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Sumar

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Mechanical and permeability properties of sportech fabrics

PELIN GURKAN UNAL MUSTAFA ERDEM ÜREYEN

REZUMAT – ABSTRACT

Proprietăţile mecanice şi de permeabilitate ale ţesăturilor sportech

Scopul acestei lucrări este determinarea parametrilor care influenţează proprietățile de permeabilitate, propunerea unor structuri de ţesături proiectate pentru îmbrăcămintea destinată diferitelor sporturi şi măsurarea proprietăților de permeabilitate. În acest context, au fost selectate 11 structuri de ţesătură diferite, care sunt utilizate în special în producția de îmbrăcăminte sport aflată pe piață, și s-au efectuat măsurători mecanice și de permeabilitate (la aer și apă). Pentru că prelevarea țesăturilor s-a realizat de pe piață, s-a acordat o atenţie deosebită ca masele ţesăturilor selectate să fie cât mai apropiate.

Rezultatele au arătat că tipul de fibră este parametrul cel mai eficient în ceea ce privește proprietățile de permeabilitate, în special permeabilitatea la apă. Caracteristicile de grosime ale țesăturilor influențează, de asemenea, proprietățile de permeabilitate ale acestora.

Cuvinte-cheie: permeabilitate la aer, permeabilitate la apă, proprietăţi mecanice, sportech

Mechanical and permeability properties of sportech fabrics

In the scope of this work, determination of the parameters that affect permeability properties and the proposition of fabric structures designed for the needs of different sports are aimed by measuring permeability properties of fabrics used in the field of sports clothing. In this context, 11 different fabric structures that are used primarily in the production of sports clothing on the market were selected and mechanical and permeability (air and water) measurements were performed. Due to the reason of supplying the fabrics from the market, the weight of the selected fabrics is paid attention to the issue that is at least close to each other.

The results showed that fibre type is the most effective parameter with regard to permeability properties especially water permeability. Since the fabrics were obtained from the market, thickness properties of the fabrics also influence the permeability properties.

Keywords: air permeability, water permeability, mechanical properties, sportech

Clothes are used to maintain and protect body temperature. In order to balance high heat that surrounds body, garment permits sweat to evaporate (cooling off by perspiration). When humans are under high temperatures or do physical exercise, the fluctuation of fabric during movement creates air streams, which increase perspiration and cooling off. Body temperature is kept cold by fabric layer that provides insulation a little. For these reasons, clothing comfort is of great importance from the point of user.

Clothing comfort can be examined in three different categories such as psychological, handle and thermal comfort. Psychological comfort can be explained with the user influenced by the fashion and culture. Fabric handle is defined basically as the feeling when thumb and index finger touches the fabric. Thermal comfort is a phenomenon, which is close to thermal and liquid permeability properties of fabrics. As for the sports clothing, thermal comfort is of great importance since it can affect performance and success of sportsman to a significant extent. There are a few studies about the development of light weight clothes which increases the comfort of sportsman especially for the popular sports like football, basketball, tennis, athleticism, swimming, in which the effect of clothing on performance is not negligible. For this purpose, there are a lot of natural and/or chemical fibres. Fabric permeability properties of the fabrics are influenced directly by the yarn geometry and structure. Fibre type, fabric thickness, shape and structure of fabric pores are other factors that have an influence on the fabric permeability properties.

There are a lot of studies about clothing comfort. Kanakaraj and his co-workers studied the effect of double layer fabric structures on the air and water vapour permeability properties of fabrics. For this purpose, double layered fabrics are produced with face and back surfaces that were connected by loop and tuck. The water and air permeability properties of the developed fabrics in the study were measured and it was found out that the differences among the double layered structures were highly significant with regard to water vapour permeability and air permeability properties of the knit fabrics. The stitch densities in the fabric were found to influence the permeability property of the fabrics more [1]. Liu and Hu examined the relationship between compression properties and air permeability of weft-knitted spacer fabrics. Compression and air permeability properties of twenty spacer fabrics with different weft knit patterns, spacer yarns, and loop lengths (stitch cam settings) were observed with the Kawabata Evaluation

System for Fabrics (KES-F). It is found out that the air resistance of fabrics made with the same-diameter monofilaments increases with the increase in the spacer yarn connecting distance. Outer layers with higher loop densities result in a poor air permeability of the fabrics [2]. Gupta and his co-workers studied the effect of yarn linear density in the inner and outer layers of single jersey plated fabrics on heat, moisture and air permeability properties. It is found out that increase in yarn linear density increases thermal resistance of fabrics. Using finer yarns and higher loop lengths in the production of plated fabrics causes more permeable structures to air and water vapour and lower thermal absorptivity, which can be used for hot days [3]. Moisture transportation and air permeability properties of fabrics knitted with viscose vortex spun yarns was investigated and it is found out that fabrics had either poor drying abilities or good water vapour permeability. There was a good correlation between air permeability and water vapour permeability of the fabrics, which was attributed to the fibre in the yarn [4]. In another study, the effect of knitted fabric structure on thermal and moisture management properties was investigated. For this purpose, two types of thermo-regulated yarns as Coolmax and Outlast were knitted. It is found out that some properties, such as, thermal properties; diffusion ability, air and water vapour permeability are influenced by both raw material type and knitted structure parameters. Wicking ability is influenced to a greater extent by the knitted structure, while the drying ability is primarily determined by raw material and to a lesser extent by the knitted structure parameters [5]. The effect of plain knit structures on flammability and air permeability of fabrics was investigated and it is found that an increase in the loop length of the fabrics increases air permeability; on the contrary an increase in the linear density of the yarn decreases air permeability of knitted fabrics.

The aim of this work is to determine the parameters that affect permeability properties of different fabric structures that are used in the field of sports clothing and to propose the best fabric structure designed for the needs of different sports. In order to do this, 10 different knitted fabric structures that are used primarily in the production of sports clothing on the market were selected and mechanical and permeability (air and water) measurements were performed.

EXPERIMENTAL

The material of this study consists of fabrics that are widely used in sports activities. Fabrics used in the field of sports activities are made of polyester yarns or natural and regenerated yarns with different properties. Therefore, fabrics supplied within the study have almost the same weights and were produced using cotton or viscose yarn on one side and PES, micro PES, Thermocool PES, Coolmax PES, cotton-like PES on the other side. Table 1 represents the general characteristics of the fabrics.

Table 1

SUPPLY FABRIC AND THEIR PROPERTIES

Fabric number	Inner face	Outer face
1	PES 83.3 dtex (39 %)	Cotton 147.6 dtex (61%)
2	PES 83.3 dtex (36 %)	Cotton 147.6 dtex Compact (64%)
3	PES 166.6 dtex (47%)	Viscose 210.9 dtex (53%)
4	PES 166.6 dtex (52%)	Viscose 147.6 dtex (48%)
5	Thermocool PES (%100)	----------
6	Thermocool PES (%100)	----------
7	Coolmax PES (%100)	----------
8	PES 144/70 dtex (%100)	----------
9	Micro PES 75/72 dtex	----------
10	Coolmax PES 196.8 dtex (%100)	----------

In addition to mechanical properties such as bursting strength and pilling, mass per unit area, permeability properties (air and water vapour) of the supplied fabrics were measured after conditioning of the fabrics at standard laboratory conditions (20 ± 2 C°, 65% ± 2). Mass per unit area measurements of the fabrics were performed according to TS 251 standard by calculating average of three specimens' results. Thickness measurements of the knitted fabrics were done using electronic micrometre that has 0.001 mm of measurement sensitivity. Average of three measurements that were obtained from three different parts of the fabrics was calculated.

Bursting strength of the fabrics was determined by calculating the average values of five measurements based on the ISO 13938-2 (area of 7.3 cm^2, 30 mm of diaphragm diameter).

Pilling properties of the knitted fabrics were measured according to ISO 12945/2 standard Martindale test. After 2000 cycles on the tester, the specimens were compared with the standard EMPA (SN 198525 K-3) photos and evaluated. In evaluation, 5 ratings were used and in addition to primary grades, intermediate grades were also used. The average values of pilling properties of the fabrics were calculated from three different specimens.

Air permeability tests of the knitted fabrics were performed according to ISO 9237 on SDL ATLAS MOZIA air permeability tester under 200 Pa pressure in 20 cm^2 of area with 10 repetitions.

Water vapour permeability measurements of the knitted fabrics were done with regard to "ASTM E-96 standard test methods for water vapour transmission of materials" that is based on Cup method. In this method, specimen having a diameter of 10 cm was placed around a cup having a diameter of 9 cm containing distilled water that was sealed with wax. In order to prevent water vapour escape, the sides of the cups were covered with a plastic cap. Three measurements from each fabric specimen were taken and observed for a week under the laboratory conditions. In every 24 hours, cups containing inside distilled water and fabric specimen over it were weighed and slopes obtained from weight loss-time graphics of each specimen were determined. Water vapour transmission rates of each fabric are obtained by dividing calculated slope values to the surface area of the cups used in the experiments.

$$WVT = (G/t)/A \quad (1)$$

where (in metric units):
G = weight change, g (from the straight line);
t = time during which G occurred, h;
G/t = slope of the straight line, g/h;
A = test area (cup mouth area), cm^2;
WVT = rate of water vapor transmission, $g/h \cdot cm^2$.

STATISTICAL PROCEDURES

Analysis of variance (one-way) was performed in order to determine the differences between the values of the different properties of the fabrics. With this statistical analysis, the aim is not to get a general idea, on the contrary to make a comparison between the groups. In order to determine whether there is a difference or not, the significance value p was compared with $\alpha = 0.05$. If the p value is greater than α, it means that there is no difference within the groups whereas in case of difference between these aforementioned values, it means that there is a significant difference between the groups. In order to find the source of the effect between the fabrics, multiple comparisons were carried out. In multiple comparisons, there are two conditions that are whether the variances are equal or not. Tukey test in the equal variance condition and Tamhane's T2 test in the unequal variance condition were used. For this reason, firstly homogeneity test of variance (Levene Test) was performed in order to determine if the variances are equal or not. After that, proper multiple comparisons tests were chosen based on the condition of variance. Furthermore, correlations between the measured properties were investigated according to the bivariate correlations procedure. In this procedure, Pearson's correlation coefficient, which is a measure of linear association, is computed with its significance levels. If the coefficient of correlation is close to 1 or –1 and the significance level is lower than $\alpha = 0.05$, it means that there is a high correlation among the related variables.

