NC STATE College of Textiles

JTATM Journal of Textile and Apparel, Technology and Management

Volume 9, Issue 3, 2015

Objective Evaluation of the Handle of Woven Terry Fabrics

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ABSTRACT

The aim of the work is development of a methodology and an integrated assessment for objective evaluation of terry fabric handle. They should meet the following criteria, which will allow to use them not only in scientific researches, but also in the quality control of products in manufacturing plants: to be based on standardized methods or universal appliances, the assessment to be easily calculated and to comply with the most common scale for handle evaluation – that of Kawabata.

The integrated assessment is derived my means of the multiple regression analysis and includes six characteristics of terry fabrics that have a proven impact on handle: thickness, relative compression at pressing, bending stiffness, coefficient of elasticity at tension, coefficient of elasticity at shearing and dynamic coefficient of friction. The assessment obtained corresponds to the subjective one.

The methodology for evaluation is worked out as a draft standard. A software application for automatic computation of the assessment is developed. It runs under Windows, does not require installation and is easy to use.

Keywords: integrated assessment of handle; objective evaluation; woven terry fabric; standard method

Introduction

Handle is one of the important quality parameters for textile products. There is no consumer who, when buying clothing, interior textiles or when evaluating the upholstery of a car, has not touched the product to see what it feels like.

The first attempts to evaluate the handle of textile products date back to 1926, when Binns set the beginning of systematic subjective evaluation (Binns, 1926). Subsequently, many authors have contributed to both its subjective and objective measuring, starting from Peirce (Peirce, 1930) who first suggested the evaluation to

be carried out by measuring the physical and mechanical properties, through Kawabata and Niwa (Kawabata, 1980; Kawabata & Niwa, 1991, 1998), Postle (1990), Pan (Pan et al., 1988a, 1988b, 1993; Pan, 2007) and many others (Matsudaira, 2006; Singh et al., 2014; Sztandera, 2008a, 2008b; Zeng, 2004). Some of the investigations led to the development of devices for objective measurement of the handle, such as KES (Kawabata's Evaluation System), FAST (Fabric Assurance by Simple Testing), PhabrOmeter System, Handle-O-Meter, etc., and other - to the development of models for integral evaluation of handle for different textiles products.

Globally, the most widespread is the system of Kawabata. From the measured characteristics through regression models, the so-called *THV* (Total Hand Value) is determined, which is based on the subjective evaluation of handle and is respectively influenced by the social and geographical situation of the experts Pan (Pan et al., 1988a). Most often, linear or combined linear-logarithmic models are used for its calculation. In 1990, a similar system – the FAST of CSIRO (Tester & Boos, 1990) appeared. It is simpler, realizes only semi-cyclical loads and the handle can be assessed by the so-called finger print.

To avoid the subjectivity, Pan proposed the determination of *THV* to be done objectively by application of the Weighted Euclidean Distance (Pan, 2007). It represents the deviation of the sample from a standard set in *n*-dimensional space where each axis is an objectively measurable property. The particular properties and their number vary by the different authors (Pan, 2007; Sztandera, 2008a, 2008b). The device PhabrOmeter (www.phabrometer.com/FAQ/pgeDefinition.aspx) works using this method, as well as many other devices and stands where the force at extraction of a circular sample through a nozzle or ring is measured. The basic parameters involved in the evaluation of handle are taken from the curve force/displacement.

The fabric handle can also be evaluated through the resistance that a sample shows when inserting it into a slot using a beam (www.thwingalbert.com/handle-o-meter.html). The resistance is function from the sample's flexibility and surface friction.

Despite the availability of numerous methods and devices for evaluating the handle, the method of Kawabata remains the most prevalent. Applying his approach, a number of translational equations for different types of fabrics have been derived.

The importance of the handle for terry products is huge (Yilmaz & Powell, 2005), but such relations for this class of fabrics have not been developed yet. Most studies examine some aspects of the problem. A more complex approach was applied by Frontczak-Wasiak and Snycerski, who suggest the use of radial diagrams for ranking of fabrics according to their handle. However, the authors do not suggest a numerical evaluation (Frontezak-Wasiak & Snycerski, 2004).

2. Experiment

The aim of the investigation is development of a methodology for evaluation of terry fabric handle. In order to be applied in manufacturing plants also, it should be relatively simple and therefore, the following requirements were set:

- use of devices, which are universal or inexpensive;
- easy calculation of the integrated assessment;
- comparability of the assessment with existing rating scales.

