UDK 677.064.1:687.268

BED TICKING FABRICS COMFORT EVALUATION*

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It is well known that hand plays an important role as the first characteristic entering to contact with consumer. With the development of new types of technologies and textile products, the objective characterization of hand becomes more important. This leads to the finding of objective techniques for prediction of subjective hand based on the special regression models (multivariate calibration). For prediction of hand the KES (Kawabata Evaluation System) is routinely used. This system is tuned for specific kinds of fabrics only. The main aim of this contribution is utilization of KES properties for creation of regression type prediction model suitable for estimation of the median of bed ticking fabrics subjective hand. The subset of properties correlated strongly with subjective hand is used.

In this contribution the subjective hand evaluation of bed ticking fabrics is discussed. For representation of results the approach based on categorized variables is used. For the case of subjective hand the ordinal median is computed. Groups of 16 respondents are used for evaluation of hand and appearance of 61 finely selected bed ticking fabrics.

The data from KES measurements are analyzed by multivariate statistical methods for evaluation of potential sources of heterogeneity (clusters and outliers) and mutual dependencies. The clusters and PCA analysis are applied for grouping tendency estimation.

The complex system for prediction of bed ticking fabrics hand is presented. The subset of KES properties connected significantly with subjective hand is specified. The methodology of prediction of subjective hand based on the combination of psychophysical transformation and predictive regression model is described. This methodology is applied for creation of predictive equation with few numbers of measured properties (especially shear and roughness).

Hand evaluation. One of the basic contact properties of textiles is hand. The term "hand" is difficult to define precisely. It belongs to textile quality evaluation as one of the most important utility properties. It is possible to include hand among subjective feelings evoked by measurable textile characteristics.

Subjective hand. The subjectively evaluated hand is connected especially with surface, mechanical and thermal properties. The first attempts of hand evaluation of textiles were published by Binns (1926). Two basic procedures of subjective hand evaluation were proposed (Howorth (1964)):

a) Direct method is based on principle of sorting of individual textiles to defined subjective grade ordinal scale (e.g., 0 – very poor, 1 – sufficient, 5 – very good, 6 – excellent)

b) Comparative method is based on sorting of textiles according to subjective criterion of evaluation (e.g., ordering from textiles with the most pleasant hand to textiles with the worst hand).

For prediction of hand using any subjective method it is necessary to solve following problems (Militký (1998)):

– Choice of respondents;
– Choice of grade scale;
– Definition of semantic.

* This work was supported by the research project “Textile center” 1M4674788501 of Czech Ministry of Education.

Choice of respondents. The method of choice of respondents has very strong influence on obtained data and therefore also on results of hand evaluation. It is obvious, that subjective evaluation is based on quality of sensorial receptors of the individual respondents. Results of evaluation are also dependent on the psychical state of respondents and the state of environment. Different results are often obtained by experts and by consumers. It is given by different points of view on textile and used terminology. Above indicated problems show that it is very difficult to maintain reproducibility and choice of respondents has to be strongly defined. The significant differences exist between men and women, too. The men evaluate usually close to scale centre in comparison with women. The special problem is size of respondent group. The minimum size for expressing of consumer meaning is 25…30 people and for looking for relationships with objective characteristics more than 200 people.

Choice of grade scale. If the paired comparison is not applied it is possible to choose grade scale according to the actual criterion and needs. The size of grade scales varies from 5 to 99. The 99-grade scale is more suitable for experts handling with fabrics. For consumers grade scale from 5 to 11 is preferred as they have not so high sensitivity for judgment of very weak differences.

Definition of Semantic. Evaluation of total hand is not sufficient when more precise results are required. It is suitable to introduce primary hand values. Primary hand values are connected with surface, thermal and geometric properties. Paired comparison of several samples is often carried out and then the ranks are got together. This method is easy for statistical data processing but it is suitable for small sets of textiles only.