RESULTS AND DISCUSSION

Average values of mass per unit area results of three repetitions are presented in figure 1. As it is seen in figure 1, values of fabric mass per unit area are close to each other. PES/CO plated single jersey fabrics have 165 and 170 g/m^2 whereas PES/VI plated single jersey fabrics have 220 g/m^2 fabric weight. Fabrics produced with Thermocool PES yarns have 170 and 200 g/m^2 fabric weights based on the changing fabric structure. Fabrics made of Coolmax PES yarns have 215 and 160 g/m^2 weights again based on the changing fabric structure. Fabrics made of PES yarns and micro PES yarns have fabric mass per unit area values of 145 and 120 g/m^2 respectively.

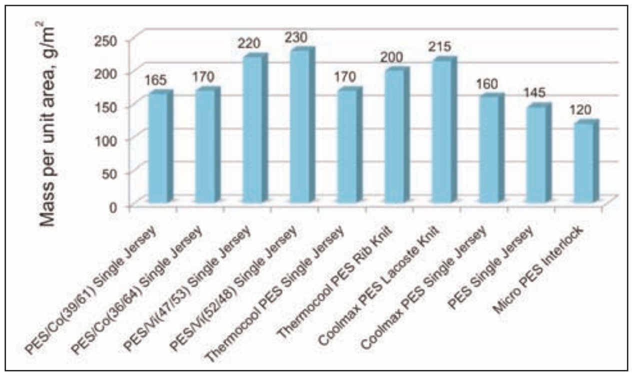

Fig. 1. Mass per unit area results of the knitted fabrics

Average thickness values of fabrics obtained with micrometre is presented in figure 2. It is found that thickness values of the fabrics are correlated with fabric mass per unit area results (95.2%).

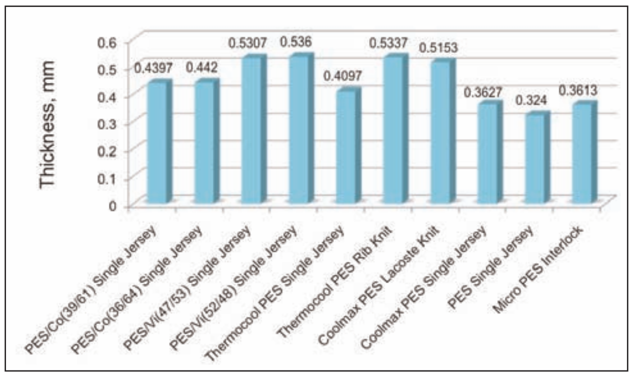

Fig. 2. Thickness results of the knitted fabrics

When the results of the thickness values were evaluated, it is obvious that fabrics having equal mass per unit results show almost the same thickness results. Results of thickness values were statistically evaluated and according to Levene Test it is found that the variances of the fabrics are equal and the p value is 0.633. After checking of variance homogeneity, one-way analysis of results was performed (table 2) and found that there is statistically significant difference between the results of the fabrics (p = 0.000) since some of the fabrics are made of two yarns while others are produced from one type of yarn.

According to ISO 13938-2, the average values of 5 repetitions of bursting strength results are presented in figure 3. When the results are evaluated, it is found that the results are close to each other. The big difference in bursting strength belongs to the lacoste

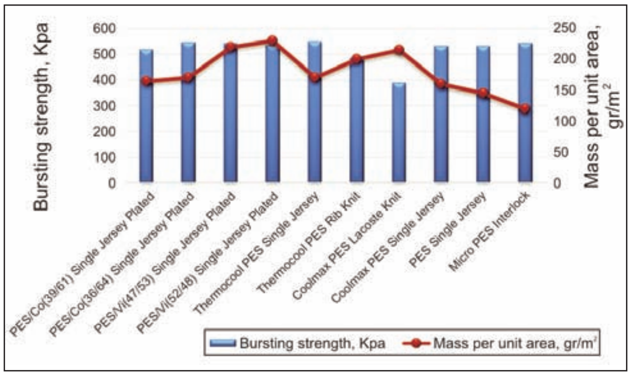

Fig. 3. Bursting strength of the knitted fabrics

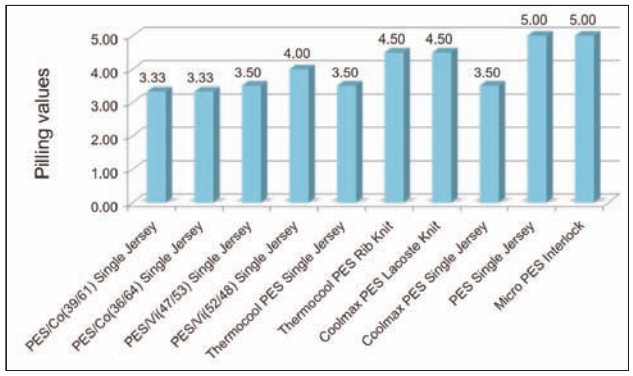

Fig. 4. Pilling properties of the knitted fabrics

Table 2

ONE WAY ANOVA ANALYSIS OF FABRIC THICKNESS				
Source	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F**
Fabrics	9	0.1743948	0.0193772	823.39
Error	20	0.0004707	0.0000235	
Total	29	0.1748655		

knitted fabric made of Coolmax PES yarn. The reason of this low value of bursting strength is thought to be the fabric construction which has holes.

When the results of bursting strength were evaluated, the variances of the fabrics are equal according to the results of Levene's Test ($p = 0.970$). The results of the anova are presented in table 3. According to the results, there is a statistical difference between the bursting strength of the fabrics which is caused probably because of the lacoste knitted fabric made of coolmax PES yarn. Since bursting strength of the fabrics is influenced by the yarns that constitute the fabrics and the fabric structure and also by the number of fabric folds such as single or double folded fabrics and the last but not the least by the material type such PES, viscose or cotton.

According to the ISO 12945/2 Martindale pilling test, the specimens were evaluated subjectively based on the standard EMPA (SN 198525 K-3) photos. The average results of the three repeated pilling values are presented in figure 4.

The results of pilling properties of knitted fabrics were evaluated and is found that there is a variance homogeneity with regard to the results of Levene's Test ($p = 0.552$). The results of the one way anova analysis of the pilling properties of knitted fabrics are presented in table 4. According to the results, there is a statistical difference between the pilling properties of the fabrics which is caused probably because of the blended knitted fabrics made of cotton or viscose. As it is generally known, pilling property is affected directly by the fibre type and fabric structure. When the results are evaluated, it is found that the blended fabrics especially contain cotton fibre have lower

Table 3

ONE WAY ANOVA ANALYSIS OF FABRIC BURSTING STRENGHS				
Source	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F**
Fabrics	9	64654	7184	11.63
Error	20	12350	618	
Total	29	77004		

Table 4

ONE WAY ANOVA ANALYSIS OF FABRIC PILLING				
Source	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F**
Fabrics	9	12.4083	1.3787	82.72
Error	20	0.3333	0.0167	
Total	29	12.7417		

pilling properties compared to PES and functional PES fibres.

Air permeability measurements of the knitted fabrics were performed according to ISO 9237 on SDL ATLAS MOZIA air permeability tester under 200 Pa pressure in 20 cm^2 of area with 10 repetitions. The average values of the obtained results and their relation with the thickness properties of the related fabrics are presented in figure 5.

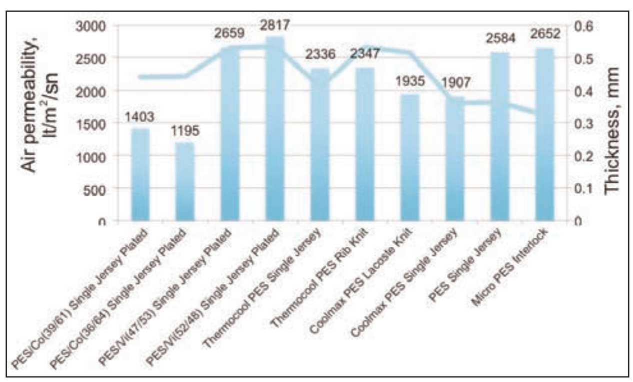

Fig. 5. Air permeability results of the knitted fabrics

When the results are evaluated in detail, increase of PES fibre ratio in the blend causes fabrics to conduct more air. This phenomenon can be observed by comparing PES/Co blended single jersey plated fabrics. The first two fabrics have the same production parameters except fibre blend ratios. In single jersey plated fabrics using viscose yarn instead of cotton yarn in the outer face makes the fabric more air permeable. This situation can be explained by comparing single jersey plated fabrics made of PES/Co yarns and PES/Vi. Fabrics produced with Thermocool PES yarns and Coolmax PES yarns have higher air permeability values compared to those of the knitted fabrics produced with PES/Co yarns. However this difference is caused by the differences of mass per unit area results and also thickness of these aforementioned fabrics. In addition to these parameters, fibres used in the production of these fabrics and also the fabric structure make differences in the air permeability of the fabrics.

The air permeability results of knitted fabrics were evaluated and it is found that there is not a variance homogeneity with regard to the results of Levene's Test ($p = 0.007$). Based on unequal variance condition, there may be some violation with the results of the one-way anova analysis. Therefore, in order to find differences between the fabrics, Tamhane's T2 test was performed. According to the Tamhane's T2 test results, there is a statistical significant difference among pairwise.

