handle, and as its regression determination coefficient is statistically important and sufficiently high, the 2nd equation is chosen for the estimation of fabric handle.

Table 9. *Regression equations calculated with SHV and fabric properties measured.*

Method	Model No	Independent variables of the models	Coefficient	Adjusted R², %
Enter method	1	Constant	10.90	86.7
		Mass per unit area	-0.0140	
		Thickness (3g/cm²)	-34.20	
		Thickness (63g/cm²)	-41.10	
		Surface thickness	17.30	
		Relative compression	-0.0103	
		Circular bending rigidity	-0.0145	
		Bending length-weft	-6.580	
		Bending length-warp	-1.690	
		Bending rigidity-weft	0.103	
		Bending rigidity-warp	0.0245	
		General bending rigidity	-0.0021	
		Drape coefficient	-0.0082	
		Drape angle	0.0427	
		Static friction coefficient	-13.40	
		Thermal absorption	0.0183	
Enter method	2	Constant	5.89	82.3
		Mass per unit area	-0.0047	
		Surface thickness	-2.35	
		Relative compression	0.0114	
		Circular bending rigidity	0.00204	
		General bending rigidity	0.0109	
		Drape coefficient	-0.0264	
		Drape angle	0.0369	
		Static friction coefficient	-10.70	
Stepwise method	3	Constant	4.6648	73.3
		Bending rigidity-weft	-0.0840	
Stepwise method	4	Constant	0.8513	87.2
		Bending rigidity-weft	-0.0579	
		Drape angle	0.055	
Stepwise method	5	Constant	3.6473	91.9
		Bending rigidity-weft	-0.0434	
		Drape angle	0.0580	
		Static friction coefficient	-10.500	

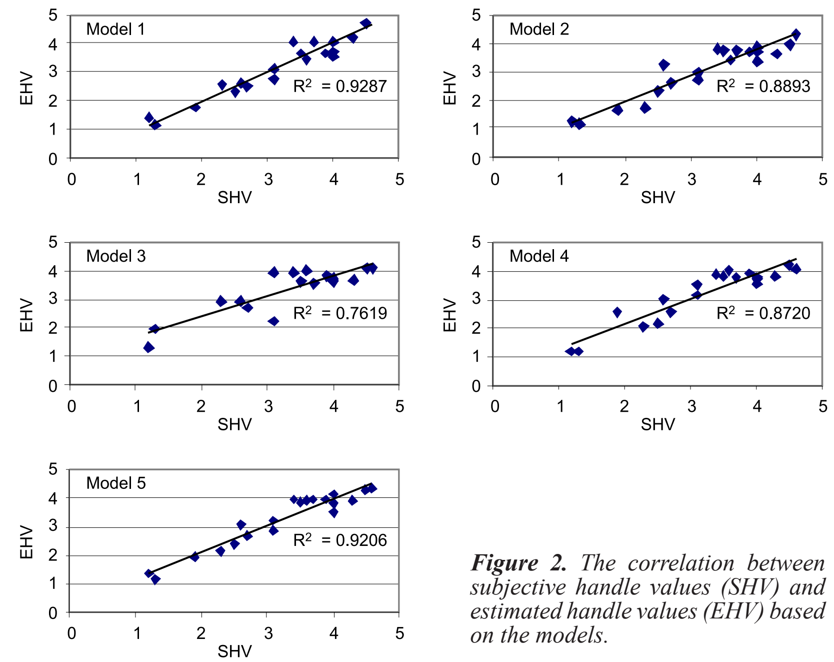

Figure 2. *The correlation between subjective handle values (SHV) and estimated handle values (EHV) based on the models.*

The fabric's general handle value (EHV) is expressed by the fallowing dependency

$$EHV = 5.89 - 0.0047\ M - 2.350\ ST + 0.0114\ RC + 0.00204\ CBR + 0.0109\ GBR - 0.0264\ DC + 0.0369\ DA - 10.7\ SFC \quad (1)$$

where:

M – weight
ST – surface thickness
RC – relative compression
CBR – circular bending rigidity
GBR – general bending rigidity
DC – drape coefficient
DA – drape angle
SFC – statistic friction coefficient.

As a second step, regression analysis was applied to the objectively measured fabric

Table 10. *Regression equations determined with calculated SHV and fabric properties measured.*

Method	Model Nr	Independent variables of the models	Coefficient	Adjusted R^2, %
Enter method	6	Constant	17.10	80.0
		Mass per unit area	-0.0168	
		Thickness (3g/cm²)	-378.0	
		Thickness (63g/cm²)	228.0	
		Surface thickness	528.0	
		Relative compression	-0.312	
		Circular bending rigidity	-0.0634	
		Bending length-weft	-15.00	
		Bending length-warp	-7.690	
		Bending rigidity-weft	0.2070	
		Bending rigidity-warp	0.0679	
		General bending rigidity	0.119	
		Drape coefficient	0.0326	
		Drape angle	0.0178	
		Static friction coefficient	6.400	
		Thermal absorption	0.0565	
Enter method	7	Constant	7.260	82.0
		Mass per unit area	-0.00439	
		Surface thickness	0.1300	
		Relative compression	0.0010	
		Circular bending rigidity	0.00299	
		General bending rigidity	-0.0158	
		Drape coefficient	-0.0260	
		Drape angle	0.0324	
		Static friction coefficient	-13.200	
Stepwise method	8	Constant	4.6650	73.3
		Bending rigidity-weft	-0.0840	
Stepwise method	9	Constant	0.8517	87.2
		Bending rigidity-weft	-0.0579	
		Drape angle	0.055	
Stepwise method	10	Constant	3.6140	91.8
		Bending rigidity-weft	-0.0423	
		Drape angle	0.057	
		Static friction coefficient	-10.40	