The approach of Kawabata was used as well as the scale proposed for evaluation of the handle quality. The investigation process was carried out in the following steps:

(1) *Determination of the properties characterizing terry fabric handle and their ranking according to the degree of influence*. For this purpose, an inquiry was developed and a survey among specialists was conducted.

Obtained results were processed by the method of rank correlation.

(2) *Conduction of a subjective evaluation of the handle of terry fabrics.* It was conducted by specialists and consumers under Evaluation Procedure 5 – Handle of Fabrics: Guidelines for Subjective Evaluation (AATCC Evaluation Procedure 5). Fabrics with different structural features and finishes were examined.

(3) *Development of a methodology for testing and evaluation of terry fabric handle.* An analysis of the existing methods for determining the properties characterizing the handle was performed, and the methods, devices and tools according to the requirements set were chosen. Examinations were conducted to establish the appropriate conditions for testing of terry fabrics.

(4) *Objective measurement of the properties influencing the handle.* The determination was performed in accordance with the selected methods, devices and test conditions.

(5) *Deriving a mathematical model for calculation of a numerical assessment of terry fabric handle.* By multiple regression analysis, relationships between subjective assessments and objectively measured properties characterizing the handle were derived. Different combinations of input parameters were tested. The adequacy of the models was examined and based on a certain requirements a model for calculation of the integrated handle assessment was selected.

(6) *Model validation.* A validation of the mathematical model through further examination of woven and nonwoven stitch-bonded structures was performed.

(7) *Drawing up the methodology as a standardization document.*

Steps 1 and 2

The results of the first two steps are presented in a particular publication of the research team (Kandzhikova & Germanova-Krasteva, 2015). They show that experts rank the criteria for evaluation of terry fabric handle according to their degree of influence in the following order: bulkiness, thickness, smoothness, stiffness, elasticity and elongation. The bulkiness was evaluated by the characteristics mass per unit area and rate of compression, the stiffness – by bending stiffness and shear stiffness, and the smoothness – by the coefficient of friction.

Step 3

For the characteristics specified in the previous step, methods for their determination were selected or adopted.

Mass per unit area

The mass per unit area of textile fabrics is determined according to the European standard EN 12127:2000. The method is suitable for terry fabrics and is cited as reference in EN 14697:2006 Textiles - Terry towels and terry towel fabrics - Specification and methods of test. The mass per unit area is determined for 5 samples with an area of 100 cm^2, and is recalculated for square meter.

Thickness and compression rate

The methods for determining the thickness and the rate of compression vary according to the test conditions. In most cases, the test is semi-cyclical (the FAST system and conventional thickness gauges). In the KES-F system it is single-cyclical and allows the determination of the degree of recovery after compression. Preliminary experiments were carried out - deformation curves were drawn for various terry fabrics by variation of the pressure from 0.1 kPa to 10 kPa.

The method standardized with EN ISO 5084:2002, in which the area of compression is 20 cm^2, and the levels of load – 0.1 kPa and 1 kPa, was selected. It was proved that the chosen values are suitable for terry fabrics.

The compression rate ZR_x was defined in percentage according to DIN 53885:1998-12:

$$ZR_x = \frac{ZA_x}{a_x}.100 = \frac{a_x - a_{10x}}{a_x}100, \quad (1)$$

where a_x = thickness at pressure x (selected to be 0.1 kPa), a_{10x} = thickness at pressure $10x$ (selected to be 1 kPa), ZA_x = absolute rate of compression, mm.

The method does not require sophisticated or expensive equipment to determine the characteristics. A thickness gauge meter with a possibility for changing the load is sufficient. The only additional requirement that should be set is to increase the number of tests from 5 to 10. The reason is the non-uniform structure of the terry fabrics, which leads to a greater dispersion of the results obtained.

Coefficient of friction

The coefficient of friction significantly affects the touch sensation.

Friction is usually realized by a relative displacement of the fabric against a friction block, determining the static and dynamic coefficients of friction. In the system of Kawabata, the friction block is replaced by a module of 5 fine metal profile bent into a U-shape.

The method set out in EN ISO 8295:2006 is chosen. It uses a friction block and many devices meet its requirements. An additional advantage is the fact that the conditions laid down therein can be easily implemented using a standard dynamometer. The mass of the friction block should be 200 g, and the sliding speed - 100 mm/min.