Water vapour permeability measurements of the knitted fabrics were performed according to "ASTM E-96 standard test methods for water vapour transmission of materials" and the average results of this property are presented in figure 6. As a result of the measurements performed under laboratory conditions, average water vapour transmission of single jersey plated fabrics made of PES/Co (39/61) is 23.6 g/h.m^2. Likewise water vapour transmission rate of single jersey plated fabrics made of PES/Co (36/64) is found to be 19.85 g/h.m^2. While the mass per unit area and thickness values of these aforementioned fabrics are statistically close to each other, the reason why water vapour transmission rates of these fabrics differ from each other is increasing cotton amount in the blend makes the fabric less water permeable. Furthermore, the air permeability behaviour of latter fabric, which contains more cotton in the blend, shows similarity with the results of the water vapour transmission rates. The cross section of cotton fibre, which is not circular, makes a porous structure, which causes less air permeability among the fibres. Besides, hydrophilic structure of cotton keeps more water in the body.

When the results of water vapour transmission rates of single jersey plated fabrics made of PES/Vi are investigated, the first one made of PES/Vi (47/53) has 19.95 g/h.m^2. Water vapour transmission rate of single jersey plated fabric made of PES/Vi (52/48) is 22.06. This is because of the increase in PES amount since mass per unit area and thickness of

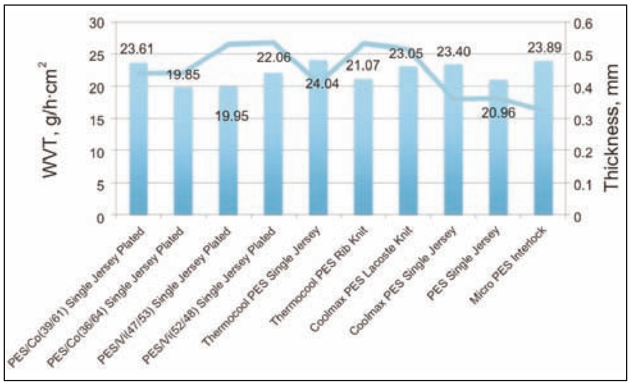

Fig. 6. Water vapour transmission rates of the knitted fabrics

Table 5

ONE WAY ANOVA ANALYSIS OF WVT

Source	Degrees of freedom	Sum of squares	Mean square	F
Fabrics	9	82.79	9.20	6.02
Error	20	30.54	1.53	
Total	29	113.33		

this fabric is more than the first two. Increase in PES amount in the fabric and using yarns with less linear densities led the fabrics transfer more water vapour in a unit time. Fabrics knitted with Thermocool PES yarns showed good results of water vapour transmission rates, especially the one that is single jersey. This fabric is the best amongst with regard to water permeability based on the fibre type. However, the second fabric has rib structure, which makes the fabric thicker, and interrupts the water vapour transmission. The fabrics made of Coolmax PES, PES or Micro PES yarns show also good results. However, because of the special structure of Coolmax PES, its ability of transmitting water is higher compared to standard PES. The one produced from Micro PES has also good results of WVT based on the increase of fibre surface inside the yarn structure.

The results of water vapour transmission rates of knitted fabrics were evaluated and is found that there is a variance homogeneity with regard to the results of Levene's Test ($p = 0.726$). The results of the one-way anova analysis are presented in table 5. According to the results, there is a statistical difference between the water vapour transmission rates of the fabrics ($p = 0.000$). This depends on the fibre type that is used in the fabric constitution and the fabric porosity. Generally the water vapour transmission rates of the single jersey plated fabrics are less than the others.

CONCLUSIONS

In the scope of this study, determination of the parameters that affect permeability and the proposition of fabric structures designed for the needs of different sports are aimed by measuring transfer properties of fabrics used in the field of sports clothing. In this context, 10 different fabrics having different structures that are used primarily in the production of sports clothing on the market were selected and mechanical and comfort measurements were performed. Due to the reason of supplying the fabrics from market, the mass per unit area of the selected fabrics is paid attention to the issue that is at least close to each other. A sample containing of 10 units is of course not enough to explain such a phenomenon, however it will give some information about the factors affecting the permeability properties of the sportech fabrics.

The study led to the following conclusions:

In order to increase performance of the fabrics, different fabric structures such as plated single jersey can be used in the sportech area. With this kind of fabric structures one type of yarn can be used in the front side and the other is vice versa. For this purpose the one used in the inner face has to be man-made such as PES and the other one could be any type. Results showed that using natural fibres causes less air and water permeability.

As it is expected, using cotton or viscose yarns also influence mechanical properties (bursting strength or pilling properties) of the fabrics. Since PES yarns exhibit superior mechanical properties compared to cotton or viscose.

The permeability of the fabrics are influenced basically by the material used (fibre genre, type), yarn (type, composition, etc.), the fabric structure (fabric sett, construction, pattern, etc.). These three parameters affect the mechanical properties as well as comfort properties of the fabrics.

According to air permeability results, fabrics containing PES or Viscose yarns regardless of considering mass per unit area or thickness values of the fabrics have good air transfer.

Using natural fibres such as cotton decreases air permeability of fabrics under the same conditions. According to water vapour transmission rates of the fabrics, it can be said that fabrics containing hydrophobic fibres transfer water quicker.

On the other hand, fabrics containing hydrophilic fibres such as cotton or viscose transfer less water.

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The prediction of elastic behaviour of fabric from stretch yarn

DUNJA ŠAJN GORJANC STANISLAV PRAČEK

REZUMAT – ABSTRACT

Predicţia comportamentului la elasticitate al ţesăturilor din fire elastice

Lucrarea prezintă o predicție a comportamentului la elasticitate al țesăturii realizate din fire elastice. Particularitatea ţesăturii elastice incluse în studiu a fost reprezentată de filamentele de elastan încorporate în fire, în direcția urzelii și a bătăturii. Scopul studiului a fost de a analiza relația dintre valoarea conținutului de elastan din fir și revenirea elastică după expunerea îndelungată la alungirea specificată. Pentru partea experimentală a cercetării, au fost analizate 115 țesături din lână cu legătură diagonal, cu fire de elastan, având diferite procente de elastan în fir, grosime și masă similare. Tehnica de exploatare a datelor a fost aleasă pentru a analiza raportul dintre conținutul de elastan din fir și revenirea din elasticitate după o oră de expunere a materialului la alungirea specificată.
Rezultatele cercetării arată relația liniară dintre valoarea conținutului de elastan din fire și revenirea din elasticitate a țesăturii.

Cuvinte-cheie: țesătură cu fir de elastan, revenire din elasticitate, regresie și arbore model

The prediction of elastic behaviour of fabric from stretch yarn

The paper presents the prediction of elastic behaviour of woven fabric produced from stretch yarn. The particularity of the stretch fabric included in the research was the elastane filaments incorporated in the yarn in the warp and weft direction. The goal of the research was to analyse the relation between the value of elastane content in the yarn and elastic recovery after longer exposing to the specified extension. For the experimental part of research, the 115 wool woven fabrics in the twill weave with elastane yarn were analysed with the different percentage of elastane in the yarn, similar thickness and mass. The data mining technique was chosen to analyse the relation between percentage of elastane content in the yarn and elastic recovery after one hour exposing the fabric to the specified extension.
The research results show the linear relation between the value of elastane content in the yarn and elastic recovery of fabric.

Keywords: fabric with elastane yarn, elastic recovery, regression and model tree

INTRODUCTION

To achieve high quality products, the textile industry acknowledges the importance of testing the textile material during production process. Elastic fabrics are exposed to the different loads in the production processes and during wearing. Applied loads cause different deformations of fabric. Since the production process involves lower loads, the large part of deformation is recoverable immediately after loading, while the smaller part is recoverable over time or non-recoverable.
That kind of fabrics are body confirming and ensure stable shape and high degree of comfort of cloths during wearing [1].
For producing the high quality cloths from fabric with the elastane yarn is the most important activity to expertise the influence of the value of elastane content in the yarn on elastic recovery, especially after longer exposing to the specified extension [2].

Viscoelastic behaviour

Textile material displays properties of an elastic solid and a viscose liquid. The elastic solid has definite shape and with deforming by external loads is stretched into new, deformed shape. When the load is removed, it returns to the original shape that was prior the deformation. Hooke`s law describes the deformations of the elastic solid which are recoverable, means linear relation between input load and deformation. Hooke`s law is valid only at a small deformations.
Viscous behaviour is the behaviour of the viscose liquid where a Newton`s law is valid. The external loads that act on the liquid are proportional to the velocity gradient in the liquid. Newton`s law of viscosity is restricted to relatively low flow rates [2, 3, 4].
When the external force is applied to the textile material, at the beginning of the test, a relation between the load and extension is proportional, extension is recoverable, and textile material acts like an elastic solid. With the increasing of load, the important changes in the load-extension relationship occur and extension increases more rapidly than the load. That leads to the change in the curvature of the load-extension curve. The border between two different regions of the load-extension curve presents the yield point. Above the yield point, which represents the limit of elastic behaviour, some of the extensions become non-recoverable when the force is removed. Above the yield point, the textile material behaves like an elastic solid and a viscose liquid. Knowledge of the load and extension in the yield point has an

important meaning to ensure stable shape of fabrics after deforming [2, 3, 4].

Recovery properties

During the production process, the fabric is stretched by applying a specified load to the definite extension. After tension is removed, the fabric returns to the initial length before loading (elastic recovery). Under lower load, a large part of extension is recoverable and smaller part is recoverable with time. With the percentage of elastane content in the yarn the extension and elastic extension also increase.

Elastic recovery E_e is the relation between elastic extension ε_e and total extension ε and is expressed in percents.

Elastic recovery is the special case of the general phenomenon of hysteresy. The surface of hysteresy depends upon the value of elastic recovery. Complete recovery means the relation between elastic extension ε_e and total extension ε is 100 % or one and there is no surface of hysteresy, incomplete recovery means the relation between elastic extension ε_e and total extension ε is smaller than 100 % and higher than zero.

The elastic recovery depends upon a time of the material is held at a definite extension [2].

Time-dependence

Elastic recovery is time-dependent property. In the case, where textile material is exposed to the constant extension for longer time, the value of elastic recovery becomes lower. The recovery is larger with exposing the textile material on the constant extension for the short time period. If the material is held at a constant extension for a long time, the lower is the level of recovery. After the load is removed, one part of total extension (called elastic extension, ε_e), returns immediately, the other part of the total extension returns in dependence of time (viscoelastic extension, ε_{et}) and depending from the value of input load, smaller part of total extension is non-recoverable (plastic extension, ε_p). It means that total extension of textile material after the load is removed from the smaller part of elastic extension ε_e and bigger part of the viscoelastic extension which is recoverable with time ε_{et} and plastic, non-recoverable extension, ε_p [3].