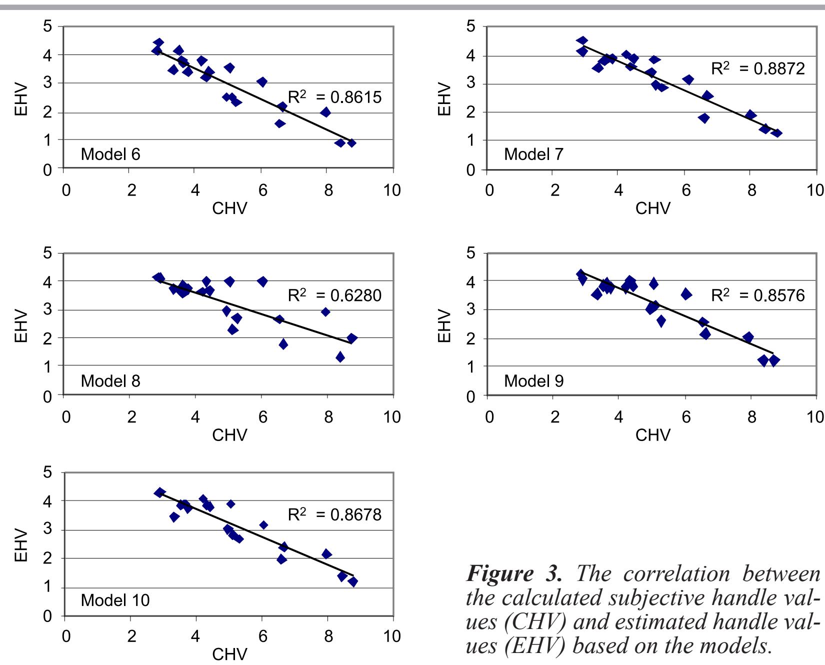

Figure 3. *The correlation between the calculated subjective handle values (CHV) and estimated handle values (EHV) based on the models.*

properties and the calculated fabric handle value (*CHV*), which is determined by using primary handle values according to their contribution to the general fabric handle. The parameters of the equations that were determined by regression analysis and their determination coefficients are given in ***Table 10***.

The regression determination coefficients of the equations, calculated using the calculated subjective fabric handle value (*CHV*) as a dependent variable, are lower compared to the coefficients of the previously explained models.

The graphics representing the comparison of the estimated fabric handle values (*EHV*) and calculated subjective fabric handle values (*CHV*) are given in ***Figure 3***.

When the graphics shown in ***Figure 3*** are examined it can be concluded that the best fabric handle estimation can be obtained with the 10th model. However, the same reasons for choosing the 2nd model in the first step of the present work are also valid here, and therefore it can be stated that the 7th model can estimate the fabric handle better compared to the other models, but again it is not better than the 2nd model.

The fabric's general handle value (EHV) is expressed by the following dependency

$$EHV = 7.26 - 0.00439\,M + 0.13ST + 0.0010\,RC + 0.00299\,CBR - 0.0158\,GBR - 0.0260\,DC + 0.0324\,DA - 13.2\,SFC \quad (2)$$

where denotations as for equation (1).

In the present work, conducted for the purpose of determining the fabric handle objectively, 10 different models were designated, and the most convenient one was chosen. In order to study the validity of the models proposed for the objective estimation of shirting fabric handle, 9 different shirting fabrics were chosen as a control group and 15 panelists performed the same kind of subjective handle tests. Objective parameters were also measured. The subjective handle evaluation results of 9 fabrics are given in ***Table 11*** (see page 62).

The limits of the evaluations of primary and general handle values of the control fabrics, as shown, are of a smaller range compared to the limits of the fabrics used in the present work, which can be the result of similar fabric properties or the lower number of panelists. The general handle values of the 20 test fabrics are between 1.2 - 4.6, whereas for the control fabrics the limits are between 1.9 - 4.3. The objective measurements of the control fabrics are given in ***Table 12*** (see page 62).

Estimated fabric handle values calculated using the 2nd model and real subjective fabric handle values given by 15 panelists are compared in ***Table 13*** (see page 62).