Measurements should be carried out both on the front and the back side and in both directions of the samples. The aim is to eliminate the influence of the direction of the loops' incline.

Bending stiffness

The bending stiffness could be determined through forced bending of the sample, in which the force or the moment of bending is measured, and through bending caused by the own weight of the sample, wherein the bending length is measured.

Based on the first method works the module B2 of the system KES-F, as the moment is measured as a function of the bending curvature. The sample is bent in one direction, unloaded and bent in the other direction. In addition to the stiffness, the hysteresis of the bending moment is determined.

The second method offers two variations depending on the manner of sample gripping: Cantilever method and Heart Loop method. Both methods are standardized in ASTM D1388-08 (2012). The Cantilever method is applied in the FAST system. Both methods are easy to implement and tests according to them were conducted.

Samples with a bending length of 15, 20 and 25 cm were tested applying the Heart Loop method. Preliminary measurements were performed and it was found that the most appropriate length for terry fabrics is 15 cm. For a good grip of the sample, it was cut to a length of 20 cm. An additional advantage of the selected length was the possibility of using the same samples for testing by the Cantilever method, with the mandatory requirement for relaxation of the samples between both measurements.

It is also necessary the testing to be conducted bending the both sides of the fabric, as often in terry fabrics they differ.

Elastic behavior

The elastic properties represent the ability of the fabric to be deformed and then to recover. They are most often assessed by the coefficient of elasticity *QA* (Figure 1) giving the share of the recoverable to the total deformation:

$$QA = 1 - \frac{A_0}{A_1}, \quad (2)$$

where A_1 = elongation at the maximum force F_1, A_0 = elongation after unloading to the pre-force F_0.

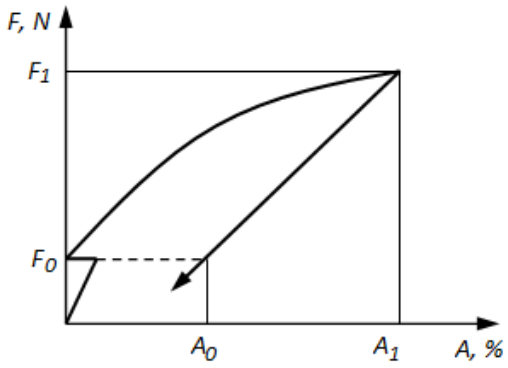

Figure 1. Determination of the coefficient of elasticity

After testing and analysis, the following test conditions were specified: test method, distance between the gripping clamps, pre-load, maximum load, speed of loading and unloading.

For testing of woven fabrics wider application has the Strip method. The width of the sample usually is 50 mm, excepting the KES-F system, where the width is 200 mm. Due to the relatively low levels of loading, the influence of the width of the sample is minimal and therefore, the Strip method with a 50 mm sample width was preferred.

The distance between the gripping clamps in various standards varies from 50 mm (KES-F) to 200 mm (EN 4704-1:2006 Method A), as in the FAST system, it is 100 mm. Tests were carried out at distances of 100 and 200 mm. No differences were obtained, and the value of 100 mm was chosen.

Large differences exist in the levels of load – both minimum (initial) and maximum. In KES-F system, the loads are 0.0981 N/cm and 4.9 N/cm, and in FAST - 0.049, 0.196 and 0.981 N/cm.

For the selection of appropriate loads, tests were carried out at levels of: 0.3 N, 0.5 N, 2 N, 5 N and 10 N for the initial loading and 6 N, 10 N, 15 N, 20 N and 25 N for the maximum loading.

The type of force-elongation curve is analyzed, as the following values are selected: for the pre- load – 0.5 N (0.1 N/cm), and for the maximum load – 25 N (5 N/cm). Both values are located in the linear zone of the deformation curve and correspond to the loads used in the system of Kawabata. Lower load levels are not suitable for terry fabrics because of their great mass per unit area and strength.

The test speed was set at 50 mm/min, which is suitable for determining the elastic properties of fabrics. For comparison: in the system of Kawabata, it is 12 mm/min, and in EN 4704-1:2006 – 100 mm/min.

The fabrics were tested in warp and weft direction. For each direction, 5 samples were tested. From the two average values, a common coefficient of elongation at tensile load was determined.