The prediction of elastic behaviour

Knowledge-discovery in databases (KDD) is the process of discovering useful knowledge from data and involves several phases as data preparation, data analysis (data mining, machine learning, statistics), evaluation and use of discovered patterns. Data mining presents only 15–25 % of the entire knowledge discovery in databases process. Data mining is the practice of automatically searching large stores of data for patterns. To do this, data mining uses computational techniques from statistics, machine learning and pattern recognition.

Data mining deals with the large collections of data in the different formats. The industry usually has huge bases of data and uses the data mining methods to find the useful patterns in data to set the model that explains these patterns [5].

Data mining techniques

The standard data mining techniques are: Predictive Data mining and Descriptive Data mining. Predictive Data Mining techniques are decision tree induction and learning the set of rules. Descriptive Data Mining technique means hierarchical clustering, subgroup discovery and association rule induction [5].

The data for the Predictive data mining technique are usually set in the several rows of tables. One row means one property or one class and with the other mean, an attribute. Examples of data with the class assignment are usually explained with the predictive induction where the supervised learning is used [5].

If the data for the analysis are numerical, then the regression tree is used for prediction.

On the contrary, when the data are nominal, the decision tree is used as predictive data mining technique. Regression tree considers as a variant of decision trees, designed to approximate real-valued functions instead of being used for classification tasks. With the combination of the regression equations with regression trees all leaves in the tree contain linear expressions/regression equations. This is called model tree. The model tree approximates continuous functions by linear patches. The model tree is also smaller and more acceptable than the regression tree. The average error values on the training data are lower using model tree instead of regression tree [6].

The learning set of rules technique based on the rule set representation. The standard form of rules is IF Condition THEN Class. (IF Fabric=high elastic recovery=THEN high elastane content=YES) [7].

EXPERIMENTAL PART

In this study, the 115 wool woven fabrics with elastane in twill weave T ½ Z were chosen. Analyzed woven fabrics involved from 0% to 6.3% of the elastane core-spun yarn with fineness from 35 to 40 tex and 400 to 900 turns per meter in the warp and weft direction (bi-stretch woven fabrics). The warp density of analysed fabrics amounts from 30 to 40 yarns/cm, while the weft density amounts from 25 to 35 yarns/cm. The presented study focuses on the influence of structural and viscoelastic properties of fabric with elastane yarn in the both directions on elastic recovery. The elastic recovery of fabrics analysed was measured after one hour keeping to the constant extension that amounts 10% according to the standard DIN 53835 [8]. The chosen extension is higher than extension in the yield point (limit of recoverable deformation) of fabrics analysed (table 1).

The experimental part of research focuses on structural properties of woven fabric with elastane yarn; such as elastane content, mass and thickness, firstly and to viscoelastic properties of chosen fabrics:

Table 1

MEASURED STRUCTURAL, VISCOELASTIC PROPERTIES AND ELASTIC RECOVERY OF ANALYZED WOVEN FABRICS WITH ELASTANE

STRUCTURAL PROPERTIES				VISCOELASTIC PROPERTIES					
Fabric mark	Elastane content, W_{el}, (%)	Mass, M (gm^{-2})	Thickness, h (mm)	Breaking force, F_{pr} (N)	Breaking extension, ε_{pr} (%)	Elasticity modulus, E_0 (MNm^{-2})	Stress in the yield point, σ_y (Nm^{-2})	Extension in the yield point, ε_y (%)	Elastic recovery, E_e (%) afer 1 hour
T1	3,10	159,80	0,35	244,80	27,50	6,00	0,05	1,15	90,10
T2	4,50	201,20	0,44	205,60	46,20	2,50	0,04	1,72	93,20
T3	4,80	237,70	0,44	204,90	50,30	2,50	0,04	1,73	92,80
T4	3,40	233,00	0,65	266,60	41,20	1,50	0,03	2,06	86,40
T5	0,00	232,60	0,51	335,40	45,40	2,50	0,04	1,82	85,30
T6	6,60	229,80	0,47	155,40	35,70	3,00	0,05	1,62	93,20
T7	4,20	298,30	0,59	190,50	50,80	2,40	0,06	2,65	90,20
T8	3,10	307,00	0,62	485,30	28,30	5,40	0,04	0,71	87,50
T9	3,30	156,00	0,32	225,60	26,40	5,00	0,04	0,85	91,30
T10	2,20	318,00	0,55	445,20	41,80	6,60	0,07	2,20	90,00
T11	2,20	314,30	0,45	439,20	39,20	5,40	0,06	2,40	85,00
T12	2,20	327,50	0,49	443,20	35,70	5,20	0,05	2,30	90,00
T13	0,00	274,00	0,47	375,40	25,40	4,90	0,05	1,90	87,00
T14	3,10	315,30	0,56	323,57	28,90	4,38	0,05	1,78	89,59
T15	3,30	188,40	0,34	313,15	30,30	3,74	0,04	1,71	89,82
T16	2,80	255,09	0,50	335,36	28,90	5,30	0,05	1,87	89,23
T17	4,10	244,13	0,49	265,05	39,41	3,77	0,04	1,71	90,69
T18	3,90	245,81	0,49	283,17	33,80	3,84	0,05	1,72	90,50
T19	3,70	247,50	0,49	293,41	32,50	3,90	0,05	1,73	90,28
T20	4,40	241,59	0,49	252,71	39,71	3,68	0,04	1,70	91,04
T21	4,20	202,30	0,45	260,66	39,66	3,55	0,04	1,69	90,80
T22	4,80	238,22	0,49	235,85	40,33	3,55	0,04	1,68	91,52
T23	5,40	233,16	0,49	210,94	41,06	3,36	0,04	1,65	92,23
T24	5,20	299,50	0,56	217,76	41,63	3,72	0,05	1,69	91,98
T25	5,10	345,30	0,61	223,66	40,55	3,96	0,05	1,71	91,87
T26	4,10	244,13	0,49	273,66	34,70	3,77	0,04	1,71	90,73
T27	3,90	245,81	0,49	273,05	39,33	3,84	0,05	1,72	90,45
T28	3,20	251,72	0,49	321,47	27,90	4,06	0,05	1,75	89,72
T29	3,60	248,34	0,47	301,00	30,50	3,93	0,05	1,73	90,18
T30	4,70	239,06	0,49	239,04	40,74	3,58	0,04	1,68	91,39
T31	5,20	234,85	0,49	217,48	41,78	3,42	0,04	1,66	91,98
T32	4,81	238,15	0,44	234,41	40,95	3,55	0,04	1,68	91,52
T33	4,88	237,57	0,49	231,90	40,84	3,53	0,04	1,68	91,60
T34	4,95	236,99	0,49	229,16	40,85	3,51	0,04	1,67	91,69
T35	5,02	236,40	0,44	226,08	41,04	3,48	0,04	1,67	91,77
T36	5,08	235,82	0,49	223,26	41,09	3,46	0,04	1,67	91,85
T37	5,15	235,23	0,49	221,45	40,60	3,44	0,04	1,66	91,94
T38	5,22	234,65	0,41	218,52	40,71	3,42	0,04	1,66	92,02
T39	5,29	234,07	0,49	215,70	40,77	3,39	0,04	1,66	92,10
T40	5,36	233,48	0,49	212,83	40,85	3,37	0,04	1,65	92,19
T41	5,43	232,90	0,43	209,87	40,98	3,35	0,04	1,65	92,27
T42	3,10	252,56	0,49	329,24	25,80	4,09	0,05	1,75	89,62
T43	3,30	250,87	0,49	314,80	29,40	4,03	0,05	1,74	89,83
T44	2,80	198,30	0,43	320,01	37,30	3,93	0,04	1,74	89,15
T45	2,77	234,20	0,47	339,23	27,50	5,60	0,05	1,90	89,21
T46	2,62	256,64	0,50	340,37	30,10	6,70	0,05	2,01	89,00
T47	2,47	257,90	0,50	350,66	27,70	6,30	0,05	1,97	88,84
T48	2,32	178,50	0,37	362,40	24,50	3,97	0,04	1,75	88,70
T49	2,17	260,43	0,50	358,06	30,10	5,80	0,05	1,93	88,46
T50	3,30	250,87	0,49	326,87	22,80	4,03	0,05	1,74	89,89
T51	3,50	249,19	0,49	312,42	26,40	3,97	0,05	1,73	90,10
T52	3,80	246,66	0,49	292,77	30,70	3,87	0,05	1,72	90,41
T53	4,10	244,13	0,47	265,00	39,44	3,77	0,04	1,71	90,69
T54	4,40	241,59	0,49	252,52	39,82	3,68	0,04	1,70	91,04
T55	4,50	240,75	0,48	248,43	39,90	3,65	0,04	1,69	91,16
T56	4,20	243,28	0,49	261,05	39,45	3,74	0,04	1,70	90,81
T57	3,90	245,81	0,49	273,72	38,96	3,84	0,05	1,72	90,45
T58	5,60	231,47	0,46	202,64	41,30	3,30	0,04	1,64	92,47
T59	5,20	234,85	0,49	219,28	40,80	3,42	0,04	1,66	91,99
T60	2,60	256,78	0,50	336,64	32,50	5,50	0,05	1,89	88,96
T61	2,70	255,94	0,50	339,29	28,90	5,70	0,05	1,91	89,11
T62	3,60	248,34	0,49	292,03	35,40	3,93	0,05	1,73	90,13
T63	4,10	244,13	0,49	264,77	39,56	3,77	0,04	1,71	90,68
T64	4,40	241,59	0,48	252,25	39,96	3,68	0,04	1,70	91,04
T65	4,50	240,75	0,49	248,37	39,94	3,65	0,04	1,69	91,16
T66	4,20	243,28	0,49	261,08	39,43	3,74	0,04	1,70	90,81
T67	3,90	245,81	0,46	273,71	38,97	3,84	0,05	1,72	90,45
T68	5,60	231,47	0,49	202,65	41,30	3,30	0,04	1,64	92,47
T69	5,20	234,85	0,49	219,28	40,80	3,42	0,04	1,66	91,99
T70	6,30	225,57	0,48	173,14	42,39	3,07	0,04	1,61	93,30
T71	4,50	240,75	0,49	249,02	39,58	3,65	0,04	1,69	91,16
T72	3,20	251,72	0,44	303,26	37,85	4,06	0,05	1,75	89,62
T73	5,80	229,78	0,49	194,87	41,25	3,23	0,04	1,64	92,71
T74	4,20	243,28	0,49	261,21	39,36	3,74	0,04	1,70	90,81
T75	4,60	239,91	0,42	243,99	40,18	3,62	0,04	1,69	91,28
T76	4,90	237,38	0,43	232,36	40,10	3,52	0,04	1,67	91,64
T77	5,80	229,78	0,49	194,19	41,63	3,23	0,04	1,64	92,70
T78	3,10	252,56	0,49	313,33	34,50	4,09	0,05	1,75	89,54
T79	2,80	255,09	0,50	335,91	28,60	4,19	0,05	1,76	89,23
T80	3,80	246,66	0,49	278,36	38,58	3,87	0,05	1,72	90,33
T81	3,50	249,19	0,49	290,03	38,64	3,97	0,05	1,73	89,97
T82	3,90	245,81	0,49	273,20	39,25	3,84	0,05	1,72	90,45
T83	4,20	243,28	0,47	260,98	39,49	3,74	0,04	1,70	90,81
T84	4,60	239,91	0,49	244,15	40,09	3,62	0,04	1,69	91,28
T85	4,90	237,38	0,49	231,73	40,44	3,52	0,04	1,67	91,64
T86	5,20	234,85	0,46	219,26	40,81	3,42	0,04	1,66	91,99
T87	5,70	230,63	0,49	198,50	41,42	3,26	0,04	1,64	92,59
T88	2,10	261,00	0,50	368,72	25,70	6,80	0,05	2,02	88,42
T89	2,60	256,78	0,49	342,49	29,30	5,70	0,05	1,91	88,99
T90	2,90	254,25	0,50	329,24	30,10	5,40	0,05	1,88	89,34
T91	3,80	246,66	0,49	285,82	34,50	3,87	0,05	1,72	90,38
T92	3,50	249,19	0,49	301,27	32,50	3,97	0,05	1,73	90,04
T93	3,90	245,81	0,49	273,23	39,23	3,84	0,05	1,72	90,45
T94	3,08	252,77	0,50	308,03	37,93	4,10	0,05	1,75	89,47
T95	2,86	254,60	0,50	335,45	27,60	4,17	0,05	1,76	89,31
T96	2,64	256,43	0,49	331,34	34,50	5,50	0,05	1,89	88,99
T97	2,43	258,26	0,47	344,25	32,10	5,20	0,05	1,87	88,75
T98	2,21	260,08	0,50	356,79	29,90	5,70	0,05	1,92	88,51
T99	4,20	243,28	0,49	260,59	39,70	3,74	0,04	1,70	90,80
T100	4,80	238,22	0,49	235,40	40,58	3,55	0,04	1,68	91,51
T101	3,30	250,87	0,47	298,10	38,53	4,03	0,05	1,74	89,73
T102	3,50	249,19	0,49	290,39	38,45	3,97	0,05	1,73	89,98
T103	3,80	246,66	0,49	278,04	38,75	3,87	0,05	1,72	90,33
T104	4,10	244,13	0,39	264,97	39,45	3,77	0,04	1,71	90,69
T105	4,40	241,59	0,49	252,52	39,82	3,68	0,04	1,70	91,04
T106	4,50	240,75	0,47	248,43	39,90	3,65	0,04	1,69	91,16
T107	4,20	243,28	0,49	260,97	39,49	3,74	0,04	1,70	90,81
T108	4,85	237,79	0,46	233,93	40,28	3,54	0,04	1,68	91,58
T109	5,09	235,74	0,49	223,80	40,61	3,46	0,04	1,67	91,87
T110	5,34	233,70	0,42	213,58	40,98	3,38	0,04	1,66	92,15
T111	5,58	231,65	0,49	203,62	41,22	3,30	0,04	1,65	92,44
T112	5,82	229,61	0,47	193,59	41,49	3,23	0,04	1,63	92,73
T113	4,80	238,22	0,49	236,31	40,08	3,55	0,04	1,68	91,52
T114	3,50	249,19	0,43	290,84	38,20	3,97	0,05	1,73	89,98
T115	4,40	241,59	0,49	253,26	39,41	3,68	0,04	1,70	91,05