Statistical treatment of subjective judgments. Statistical analysis of subjective hand results is obviously based on the classical arithmetic mean. The more correct approach is based on the categorized variables (Militky (1993), Rehak (1986)). Generally, for categorized variable case the population of all events is divided to the categories $C_1,.....C_P$. Special case of categorized variable is ordinal variable (Rehak (1986)). For ordinal variable the categories $C_1,.....C_P$ are sorted according to external criterion (here hand). It is assumed that the first category is worst and last category is best. The category C_{i+1} is better that C_i for all $i = 1,...P-1$. Statistical treatment of ordinal variable is based on absolute frequencies $n_i, i = 1,....P$ corresponding to categories $C_1,.....C_P$. Total number of events is

$$n = \sum_{i=1}^{P} n_i .$$

Relative frequencies and cumulative relative frequencies are then

$$f_i = \frac{n_i}{n} \qquad F_j = \sum_{i=1}^{j} f_i \qquad j = 1,....P .$$

For characterization of location of ordinal variable the sample rating median can be computed. The median category *Me* is defined by inequalities $F_{Me-1} < 0.5$, $F_{Me} \geq 0.5$

The sample-rating median of ordinal variable has the form

$$X_{Me} = Me + 0.5 - \frac{F_{Me} - 0.5}{f_{Me}} .$$

For estimation of mean handle grade the sample rating median X_{Me} is suitable. Characteristic X_{Me} is estimator of population rating median Med. The simple method for constructing confidence interval for Med is described in works (Militky (1998)).

Objective methods for hand prediction. A lot of methods are used for indirect objective hand evaluation. These techniques can be divided to three groups according to used instruments:

a) Special instruments – the hand is result of the measurement. Drawing of textile through the nozzle of defined shape and evaluation of dependence "strength-displacement" course is usual principle (Alley (1980)).

b) Set of special instruments for measuring of properties corresponding to hand. Kawabata's evaluation system (KES) belongs here. It consists of four instruments for measuring tensile, shear, bending, surface and compressive properties under special conditions of measuring. Totally 16 mechanical characteristics are measured by using these instruments (Kawabata (1982)).

c) Standard instruments for evaluation of fabric properties connected with hand (Raheel (1991) Militky (1998)).

Techniques of objective hand evaluation can be divided to two groups according to data processing.

a) Result is one number characterizing hand - this number is very often obtained from conversion equation (e.g., regression model), where subjective hand is endogenous variable and measured properties are exogenous ones (Militky (1998)).

b) Result is the vector of numbers characterizing hand. Comparison of hand is then carried out on the basis of multivariate statistical methods (Pan (1988), Brand (1964)) (e.g., factor analysis, discrimination analysis and cluster analysis.

Applicability of various methods for objective hand prediction is connected with the choice of measured textiles properties.

Kawabata evaluation system (KES).

The KES systems of instrumentation for measuring the fundamental mechanical properties of fabric and regression type model for prediction of subjective hand are described in work (Kawabata (1982)).

The properties being measured are grouped into six blocks. Corresponding characteristics are collected in the Table 1.

Table 1. Characteristic values of basic properties

Properties	Symbols	Characteristic	unit
Tensile	LT x1	Linearity	-
	WT x2	Tensile energy	gf.cm/cm^2
	RT x3	Resilience	%
Bending	B x4	Bending rigidity	gf.cm^2/cm
	2HB x5	Hysteresis	gf.cm^2/cm
Shearing	G x6	Shear stiffness	gf/cm.degree
	2HG x7	Hysteresis at ∅ = 0,50	gf/cm
	2HG5 x8	Hysteresis at ∅ = 50	gf/cm
Compression	LC x9	Linearity	-
	WC x10	Compressional energy	gf.cm/cm^2
	RC x11	Resilience	%
Thickness	T x12	Thickness at 0,5 gf/cm2	mm
Surface	MIU x13	Coefficient Friction	-
	MMD x14	Mean deviation of MIU	-
	SMD x15	Geometrical roughness	micron
Areal weight*)	W x16	Weight per unit area	mg/cm^2

*) Denote that in our prediction equation is areal weight W expressed in g/m^2.

Details about measurement principles, sample preparation and prediction of subjective hand are collected in (Kawabata (1982)). The results of Kawabata procedure is so called THV value in the range [0, 5]. For computation of THV it is necessary to know special constants valid for specific types of fabrics.

Model construction for hand prediction. For many fabrics types constant required for THV computation are unavailable. Regression type model for subjective hand prediction based on the characteristics listed in the Table 1 can constructed by the following procedure (Militky (2001)):

I. Standardization of data $x_{ji}, j = 1, 2, ...16$, $i = 1, 2, ...$ by using relation $u_{ji} = \frac{x_{ji} - x_j^*}{s_j}$, where x_j^* is sample mean and s_j is corresponding standard deviation for $j-$th variable.