Behavior at shear loading

For assessment of the behavior of fabrics at shear, the following characteristics are used: shear stiffness, coefficient of elasticity at shear, shear angle, etc.

In KES the shear stiffness and the hysteresis at two shear angles (0.5º and 5º) are determined. In the frame constructions, the critical shear angle is measured. The determination of the exact moment of the first fold appearing and the need for special clamps or frame constructions make the examinations complicated and expensive.

The method used in FAST was preferred, because it can be realized by a universal dynamometer and standard clamps for testing of fabrics. The sample was cut at an angle of 45º to the warp/weft threads and thus the load occurs in a diagonal direction, creating shear forces in the fabric. In the FAST system, the load is semi-cyclical, but with a universal dynamometer it can be performed cyclically, which will allow the determination of the coefficient of elasticity at shear.

Examinations were carried out at various levels of load: 2 N, 5 N, 10 N and 15 N, as the moment of occurrence of the first folds was determined. A load up to a force of 5 N (1 N/cm) and a pre-load of 0.5 N (0.1 N/cm) were identified as appropriate.

The other test conditions corresponded to those for determination of the coefficient of elasticity at tension.

Step 4

In this step, a measurement of the characteristics defining the handle of terry fabrics was performed. They were determined by the methods defined in the preceding stage. Nine different fabrics were examined, the main characteristics of which are given in Table 1.

Table 1. Characteristics of the investigated fabrics

Characteristics	Mass per unit area, g/m^2	Thread density, threads/dm		Pile length, mm	Linear density, tex			Finishing
		warp	weft		warp	weft	pile	
Fabric 1	350	220	160	10	30	35	40	softened
Fabric 2	460	260	160	11	35	55	30	softened
Fabric 3	320	220	160	8	28	38	37	softened
Fabric 4	360	240	160	8	37	50	22	softened
Fabric 5	510	260	220	10	22 x 2	40	33	softened
Fabric 6	630	240	180	12	30 x 2	36	54	softened
Fabric 7	500	260	180	9	21 x 2	36	30 x 2	softened
Fabric 8	460	260	180	10	55	34	35	no softened
Fabric 9	390	240	160	12	60	34	35	raw

In Tables 2-7, the results for the following characteristics defining the handle are presented: mass per unit of area, thickness and compression rates, static and dynamic coefficients of friction, bending stiffness, coefficient of elasticity at tension, coefficient of elasticity at shear and shear stiffness.

Table 2. Mass per square unit

	Fabric №								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Mass per square unit, g/m^2	353.28	458.15	318.15	361.45	506.75	626.00	503.43	455.88	385.28

Table 3. Thickness and compression rates

	Fabric №								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Thickness at 0.1 kPa, mm	5.01	5.53	3.60	4.04	6.78	6.83	5.13	4.79	5.20
Thickness at 1 kPa, mm	3.18	3.98	2.57	2.81	4.86	5.16	4.32	3.44	3.12
Absolute rate of compression, mm	1.82	1.55	1.03	1.24	1.92	1.67	0.81	1.36	2.08
Relative rate of compression, %	36.27	28.05	28.46	30.37	28.33	24.52	15.81	28.32	39.76

Table 4. Coefficients of friction

	Fabric №								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Static, -	0.399	0.382	0.438	0.362	0.402	0.427	0.472	0.328	0.505
Dynamic, -	0.980	0.862	0.947	0.971	0.873	0.921	1.019	0.933	0.880

Table 5. Bending stiffness

Bending stiffness, μN.m		**Fabric №**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Cantilever	**Warp**	6.87	20.42	6.91	7.85	20.24	18.72	15.05	25.27	28.84
	Weft	7.18	14.06	7.11	7.68	13.92	11.64	7.45	11.39	12.13
	Mean	**7.03**	**17.24**	**7.01**	**7.76**	**17.08**	**15.18**	**11.25**	**18.33**	**20.48**
Heart Loop	**Warp**	9.78	23.90	12.77	10.00	31.25	37.79	29.16	27.12	26.13
	Weft	12.23	19.94	9.93	12.87	28.21	30.04	20.51	13.88	16.54
	Mean	**11.00**	**21.92**	**11.35**	**11.44**	**29.73**	**33.91**	**24.84**	**20.50**	**21.33**