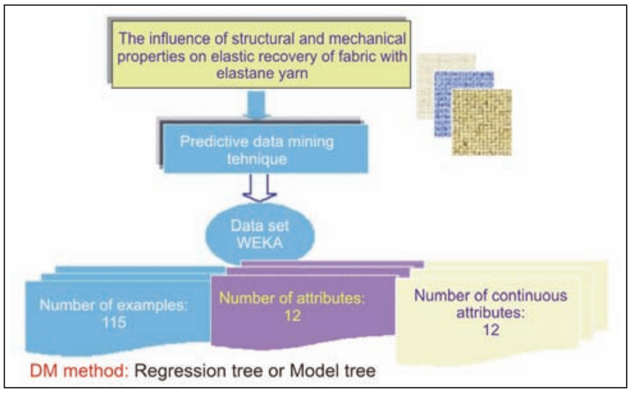

Fig. 1. The method of research of the influence structural and mechanical properties of fabric with elastane yarn on elastic recovery using the data mining method (DM method)

breaking load, breaking extension, elasticity modulus, stress and extension in the yield point, secondly. With the research, the predictive data mining technique was used to find out which structural and viscoelastic property of fabric with elastane yarn has the most important influence on elastic recovery after one hour exposing to the constant extension.

The research is oriented to the model to explain the influence of given properties of fabric on elastic recovery level with regression and model tree induction (figure 1).

For the data mining technique, the machine learning software WEKA version 3.4 written in Java was used. Weka is a collection of machine learning algorithms for data mining tasks. The algorithms can either be applied directly to a dataset or called from your own Java code.

WEKA was used for processing the set of data with learning algorithms and evaluation methods including data visualization [9, 10]. Weka contains tools for data pre-processing, classification, regression, clustering, association rules, and visualization. It is also well suited for developing new machine learning schemes and is open source software [11].

For the pre-processing of the data in Weka, the data were prepared in the CSV format in the Excel table.

Measured data, prepared in the Excel table, contained nine different attributes (measured structural and viscoelastic properties of fabric with elastane) and 115 different examples. Measured data of analyzed fabrics with elastane yarn is presented in table 1.

THE RESULTS WITH DISCUSSION

The results of research of the influence of structural and viscoelastic properties of woven fabrics with elastane yarn on elastic recovery after longer exposing to the constant extension using the predictive data mining techniques with the WEKA software are presented as:

- results of elastic recovery;
- regression tree induction (numerical data – algorithm M5P);
- model tree induction (numerical data – algorithm M5P with specific preparation);
- correlation between the experimental obtained values of elastic recovery and calculated values using regression and model tree induction.

Results of elastic recovery

The results of elastic recovery after one hour keeping to the constant extension of analysed fabrics are presented in figure 2 that draws also the elastane content value for 115 analyzed fabrics.

Analysis of results of elastic recovery of used fabrics (from 0 to 6.6 % of elastane content) shows that elastic recovery moves between 85 and 93 % (table 1). Analysis of results also shows increasing of the elastic recovery with increasing of elastane content in the yarn, from 0 to 6.6 % (figure 2). Elastic recovery mainly depends upon the value of elastane content in the yarn. Elastic recovery is time-dependent property and decreases with time of exposure of the fabric to the constant extension. Even after one hour keeping the fabric to the constant extension (10 %), the elastic recovery is very high for all used fabrics and depends upon the value of elastane content in the yarn. If the elastane content in the yarn is higher than 4 %, then the elastic recovery is higher than 90 %. Meanwhile fabrics that have lower elastane content in the yarn than 4 %, have lower elastic recovery than 90%.

Fabrics that have higher elastane content in the yarn than 4% have also wider region of elastic extension and consequently the value of elastic recovery (table 1).

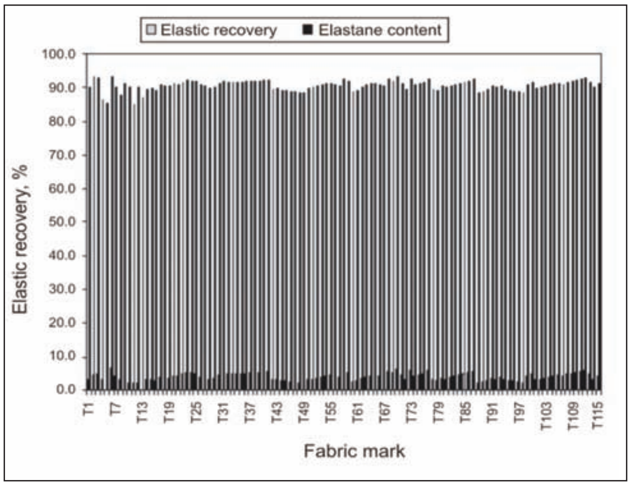

Fig. 2. The results of Elastic recovery, E_e and elastane content in the yarn level, W_{El}

Regression tree induction and discussion

The results of the research of analyzed structural and viscoelastic properties of woven fabric are shown as the regression tree (figure 3).