As can be seen in ***Table 13***, the model used for the objective estimation of the fabric handle is a quite estimator due to the fact that the deviation between the real sub-

Table 11. *Subjective handle evaluation values.*

Fabric no	Thinness-Thickness		Softness-Stiffness		Roughness-Smoothness		Warm-Cool Feeling		General Handle	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
1	5.0	1.202	5.6	1.008	5.0	1.757	6.6	2.371	2.3	0.842
2	3.2	1.014	3.7	0.957	3.8	1.097	6.6	2.086	3.2	0.994
3	3.4	1.077	3.0	1.060	2.9	0.834	6.5	1.950	4.3	0.923
4	3.5	1.172	3.2	0.748	3.7	0.797	6.0	1.753	3.8	0.645
5	4.5	1.482	4.4	1.008	5.7	2.068	6.1	2.187	3.4	0.481
6	6.7	2.225	7.3	1.731	7.8	1.839	5.5	2.175	1.9	1.089
7	4.2	1.067	4.1	1.695	4.4	1.147	5.7	1.878	3.9	1.116
8	4.6	1.671	3.5	0.834	3.2	1.175	6.2	2.380	3.7	1.047
9	4.9	0.890	5.1	1.628	7.5	1.369	4.4	0.954	2.9	0.896
max	6.7	2.225	7.3	1.731	7.8	2.068	6.6	2.380	4.3	1.116
min	3.2	0.890	3.0	0.748	2.9	0.797	4.4	0.954	1.9	0.481

Table 13. *SHV and EHV values of the control fabrics.*

SHV	Estimated SHV	Deviation (SHV-EHV)
2.8	3.0	-0.2
4.1	4.1	0.0
3.9	3.8	-0.1
3.8	4.0	-0.2
3.5	3.7	-0.2
2.7	2.6	+0.1
3.9	3.9	0.0
3.7	3.5	+0.2
3.7	3.9	-0.2

jective fabric handle and estimated handle value varies between the range ± 0.2.

Conclusions

This study aimed to define an equation for the objective estimation of shirting fabric. For this purpose, by using subjective evaluation values and 16 different measured parameters of 20 shirting fabrics, multiple regression analysis was performed, which led to the following conclusions:

- The 2nd model, consisting of fabric mass per unit area, surface thickness, relative compression, circular bending rigidity, general bending rigidity, drape coefficient, drape angle and static friction coefficient values, was chosen as a good estimator of fabric handle since the correlation between the real and estimated fabric handle is 88.9%. Also the equation includes different fabric properties related to fabric handle.
- In order to check the validity of the model, 9 different shirting fabrics were used. The maximum deviation between the real and estimated handle values of the control fabrics was determined as ± 0. 2.
- Consequently, it can be stated that the model determined can be used in the objective handle evaluation of shirt fabrics as a good estimator.

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Table 12. *Objectively measured parameters of the control fabrics.*

Fabric Nr	Mass per unit area, g/m^2	Thickness, mm (3 g/cm^2)	Thickness, mm (63 g/cm^2)	Surface thickness, mm	Relative compression, %	Circular bending rigidity, cN	Bending kength -weft, cm	Bending length - warp, cm	Bending rigidity-weft, mg·cm	Bending rigidity-warp, mg·cm	General bending rigidity, mg·cm	Drape coefficient	Drape angle, °	Static friction coefficient	Thermal absorbsion, Ws$^{1/2}$/m^{2}K
1	146	0.27	0.20	0.07	24.8	41.8	1.31	3.40	33.05	72.71	49.02	54.15	64.9	0.269	171
2	102	0.28	0.21	0.08	26.5	6.83	1.44	3.13	30.58	38.98	34.52	32.48	70.9	0.263	136
3	109	0.24	0.18	0.08	25.0	7.58	1.53	2.74	39.30	28.14	33.25	34.51	72.6	0.293	151
4	110	0.26	0.18	0.08	31.4	7.58	1.10	2.43	14.82	19.69	17.09	37.92	73.7	0.283	129
5	90	0.26	0.17	0.07	33.3	7.58	1.09	2.54	11.94	18.55	14.88	45.31	65.8	0.283	145
6	120	0.28	0.21	0.08	26.6	125.1	1.30	4.22	26.96	112.50	55.06	72.49	60.5	0.286	143
7	93	0.28	0.21	0.08	25.0	8.25	1.40	2.89	25.83	28.10	26.95	39.25	72.3	0.282	116
8	119	0.29	0.21	0.07	27.6	6.67	1.41	2.90	33.86	36.30	35.08	37.79	72.1	0.303	159
9	112	0.30	0.21	0.08	28.8	7.33	1.35	3.03	27.44	38.89	32.67	35.11	72.5	0.275	125
X	111	0.27	0.20	0.08	27.67	24.30	1.33	3.03	27.09	43.76	33.17	43.22	69.5	0.28	141
s	16,6	0.02	0.02	0.00	3.00	39.48	0.15	0.53	8.83	30.35	13.08	12.80	4.58	0.01	17.2
max	146	0.3	0.21	0.08	33.3	125.1	1.53	4.22	39.3	112.5	55.06	72.49	73.7	0.303	171
min	90	0.24	0.17	0.07	24.8	6.67	1.09	2.43	11.94	18.55	14.88	32.48	60.5	0.263	116