Table 6. Coefficient of elasticity at tension

		Fabric №								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Coefficient of elasticity at tension	**Warp**	0.629	0.706	0.700	0.684	0.606	0.590	0.696	0.576	0.757
	Weft	0.716	0.671	0.723	0.710	0.587	0.600	0.623	0.550	0.738
	Mean	**0.672**	**0.688**	**0.711**	**0.697**	**0.597**	**0.595**	**0.659**	**0.563**	**0.747**

Table 7. Elastic properties at shear

	Fabric №								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Coefficient of elasticity, -	0.434	0.435	0.432	0.458	0.375	0.399	0.468	0.466	0.448
Stiffness at shear, N/m	9.889	10.35	11.53	10.02	10.09	9.706	9.785	8.774	11.51

Step 5

The equation for calculation of the integrated assessment of terry fabric handle was obtained by means of multiple regression analysis.

The number of input parameters was chosen to be 6, which allows the inclusion of a maximum number of characteristics in it and the presence of sufficient levels of freedom to verify its adequacy. For some input parameters, different characteristics were tested, as the goal was to determine which of them are more suitable and provide a more accurate model.

The input parameters were, as follows:

x_1 – thickness;
x_2 – absolute or relative compression;
x_3 – bending stiffness according to the Cantilever method or the Heart Loop method;
x_4 – coefficient of elasticity at tension;
x_5 – coefficient of elasticity at shear or shear stiffness;

x_6 – static or dynamic coefficient of friction.

Sixteen combinations of input parameters were developed. For the output parameter *Y*, the assessments from the subjective evaluation of the fabrics were used.

The adequacy of the 16 derived models was verified and for calculation of the integrated terry handle assessment was selected the one with the highest degree of accuracy and maximum number of significant coefficients.

The variant which corresponds to the specified criteria (Multiple R = 0.99861 and 6 relevant factors) is presented in Table 8. The last column shows the values calculated by the model.

Table 8. Data for derivation of the regression equation

	Thickness, mm	Relative compression, %	Bending stiffness (Heart Loop method), μN.m	Coefficient of elasticity at tension, -	Coefficient of elasticity at shear, -	Dynamic coefficient of friction, -	Subjective assessment	Values calculated by the model
	x_1	x_2	x_3	x_4	x_5	x_6	Y	Y_{calc}
Fabric 1	5.01	36.27	11.75	0.67	0.43	0.98	3.64	3.70
Fabric 2	5.53	28.05	22.70	0.69	0.44	0.85	2.89	2.96
Fabric 3	3.60	28.46	11.96	0.71	0.43	0.95	2.21	2.26
Fabric 4	4.04	30.37	10.00	0.70	0.46	0.96	3.25	3.19
Fabric 5	6.78	28.33	28.70	0.60	0.37	0.86	4.46	4.37
Fabric 6	6.83	24.52	33.91	0.60	0.41	0.92	2.50	2.58
Fabric 7	5.13	15.81	24.84	0.66	0.47	1.02	2.46	2.42
Fabric 8	4.79	28.32	20.50	0.56	0.47	0.93	2.14	2.13
Fabric 9	5.20	39.76	21.20	0.75	0.45	0.90	0.21	0.17

The regression equation for calculation of the integrated assessment has the following expression:

$$Y_{calc} = 17.848 + 1.906x_1 - 0.170x_2 - 0.342x_3 - 5.203x_4 - 10.705x_5 - 5.485x_6, \quad (3)$$

where Y_{calc} = assessment of terry fabric handle according to the scale of Kawabata (from 0 to 5), x_1 = thickness of the fabric, x_2 = relative compression rate, x_3 = bending stiffness determined by the Heart Loop method, x_4 = coefficient of elasticity at tension, x_4 = coefficient of elasticity at shear, x_5 = dynamic coefficient of friction.

The accuracy of the model is very high which is confirmed both by the value of the coefficient of multiple correlation and by the low value of the level of significance (Significance F = 0.0083).

Step 6

The validation of the mathematical model was done by examining two additional groups of terry fabrics – woven and nonwoven (Malipol).

The first group consisted of 3 new fabrics. As it can be seen in Table 9, the calculated by the model values are very close to the subjective assessments of the experts. Adding these three fabrics to the others, the value of the coefficient of multiple correlation did not change, but the significance of the model substantially increased, reaching level of Significance F = 1.338E-05.