For the building of the regression tree, the following parameters were used:

- *Scheme: weka.classifiers.trees.M5P -R -M 30.0 (pruned regression tree, minimal number of instances in the each leave = 30).*
- *Number of examples: 115.*

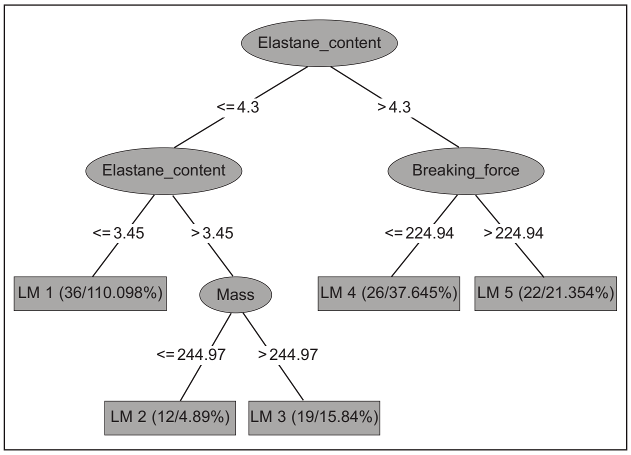

Fig. 3. The regression tree; LM – the value of the elastic recovery E_e in the leave of the regression tree; LM 1 = 89.4054 %, LM 2 = 90.3361 %, LM 3 = 90.203 %, LM 4 = 91.7995 % and LM 5 = 91.3358 %

- *Attributes (structural and viscoelastic properties of fabric): Elastane content W_{El}, Mass M, Thickness h, Breaking force F_{pr}, Breaking extension ε_{pr}, Elasticity Modulus E_0, Stress in the yield point σ_y, Extension in the yield point ε_y and Elastic recovery E_e.*
- *Test mode: 10-fold cross-validation.*
- *Classifier model: M5 pruned regression tree (using smoothed linear models.)*

The results of the regression tree show that with analyzed structural properties of fabric, the elastane content has the significant influence on elastic recovery value of fabric (figure 3). Those results are expected. If the fabric with the higher value of elastane content in the yarn is exposed to the extension which is higher than extension in the yield point, then the stretched elastane filaments, when the load is removed, react like a spring, with returning to the original length. The higher content of elastane filament in the fabric causes higher recovery (elastic recovery). If the elastane content in the yarn is higher than 4.3%, then the elastic recovery is higher than 90% (figure 3), on the contrary, if the elastane content in the yarn is smaller than 4.3%, then elastic recovery is smaller than 90%. The second significant property to predict the behaviour of stretch woven fabrics after exposing to the constant extension is the breaking force (figure 3). It means that the fabrics with higher elastane content have also lower breaking force and proportionally higher breaking extension and consequently extension in the yield point (table 1). Fabrics with elastane have higher region of elastic deformations and consequently higher value of elastic recovery. Analysis of results also shows that even after one hour keeping the fabric to the constant extension, the elastic recovery is around 90% and higher for fabrics with elastane content that is 4.3% and more (figure 3).

From the regression tree (figure 3) it is seen that fabrics with elastane content in the yarn which is higher than 4.3% and with breaking force which is lower than 224.94 N, the elastic recovery is the highest (around 91.7%).

From the regression tree induction it is clearly seen that the value of elastane content in the yarn has the significant influence on elastic recovery level after stretching.

Model tree induction and discussion

For the explanation the influence of the structural and viscoelastic properties on elastic recovery of elastic fabrics, the model tree induction was also used. With the model tree induction is possible to find the regression equation to explain the relation between the structural and viscoelastic properties and elastic recovery value. The model tree approximates continuous functions by linear patches and is smaller and more exceptable than the regression tree.

For building the model tree, the following parameters were used:

- *Scheme: weka.classifiers.trees.M5P -M 4.0 (pruned model tree, minimal number of instances in the each leave = 4).*
- *Number of examples: 115.*
- *Attributes: Elastane content W_{El}, Mass M, Breaking force F_{pr}, Breaking extension ε_{pr}, Elasticity Modul E_0, Stress in the yield point σ_y, Extension in the yield point ε_y and Elastic recovery E_e.*
- *Test mode: 10-fold cross-validation.*
- *Classifier model: M5 pruned model tree: (using smoothed linear models).*

Model tree presents equation (1):

$$E_e = 0{,}9455\ W_{El} - 0{,}0089\ F_{pr} - \\ - 0{,}3362 E_0 + 87{,}8902 \quad (1)$$

Where:

E_e is elastic recovery (%);

F_{pr} – breaking force (N);

W_{El} – elastane content in the yarn (%);

E_0 – elasticity modulus (MNm^{-2}).

The model tree shows that elastane content in the yarn, the elasticity modulus, and the breaking force values are significant to predict elastic recovery level (equation 1).

It is already known that with increasing the elastane content in the yarn also increases extension in the yield point and elastic region and elastic recovery consequently. Analysis of results also shows that elasticity modulus is the significant parameter (equation 1). With increasing of the elasticity modulus, the elastic recovery decreases. Fabrics with higher value of elastane content have also lower value of elasticity modulus, means the resistance of fabric on extension. It is valid that with higher extension of fabric, also grows the orientation of the elastane filament fibres incorporated into the yarn. After the load is removed, the oriented elastane fibres intended to

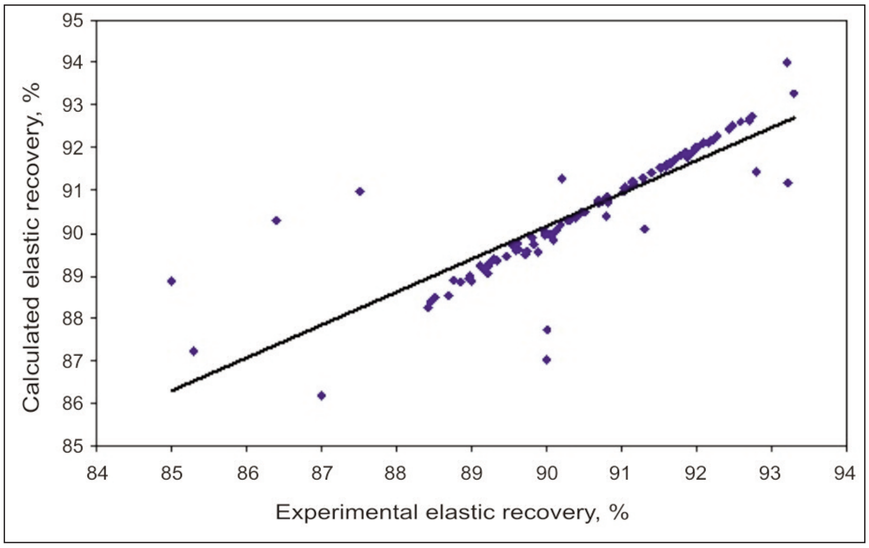

Fig. 4. Correlation between experimental obtained and predicted values of elastic recovery using regression tree induction (R^2 = 0.79)

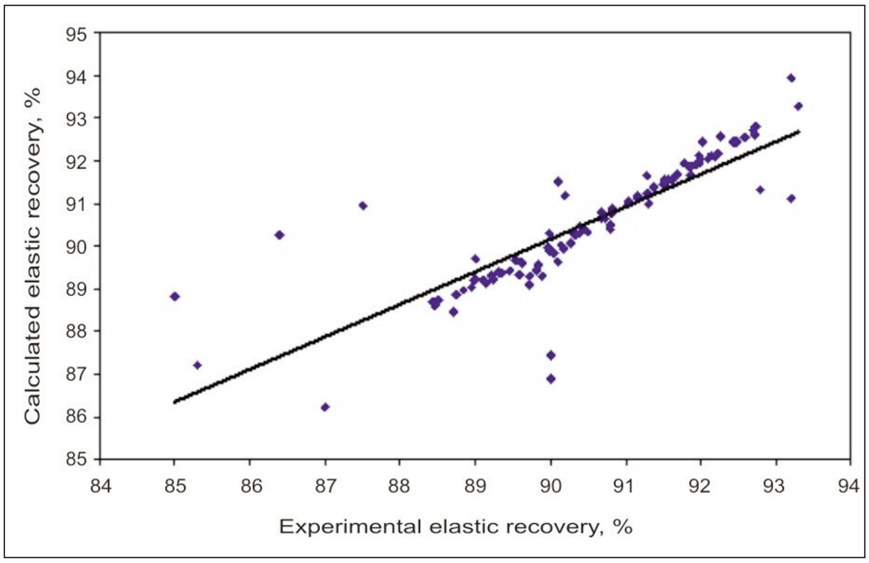

Fig. 5. Correlation between experimental obtained and predicted values of elastic recovery using regression tree induction (R^2 = 0.86)

return to the original shape. That causes higher elastic recovery.

It is well known that fabrics with elastane have higher elastic recovery than ordinary fabrics.

Even after longer exposure of the fabric with elastane to the constant deformation, the elastic recovery is still high and amounts around 90% (figure 2, table 1).

Correlation between experimental obtained and predicted values of elastic recovery using regression and model tree induction

The results of the correlation between experimental obtained and predicted values of elastic recovery using regression and model tree induction are given in figures 4 and 5.

The analysis of results of correlation between experimental obtained and predicted values of elastic recovery using regression and model tree induction shows that using model tree induction is better than regression tree induction (figures 4 and 5). The reason lies in linear relation between analyzed properties of fabric (structural and viscoelastic properties) and elastic recovery. The linear equation of the model tree better explains the influence of the analyzed properties on elastic recovery. The coefficient of determination, R^2, between experimental obtained and predicted values of elastic recovery using model tree induction is 0.86 (figure 5) and is higher than with using regression tree induction technique where coefficient of determination amounts 0.79 (figure 4). The model tree is also smaller and more acceptable than the regression tree.

CONCLUSIONS

Based on the study of the influence of the structural and viscoelastic properties of fabric with elastane yarn on elastic recovery using the data mining techniques it is concluded that the elastane content in the yarn has the significant influence on elastic recovery of fabric. With fabrics that have higher elastane content in the yarn than 4.3%, the elastic recovery after one hour keeping to the constant extension amounts around 91 %. The research indicates that fabrics with lower breaking force than 224.94 N have also higher value of elastane content in the yarn than 4.3%. Fabrics with higher value of elastane content in the yarn than 4.3% have the highest elastic recovery after one hour stretching with the constant extension (91.79%).