II. Non-linear transformation to the special psychophysical scale by using Harrington type function

$$H(u_{ji}) = w_{ji} = 1 - \exp(-\exp(-u_{ji})) .$$

III. Selection of statistically suitable regression sub-model from linear one

$$y_i = b_0 + \sum_{j=1}^{m} b_j w_{ji} + \varepsilon_i \ .$$

Predicted correlation coefficient R_p and mean quadratic error of prediction MEP are used for determination of regression models quality. For calculation of MEP and R_p the following equations are valid

$$MEP = \frac{1}{n} \sum_{(i)} \frac{e_i^2}{(1 - H_{ii})^2} ,$$

$$R_p = \sqrt{\frac{1 - n.MEP}{\sum_{(i)} y_i^2 - n.y^{*2}}} ,$$

where $e_i = y_i - y_{ipred}$, H_{ii} are diagonal elements of projection matrix $X(X^T X)^{-1} X^T$ and y^* is median of ordinal variable hand. Instead of MEP the relative error of prediction MEPR can be used. Both these characteristics use the special prediction from estimates where single points are left out when the prediction is calculated (prediction in $i-th$ point is calculated without information about this point) (Meloun Militký (1994)).

Experimental part. The 61 bed ticking fabrics types used frequently in Czech Republic or specially prepared in pilot scale plant have been collected. Material used is pure cotton, cotton/polyester blends and Lyocell. This set of fabric cover the range of areal weight 75...185 g/m2, yarn fineness 5,3…25 tex and sett 30…75 yarns/cm.

Subjective hand was carried out by means of group of 16 well-informed respondents. They had P = 12 order grade scale to disposal (1 – very bad, 12 – excellent). The estimations of median values from subjective evaluation results were treated by means of technique described in chap. 2.2. Median of ordinal variable was used as relative subjective hand $y_i = X_{Me}$.

The 16 characteristics (see Table 1) of all fabrics were evaluated by KES system. Individual x data are mean values computed from 3 repeated measurements in both major directions.

Results and discussion. Data from KES measurements were analyzed by multivariate statistical methods for evaluation of potential sources of heterogeneity (clusters and outliers). For prediction of subjective hand the methodology described in chap. 2.5 has been used.

Preliminary data analysis. In the Fig.1 are arranged data in the space of variables HB, HG, G as result of K means clustering (procedure is described in (Meloun Militky (1994)).

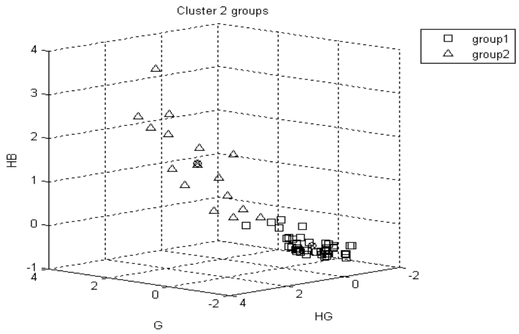

Fig. 1. Results of K means clustering for both sets I and II

There are two clusters visible. In the smaller cluster I (markers are triangles) fabrics are having higher values of shear stiffness G. In the bigger cluster II (markers are squares) there are fabrics with smaller nearly constant G. These two clusters were analyzed as separate groups. The paired dependencies between selected variables are given in Fig.2.

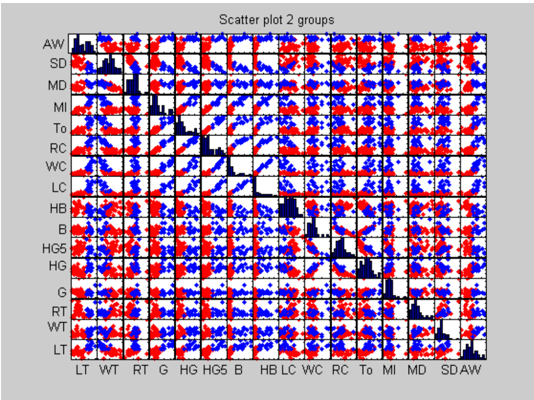

Fig. 2. Paired dependencies between variables

There are some strong correlations visible, especially between compressional characteristics and thickness and between shear characteristics.

It is visible that clusters I and II are separated for some characteristics. The distribution of some variables is skewed to the right but very probably unimodal.