Table 9. Validation of the model for woven structures

	Thickness, mm	Relative compression, %	Bending stiffness according to the Heart Loop method, μN.m	Coefficient of elasticity at tension, -	Coefficient of elasticity at shear, -	Dynamic coefficient of friction, -	Subjective assessment	Values calculated by the model
	x_1	x_2	x_3	x_4	x_5	x_6	Y	Y_{calc}
Fabric 10	4.03	29.77	15.37	0.51	0.369	1.03	3.12	2.96
Fabric 11	5.43	26.69	24.46	0.58	0.411	0.95	2.87	2.69
Fabric 12	6.65	28.12	25.94	0.59	0.429	0.78	4.89	4.96

The second group consisted of 5 Malipol products, four of which had loop coverage on both sides and one – one-side cut pile coverage. The purpose of the check-up was to examine the applicability of the model for other types of loop structures. The results are presented in Table 10. They clearly show that the developed model is not applicable for nonwoven loop structures due to their different structure and behavior under load.

Table 10. Validation of the model for nonwoven structures

	Thickness, mm	Relative compression, %	Bending stiffness according to the Heart Loop method, μN.m	Coefficient of elasticity at tension, -	Coefficient of elasticity at shear, -	Dynamic coefficient of friction, -	Subjective assessment	Values calculated by the model
	x_1	x_2	x_3	x_4	x_5	x_6	Y	Y_{calc}
Fabric 13	4.076	30.29	11.092	0.547	0.500	1.005	2.97	3.50
Fabric 14	4.969	25.14	12.183	0.586	0.530	0.950	4.95	4.11
Fabric 15	4.470	32.06	12.664	0.598	0.577	1.049	1.55	4.25
Fabric 16	4.412	33.56	16.057	0.614	0.635	1.062	-0.75	3.07
Fabric 17	4.736	32.01	18.37	0.564	0.558	1.169	-0.16	4.07

Step 7

In the last stage, the developed methodology for testing and calculation of the integrated assessment for terry fabric handle was described as standard in compliance with the requirements for such a document. A draft version is presented below.

TEXTILE
TERRY FABRICS
Method for Determination and Assessment of the Handle of Woven Terry Fabrics

1. Scope

The standard describes a method for objective assessment of the handle of woven terry fabrics by measuring the following characteristics: mass per unit area, thickness, compression rate, coefficient of friction, bending stiffness, coefficient of elasticity at tension and coefficient of elasticity at shear.

2. Referenced Documents

Listed below standards contain requirements for the application of the method for determination and assessment of terry fabric handle.

EN 20139:2000	Textiles - Standard Atmospheres for Conditioning and Testing
EN 12127:2000	Textiles - Fabrics - Determination of Mass per Unit Area using Small Samples
EN ISO 5084:1996	Textiles - Determination of Thickness of Textiles and Textile Products
EN ISO 8295:2004	Plastics - Film and Sheeting - Determination of the Coefficients of Friction
EN 14704-1:2005	Determination of the Elasticity of Fabrics - Part 1: Strip Tests
ASTM D1388-96	Standard Test Method for Stiffness of Fabrics

3. Definition

Handle is the perception caused by the senses of touch with a textile product.

4. Principle

The various aspects of the perception may be determined objectively, by measuring the parameters listed in item 1. The integrated assessment of the handle is a mathematical model linking the particular properties in a common assessment corresponding to the manual one.

5. Apparatuses

5.1. Balance

Balance with a precision ± 1 mg.

5.2. Thickness gauge meter

Thickness gauge meter in accordance with EN ISO 5084:1996.

5.3. Device for measuring the coefficient of friction

μ-meter in accordance with EN ISO 8295:2004.

5.4. Device for measuring the bending stiffness according to the Cantilever method

Device for measuring the bending stiffness according to the Cantilever method (ASTM D1388-96).

5.5. Device for measuring the bending stiffness according to the Heart Loop method

Device for measuring the bending stiffness according to the Heart Loop method (ASTM D1388-96).

5.6. Dynamometer able to perform cyclic tensile loads

Dynamometer with an option to realize cyclic tensile load in accordance with EN 14704-1:2006.

5.7. Stopwatch with precision of 1 s

5.8. Ruler with a measuring accuracy of 0.5 mm

5.9. Cutting device - scissors, guillotine or other cutting device

6. Conditioning

Precondition the specimens for 24 h by bringing them to approximate moisture equilibrium in the standard atmosphere for preconditioning textiles as directed in ISO 139:1993.