Regression and model tree induction are appropriate to analyze which property (from analyzed structural and viscoelastic properties) has the significant influence on elastic recovery level of fabrics with elastane in the yarn.

Better results were obtained with the model tree technique (R^2 = 0.86). The reason lies in the linear relation between the value of elastane content, breaking force, elasticity modulus and elastic recovery.

The prediction of the level of elastic recovery of fabric with the different percentage of elastane content in the yarn after stretching is very important for better understanding of the behaviour of stretch woven fabrics during production process and use of that kind of fabrics.

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Electrically heated sleeping bags could improve the human feet thermal comfort in cold outdoor environments

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REZUMAT – ABSTRACT

Sacii de dormit încălziți electric ar putea îmbunătăți confortul termic al picioarelor oamenilor în medii externe cu temperatură scăzută

În acest studiu, au fost dezvoltați doi noi saci de dormit încălziți electric, prin inserarea de perne electrice în sacii de dormit tradiționali, în regiunea piciorului. Au fost examinate răspunsurile fiziologice și psihologice a șase subiecţi umani (3 bărbați și 3 femei), în timpul utilizării de saci de dormit neîncălziți (de exemplu, atunci când sursa de încălzire a fost oprită) și saci de dormit încălziți electric (de exemplu, atunci când sursa de încălzire a fost pornită). S-a constatat că sacii de dormit încălziți electric ar putea îmbunătăți și menține în mod substanțial starea microclimatului în zona picioarelor într-un intervalul termic neutru (de exemplu, 24–34°C). În plus, sacii de dormit încălziți au îmbunătățit în mod semnificativ percepția termică a subiecților la nivelul picioarelor. Prin contrast, temperatura de vârf a subiecților în sacii de dormit neîncălziți a scăzut linear la 15°C și au fost raportate disconfort din cauza frigului și senzații de durere la sfârşitul perioadelor de expunere la rece cu o durată de 3 ore. Astfel, s-a ajuns la concluzia că noii saci de dormit încălziți electric ar putea îmbunătăți în mod eficient confortul termic uman la nivelul picioarelor.

Cuvinte-cheie: saci de dormit, textile funcționale, perne electrice, temperatura la nivelul picioarelor, percepția subiecților

Electrically heated sleeping bags could improve the human feet thermal comfort in cold outdoor environments

In this study, two novel electrically heated sleeping bags were developed by inserting heating pads into two traditional sleeping bags at the foot region. The physiological and psychological responses of six human subjects (3 males and 3 females) while wearing the non-heated sleeping bags (i.e., when heating power was turned off) and the electrically heated sleeping bags (i.e., when heating power was turned on) were examined. It was found that the electrically heated sleeping bags could dramatically improve and maintain the microenvironment condition at the feet area within the thermal neutral range (i.e., 24–34 °C). Besides, the heated sleeping bags significantly improved the subjective perceptions at the feet. In contrast, the toe temperature of the subjects in the non-heated sleeping bags dropped linearly to 15°C and cold discomfort and pain sensations were reported at the end of the 3-hour cold exposures. It was thus concluded that the new electrically heated sleeping bags could effectively improve the human thermal comfort at the feet.

Keywords: sleeping bags, functional textiles, heating pads, toe temperature, foot temperature, subjective perception

INTRODUCTION

Sleeping bags are portable and essential protective products for people sleeping outdoors. They have been widely used for wilderness training, rescue and leisure activities [1]. In general, a sleeping bag consists of an outer layer, an inner layer and the filler. In order to meet different user requirements, manufacturers designed sleeping bags with different shapes (e.g., mummy and rectangular shaped) and different thermal insulation levels [2]. As per EN 13537 (2012) sleeping bags are normally labelled with four temperatures, namely, the maximum temperature, the comfort temperature, the limit temperature and the extreme temperature [3]. Among these four labelled temperatures, the comfort temperature and the limit temperature are considered to be the most useful. The comfort temperature is defined as the temperature at which a standard woman could sleep for 8 hours without cold feeling in a relaxed posture. The limit temperature is the temperature at which a standard man could sleep for 8 hours without feeling cold with a curled up posture [3]. Previous documents have demonstrated that manufacturers used difference methods to determine the comfort and limit temperatures of the sleeping bags [1, 4, 5]. It has been reported that labelled temperatures defined by different methods varied greatly for bags with similar levels of insulation [4]. For instance, some manufacturers label the temperatures based on customers' feedback; some manufacturers determine the temperatures based on the sleeping bag's physical properties such as the thickness, weight and loft. Other manufacturers rate the temperatures by comparing the design and material of their sleeping bags with those of their competitors [4, 5].

Many models have been developed to predict the operating temperature of the sleeping bags, e.g., the EN 13537 (2012) model, Goldman's model, KSU model, Belding's model, IREQ model and the den

Hartog's model [6, 7]. Unfortunately, these models were developed from a global thermal comfort perspective. Local thermal discomfort at the extremities such as the human feet has been widely reported even though the mean skin temperature of the wearers fell within the thermoneutral range (i.e. 32–34 °C) [5, 8]. Lin et al. found that the toe temperature of the subjects dropped continuously and rapidly in sleeping bags under the EN 13537 (2002) defined operating temperatures [5]. Approaching the end of the 2-hour exposure, most subjects had strong cold sensations at their toes. In contrast, the mean skin temperature was well maintained within the thermal neutral range. Huang also observed decreasing toe temperatures on both male and female subjects who were exposed to the KSU model defined comfort temperatures [8]. It could be deduced from the aforementioned work that the operating temperatures defined by the existing models failed to provide the wearers an 8 hours comfortable sleep due to the severe local discomfort registered at the toes/feet.

Compared to the other body parts, human extremities are more sensitive to cold environments. The temperatures of human feet could drop rapidly during exposure to cold environment because of their large specific surface area and relatively low local metabolic rate [9]. The surface area to mass ratio of the human feet is 2.5–3.0 times larger than that of the whole body, which indicates the extremities tend to lose more heat when exposed to cold [9, 10]. Thermal discomfort sensation caused by the temperature decrease in the toes and feet could eventually develop pain [8, 9]. Further, it has been found that the accumulation of local discomfort at the extremities could significantly impact the whole body thermal comfort [11]. Thus it is reasonable to expect that improved thermal comfort at the body extremities (i.e., the feet) could contribute to enhancing the overall body thermal comfort.

In this study, two novel electrically heated sleeping bags were developed by incorporating heating fabric pads into traditional sleeping bags at the feet regions. Physiological and psychological responses of the human subjects while wearing non-heated traditional sleeping bags (i.e., when heating power was turned off) and electrically heated sleeping bags (i.e., when heating power was turned on) were investigated and compared. It was anticipated that the heated sleeping bags could improve the wearers' local thermal comfort at the feet under the defined operating temperatures.

METHODOLOGY

Subjects

Six healthy subjects including three females and three males voluntarily participated in this study. They had no or very limited experience in using a sleeping bag. The detailed physical characteristics of the subjects are summarized in table 1.

All subjects were informed on the purpose, procedure and the minor potential risks of the trial. They signed a written consent prior to participation. Subjects were not allowed to consume alcohol or do intensive physical activities at least 24 hour before each trial. They were also requested not to smoke, drink tea or coffee at least 2 hours before the trial. In order to eliminate the circadian variations, each participant performed the trials at the same time of the day and each trial was separated by at least 48 hours. This study was approved by the Ethical Committee of Soochow University.

Sleeping bags

Two electrically heated sleeping bags (code: MAR and VAU) with different levels of thermal insulation were developed based on two traditional sleeping bags randomly selected from the market. They are mummy-shaped and rectangular-shaped, respectively. The specifications of these two sleeping bags are shown in table 2. The thermal insulation of these two sleeping bags was measured by a 'Newton' thermal

Table 1

THE DEMOGRAPHIC DATA OF THE HUMAN SUBJECTS

Subjects	Age(yr)	Height (cm)	Weight (kg)	BSA (m^2)	BMI (kg/m^2)
Male	25±1.2	174±3.3	63.9±2.3	1.77±0.04	21.23±0.92
Female	23±2.0	160±2.6	48.2±2.3	1.48±0.04	18.81±0.54

Note: data are presented as mean ± SD (standard deviation). BSA, the Dubois body surface area. BMI, the body mass index.

Table 2

DETAILED INFORMATION OF SLEEPING BAGS

Sleeping bag	Material and weight (g)	T_{com-l} (°C)	T_{lim-l} (°C)	T_{com-m} (°C)	T_{lim-m} (°C)
MAR	Shell: nylon, lining: polyester, Filler: goose down. 1025 g	–2.4	–8.7	–0.4	–6.4
VAU	Shell: nylon, Lining: nylon, Filler: polyester. 1860 g	2.0	–3.0	5.5	0.5

Note: T_{com-l}, the labelled comfort temperature; T_{lim-l}, the labelled limit temperature; T_{com-m}, the measured comfort temperature based on the EN 13537 standard; T_{lim-m}, the measured limit temperature based on the EN 13537 standard.

manikin (Thermetrics LLC, Seattle, WA) according to the EN13537 (2012) standard. The detailed procedure was described as follows: before the manikin test, the sleeping bag was taken out from the package and conditioned for 12 hours. The manikin was first dressed with briefs, long cotton knitted underwear (the fabric's thermal resistance: 0.049 °C·m^2/W), knee-length socks and balaclava. Afterwards, the manikin was completely inserted into the sleeping bag, the zippers of the bag were closed and the hood was also closed tightly. The whole manikin-sleeping bag system was placed on a 40 mm inflated mattress (Therm-a-Rest®, Cascade designs Inc., Seattle, USA) with a labelled thermal insulation of 0.791 °C·m^2/W, which was supported by a 17 mm thick wooden table (1.8 m × 0.8 m × 0.9 m) [3]. Each test scenario was repeated three times. Each sleeping bag was repacked and shaken in between any two tests in order to eliminate the effect of packing on thermal insulation [12].