The differences between individual fabrics in the cluster I and cluster II are visible from profile plot in the Fig. 3. Construction of this plot is described in (Meloun Militky (1994)).

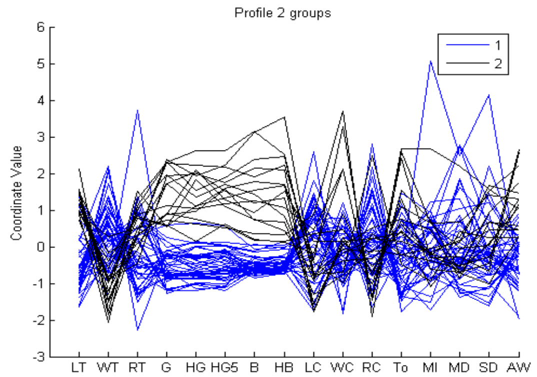

Fig.3. Profiles for all points in cluster I and cluster II

There are visible differences, especially due to shearing and bending characteristics. The profiles for individual clusters are in the Fig. 4.

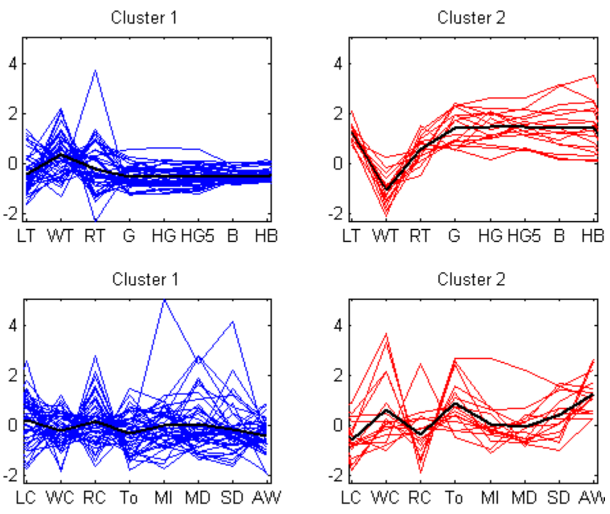

Fig. 4. Profiles for individual clusters

These plots are supporting the differences due to shearing and bending characteristics.

This fact is supported by projection of both cluster I and II to the first three principal components Meloun Militky (1994)) shown in Fig. 5.

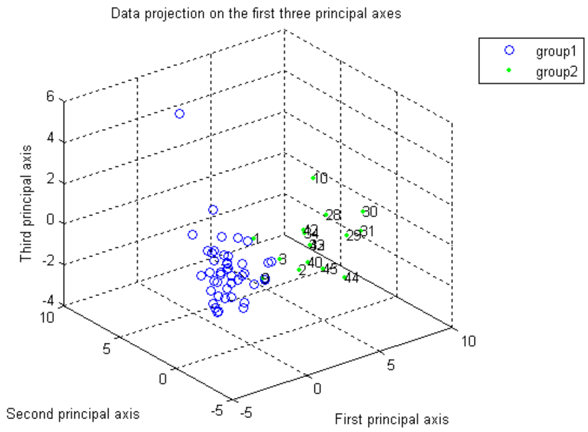

Fig. 5. Projection of both data sets to the principal components

The potentially outlying points are characterized by the high Mahalanobis distances (Meloun Militky (1994)). The plots of Mahalanobis distances for both clusters are shown in the Fig. 6

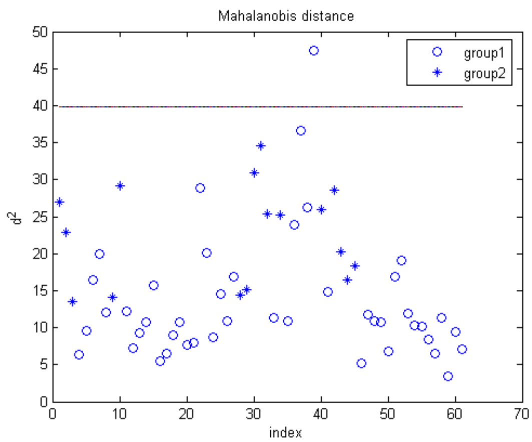

Fig. 6. Mahalanobis distances of fabrics

It is visible that one outlying point is above the limit but its importance is not very high. Both clusters are separated and there exists some outlying fabrics in some properties but differences are not so critical for subsequent analysis.