7. Sampling and test specimens

7.1. Take samples as follows:

7.1.1. in accordance with the instructions given in the specification of the material;

7.1.2. when such instructions are absent - in accordance with the procedures agreed between the parties concerned.

7.2. Relaxation of the fabrics

Place terry fabrics in a free state for 24 h for conditioning in accordance with item 6. After cutting the appropriate number of samples, left them in a standard atmosphere for 4 h. If a specimen will be re-tested, leave it for conditioning and relaxation as described above.

8. Procedure

8.1. Determination of the mass per unit area

In accordance with EN 12127:2000.

8.2. Determination of the thickness and the compression rate

8.2.1. Thickness determination

In accordance with EN ISO 5084:2002.

8.2.2. Compression rate determination

In accordance with EN ISO 5084:2002.

8.2.3. Number of test specimens

Prepare 10 test specimens for each sample.

Calculate the arithmetic means with an accuracy of 0.01 from the respective unit.

8.3. Determination of the coefficients of friction

In accordance with EN ISO 8295:2006.
Cut the sample strips along the warp and weft threads. Perform friction between two samples of the tested terry fabrics. Test in both directions (along the long side) on the front and on the back side.
Calculate the arithmetic means with an accuracy of 0.01.

8.4. Determination of the bending stiffness

8.4.1. According to the Cantilever Method (ASTM D1388-96)
Calculate the bending length for each testing direction to the nearest 0.1 cm, using the formula:

$$c = \frac{l}{2},$$

where c is the bending length, mm;
l – the length of overhang, mm.

8.4.2. According to the Heart Loop Method (ASTM D1388-96)
Cut the samples with a length of 20 cm, leaving a 15 cm length between the claps.
Calculate the bending length using the formulas:

$$c = l_0 . f(\theta),$$

$$l_0 = 0.1337 . L$$

$$f(\theta) = \frac{\cos\theta}{\tan\theta},$$

$$\theta = 32.85 \frac{l - l_0}{l_0},$$

where c is the bending length, cm;
l_0 – initial loop length, cm;
L – strip length, circumferential length of the unclamped portion of the specimen, cm;
θ – bending angle, degree;
l – loop length, distance between the bars when the strip is mounted, cm.

Calculate the flexural rigidity for each testing direction as:

$$G = W . c^3 . g . 10^{-6},$$

where G is the flexural rigidity, μN.m;
W – fabric mass per unit area, g/m^2;
c – bending length, mm;
g – standard gravity, m/s^2.
Calculate the average bending stiffness for both directions with an accuracy of 0.01 μN.m.

8.5. Determination of the coefficient of elasticity at tension

In accordance with EN 4704-1:2006 (Method A).
Perform a single-cycle test of the pre-cut strips (150 mm x 50 mm), by pre-load of 0.5 N and maximum load of 25 N. Determine the elongations at 25 N tensile load and after unloading - at 0.5 N. The initial distance between the clamps set at 100 mm and the test speed – at 50 mm/min.
Test the fabric in the direction of warp and weft threads. Number of test specimens - at least 5.
Calculate the coefficient of elasticity for each direction using the following formula:

$$QA_t = 1 - \frac{A_0}{A_1},$$

where QA_t is the coefficient of elasticity at tension;
A_0 – elongation after unloading to the pre-load, %;
A_1 – elongation at the maximum load, %.
Calculate the average coefficient of elasticity at tension for both directions to the nearest 0.01.

8.6. Determination of the shear stiffness and coefficient of elasticity at shear

In accordance with EN 4704-1:2006 (Method A).
Cut at least 5 specimens of 150 mm x 50 mm at an angle of 45º toward to the warp threads. Perform a single-cycle load at a pre-load of 0.5 N, and maximum force of 5 N. Determine the elongation of the material at load of 5 N, and by unloading – at 0.5 N. The initial distance between the clamps to be set at 100 mm and the test speed – at 50 mm/min.
Calculate the coefficient of elasticity at shear by the formula:

$$QA_{sh} = 1 - \frac{A_0}{A_1},$$

where QA_{sh} is the coefficient of elasticity at shear;
A_0 – elongation after unloading to the pre-load, %;
A_1 – elongation at the maximum load, %.
Calculate shear stiffness by the formula:

$$G = \frac{4.9}{4\,EB5}.\ 100,$$

where G is the shear stiffness, N/m;
$EB5$ – elongation at load of 5 N, %.
Calculate the average shear stiffness for both directions to the nearest 0.01.