Predictive model creation. For creation of prediction type model the data were standardized and transformed by Harrington function. The linear regression models defined in chap. 2.5 was used. Results for full model (16 characteristics are given in the Table 2). The partial correlation coefficients characterize correlation between individual variables and subjective hand (other variables are statistically constant – see (Meloun Militky (1994)).

Table 2. Results for linear regression (all variables)

Variable	regression coefficient b_j	Standard deviation of regression coefficient	t- statistics	Partial Correlation
intercept	13,9	1,36	10,2	-
LT	0,104	0,852	0,122	0,095
WT	0,407	1,01	0,405	0,301
RT*)	-1,03	0,872	-1,18	0,697
G	-2,49	2,45	-1,02	0,44
HG	-2,87	2,78	-1,03	0,558
HG5*)	-4,15	3,10	-1,34	0,638
B	0,189	4,15	0,046	0,031
HB	0,226	4,61	0,049	0,027
LC	-0,027	0,79	-0,034	0,094
WC	-0,038	1,84	-0,021	0,007
RC	0,071	0,733	0,096	0,079
To	-0,50	2,52	-0,191	0,111
MI	0,071	0,549	0,129	0,114
MD*)	-0,808	0,629	-1,28	0,725
SD*)	-1,08	0,639	-1,69	0,571
AW	-0,975	1,03	-,0943	0,502

*)Gray color is used for highly significant variables.

Linear model was used for all variables (x1…x16) and also for the four (x3, x6, x14, x15) and three (x3, x6, x15) statistically most important variables. For all these models the characteristics of model quality RP and MEPR are shown in Table 3. The multiple correlation coefficients RD are shown here for comparison only (this characteristic is no decreasing function of number of variables)

Table 3. Characteristics of regression model quality for various models

Model variables	RD [%]	RP [%]	MREP [%]
All variables	95,32	88,81	16,68
3,6,14,15	94,11	92,75	15,78
3,6,15	93,76	92,52	15,32
3,6,15 raw data	91,47	89,93	20,24

It is evident that from the point of view of prediction ability the model with three variables (x3, x6, x15) is the best one. The model with all 16 characteristics is over-parameterised. The model with three variables without standardization and Harrington transformation has worse prediction ability (see Table 3). The estimates of parameters b_0, b_1 ,b_2, b_3 for optimal three variables model together with standard deviations are presented in the Table 4.

Table 4. Results for linear regression (three variables)

Variable	Beta	Standard deviation of beta	t- statistics
intercept	13,8e	0,317	43,6
RT	-1,68	0,398e	-4,23
HG5	-9,58	0,436	-22,0
SD	-1,56	0,437	-3,58

The relation between predicted and measured subjective hand for this model is shown in the Fig. 7.

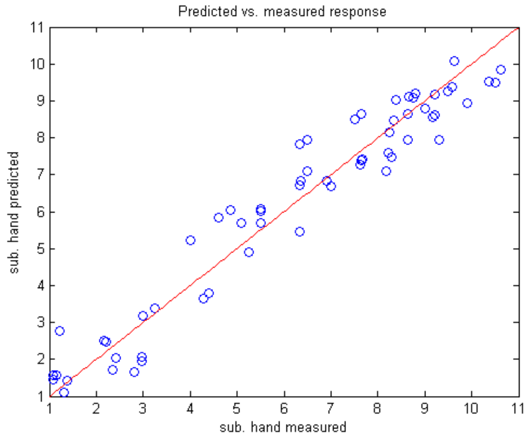

Fig. 7. Relation between measured and predicted subjective hand (from model with three variables)

The hand of bed ticking fabric is therefore dependent mainly on the tensile resiliency, shearing hysteresis and geometrical roughness. These characteristics can be in practice modified by using of special softening agents (finishing) or by proper design of raw fabric.

CONCLUSIONS

Prediction linear model with variables RT, HG5 and SD is very simple and suitable for prediction of the bed ticking fabrics subjective hand. Precision of the prediction is sufficiently high. The Kawabata testing system can be replaced for this purpose by tensile testing apparatus with adapter for shearing measurement and adapter for surface roughness evaluation.

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Recommended by Scientific and Technical Counsil of Moscow State Textile University named aftert A.N. Kosygin. Recieved 05.06.09.