9. Evaluation of terry fabric handle

Calculate the integrated assessment of the terry fabric handle to the nearest 0.01 by the formula:

$$Y = 17.848 + 1.906x_1 - 0.170x_2 - 0.342x_3 - 5.203x_4 - 10.705x_5 - 5.485x_6,$$

where Y is the assessment of terry fabric handle according to the scale of Kawabata (0-5);
x_1 – the thickness, mm;
x_2 – the relative compression rate, %;
x_3 – the bending stiffness determined by the Heart Loop method, μN.m;
x_4 – the coefficient of elasticity at tension, -;
x_5 – the coefficient of elasticity at shear, -;
x_6 – the dynamic coefficient of friction, -.
Classify the terry fabric according to the quality scale of Kawabata for Total Hand Value:

Perception	THV
Excellent	**5**
Good	**4**
Average	**3**
Satisfactory	**2**
Poor	**1**
Unusable	**0**

10. Report

Report the following information for each laboratory sampling unit and for the lot as applicable to a material specification or contract order:
10.1. that the testing, assessment calculation and evaluation were performed as directed in the standardization document;
10.2. the date of conducting the evaluation;
10.3. the average values of all measured characteristics, and (if required) the coefficient of variation, and the 95% confidence limits;
10.4. the assessment and the classification of the tested fabric regarding its handle ;
10.5. any deviation from the procedure made with the consent of the parties or for other reasons and the reasons for it.

3. Automated calculation of the assessment

For facilitating the putting into practice the methodology a software application has been developed that automatically calculates the terry fabric handle assessment. It was developed using Microsoft Visual Studio, does not require installation and works under the most used versions of Windows – Windows 2003 and Windows 7, both for 64-bit and 32- bit versions.

The interface consists of three tabs – "Home", "Calculator" and "Contacts". The main part of the application is the calculator for calculating the numerical assessment of terry fabric handle. By entering the necessary parameters, the program calculates the assessment according to the mathematical model derived above. For the users' convenience, suggestive text fields appear by entering the values. Depending on the received assessment, a text in the "Result" field is displayed, interpreting the resulting numerical evaluation according to rating scale of Kawabata (Figure 2).

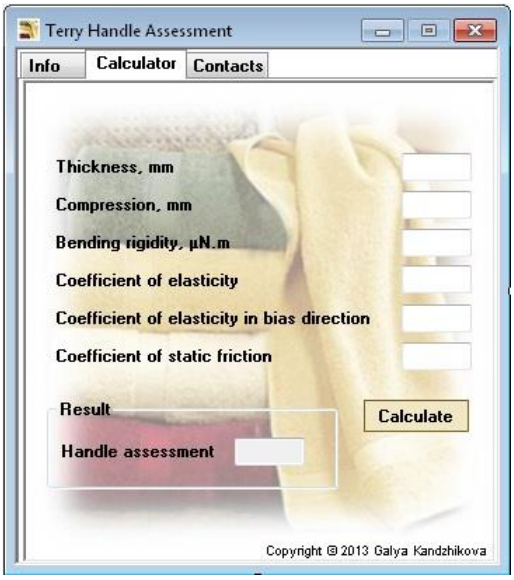

Figure 2. Interface of the software for calculation of terry fabric handle assessment

4. Conclusions

A methodology for the determination of the properties characterizing the handle of terry fabrics was developed. It includes a description of the methods, the devices, and the test conditions. Most methods are standardized and do not require any specialized equipment.

Using a regression analysis, an integrated assessment of the terry fabric handle was derived, including the thickness of the fabric, the relative compression rate, the bending stiffness determined by the Heart Loop method, the coefficient of elasticity at tension, the coefficient of elasticity at shear and the dynamic coefficient of friction.

The assessment is validated. The validation showed that it is suitable for fabrics and inapplicable for nonwoven loop and plush products.

Software for automated calculation of the handle assessment was developed. The application has an easy-to-use interface, works under Windows and does not need installation. The program displays a message about the quality level of the handle according to the scale of Kawabata.

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