The thermal insulation of the sleeping bags was calculated by the serial method. The insulation was then translated into the comfort temperature (T_{com-m}) and limit temperature (T_{lim-m}) according to EN13537 (2012). As shown in table 2, the labelled comfort and limit temperatures were at least 2.0 °C lower than the EN13537 (2012) defined comfort and limit temperatures.

Test protocol

Two test scenarios were chosen for each sleeping bag: the bag with heating power turned off (i.e., the control, MAR_{CON} and VAU_{CON}), and the bag with heating power turned on (i.e., MAR_{HT} and VAU_{HT}). Two pieces of flexible heating fabric pads (size: 38 cm × 38 cm) were inserted at the feet region of the traditional sleeping bags. The heating fabric pads had a sandwiched structure composed of carbon fibre heating wires and cotton fabric. In this study, the heating power was set to 20 W (the input voltage: 9 V). Subjects were asked to sleep in the assigned sleeping bags in a random order. A total of 24 trials (i.e., 4 test scenarios × six subjects) were performed. Upon arrival, the subjects were asked to rest on a chair at room temperature (i.e., 20 ± 2 °C) to adjust initial thermal status. The subjects were then equipped with skin temperature sensors, heart rate belt and the skin blood flow sensor, and the defined clothing. The same pairs of cotton underwear and knee-length socks adopted in the manikin tests were used in the human trial study. After the preparation, the subjects entered into the chamber (where the test condition was set to the defined testing temperature) and they were laid in the tested sleeping bag on his/her back with a flat body posture. The sleeping bag was placed on an inflated mattress and the whole system was supported by the same wooden table that was used in the manikin tests. The total duration of each trial was 3 hours. The trials were terminated if one or more of the criteria were met: (i) the subject could not continue; (ii) the toe temperature dropped to below 12.0 °C; (iii) any other emergency situation which has to stop the experiment, and (iv) the subjects finished the 3 hours trial. The metabolic rate test was measured continuously for 5 min from the 20th min of the trial using a MetaMax®3B cardiopulmonary tester (Cortex Biophysik GmbH, Leipzig, Germany). After 3 hours, the participants left the chamber and took off the clothing and equipment. The schematic chart of the trial is presented in figure 1.

Measurements

The skin temperature was measured at ten sites on the left side of the body (i.e., the forehead, upper arm, forearm, chest, specula, hand, ring finger, thigh, calf, foot and the 4th toe) using thermistors (MSR® 145B4, accuracy: ±0.1°C, MSR Electronic GmbH, Seuzach, Switzerland). The heart rate was recorded throughout each trial via a Polar® chest strap (Polar Electro Oy, Kempele, Finland). The blood flow (i.e., the total blood volume per minute per 100 g skin soft tissue) of the fourth toe was continuously measured using a Doppler-type laser flow meter (ALF 21R,

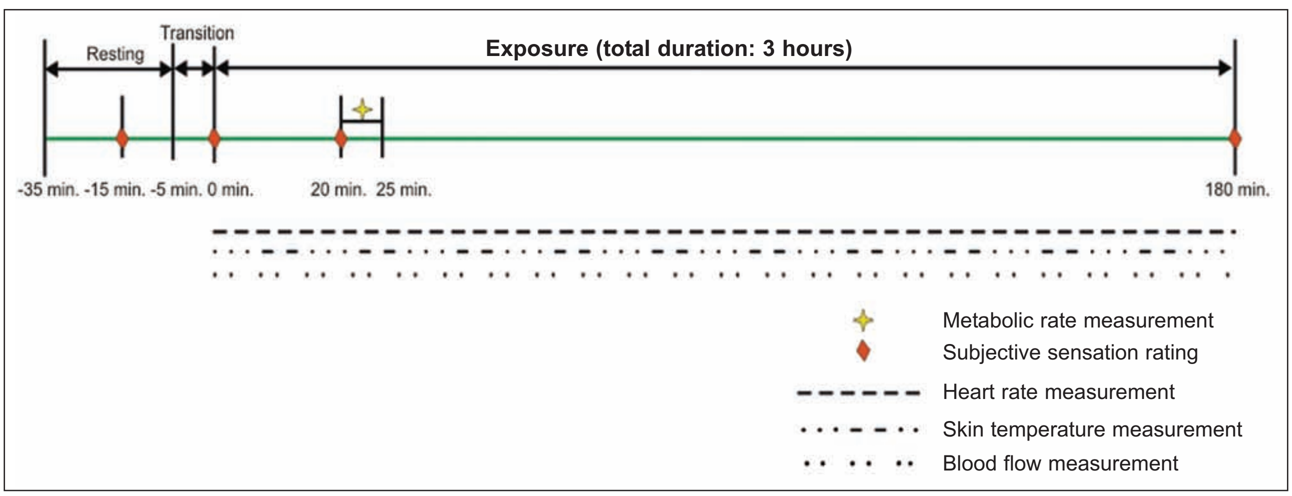

Fig. 1. Schematic graph of the trial design and measurement schedule

Advance Co. Ltd., Tokyo, Japan) throughout the test. The blood flow, heart rate and temperature were logged at intervals of 30 s.

Subjective sensations

Subjective sensations of the whole-body, hands and feet, were rated at certain times during each trial, namely: 15 min before the test, immediately after the subject entered the sleeping bag, the 20th min and the 180th minute of each trial (see figure 1). Thermal sensation (TS) was rated using a 9-point thermal sensation scale (–4 = very cold, –3 = cold, –2 = cool, –1 = slightly cool, 0 = neutral, 1 = slightly warm, 2 = warm, 3 = hot, 4 = very hot); comfort sensation (CS) was rated using a 4-point comfort sensation scale (0 = neutral, 1 = slightly uncomfortable, 2 = uncomfortable, 3 = very uncomfortable); skin wetness (SW) was rated using a 4-point skin humidity sensation scale (0 = neutral, 1 = slightly wet, 2 = wet, 3 = very wet) [13].

Test conditions

For manikin tests, the ambient temperature was –2.0 ± 0.5 °C, the relative humidity was 80 ± 5 % and the air speed was 0.5 ± 0.1 m/s. For human trials, the female and the male subjects had different test conditions. The females were exposed to –0.4 °C and 5.5 °C (i.e., the EN 13537 defined comfort temperatures, $T_{com\text{-}m}$) in MAR and VAU, respectively. The male subjects were exposed to –6.4 °C and 0.5 °C (i.e., the EN 13537 defined limit temperatures, $T_{lim\text{-}m}$) in MAR and VAU, respectively. The wind velocity inside the climatic chamber was 0.5 ± 0.1 m/s, and the relative humidity was 80 ± 5 %.

Calculations

The thermal insulation (I_t, in clo) of the sleeping bag was calculated by the serial method according to EN 13537 (2012), as expressed in equation 1.

$$I_t = \frac{1}{0.155}\sum_{i=1}^{n}\frac{a_i}{A}\,\frac{T_{ski}-T_a}{H_{ci}} \tag{1}$$

where: n is the segment number, n = 32; a_i is the surface area of the segment i, m^2; A is the total surface area of the manikin (i.e., 1.697 m^2); T_{ski} is the surface temperature of the segment i, °C; T_{a} is the air temperature, °C; H_{ci} is the heat flux of the segment i, W/m^2.

The mean skin temperature (T_{sk}) of human subjects was calculated using the 8-point prediction equation of Gagge and Nishi (Gagge and Gonzalez, 2011).

$$\begin{aligned} T_{sk} = {} & 0.07\,(T_{forehead} + T_{upperarm} + T_{forearm}) + \\ & + 0.175\,(T_{chest} + T_{specula}) + 0.05\,T_{hand} + \\ & + 0.19\,T_{thigh} + 0.20\,T_{calf} \end{aligned} \tag{2}$$

Statistical analysis

Data were presented as mean ± standard deviation (SD). A two-way repeated measures ANOVA analysis (test scenarios and time) and the Paired Samples t-tests were performed using IBM SPSS Statistics v.20.0 (IBM Corporation, Armonk, NY, USA), to analyse the difference in physiological and psychological responses between test scenarios, time effect and interaction effect between different scenarios and time points. The statistical significance level was accepted at $p < 0.05$.

RESULTS

Heart rate and metabolic rate

All subjects successfully finished the 3 hours trials. Heart rates were between 60-75 beats/min, and the average values were 65 ± 4, 64 ± 3, 68 ± 4, 58 ± 5 beats/min on female subjects in VAU_{CON}, VAU_{HT}, MAR_{CON}, MAR_{HT}, respectively. For male subjects, the averaged heart rate was 68 ± 3, 64 ± 3, 64 ± 4, 59 ± 3 beats/min in VAU_{CON}, VAU_{HT}, MAR_{CON}, MAR_{HT}, respectively. There was no significant difference in the heart rate between VAU_{CON} and VAU_{HT} ($p > 0.05$), and also between MAR_{CON} and MAR_{HT} for both genders ($p > 0.05$).

Metabolic rate was relatively stable throughout the whole trials under all testing scenarios. No significant difference was observed between VAU_{CON} and VAU_{HT} ($p > 0.05$), and between MAR_{CON} and MAR_{HT} for both genders ($p > 0.05$). The mean metabolic rate of female subjects was 1.29 ± 0.08, 1.36 ± 0.04, 1.18 ± 0.2, 1.14 ± 0.13 METs in VAU_{CON}, VAU_{HT}, MAR_{CON}, MAR_{HT}, respectively. Similarly, the mean values on male subjects were 1.23 ± 0.09, 1.09 ± 0.16, 1.08 ± 0.25, 1.06 ± 0.18 METs in VAU_{CON}, VAU_{HT}, MAR_{CON}, MAR_{HT}, respectively.

Mean skin temperature (T_{sk})

The evolution of T_{sk} under all test scenarios is presented in figure 2. During the first 20 min, T_{sk} increased dramatically and the main time effect (p<0.05) was observed during this period. Afterwards, the T_{sk} remained stable throughout the remaining duration of the trials. For female subjects, T_{sk} was maintained around 33.0 °C in both VAU_{CON} and VAU_{HT}, whereas it was plateaued at 32.8 and 33.4 °C in MAR_{CON} and MAR_{HT}, respectively. For male subjects, the steady-state T_{sk} stayed between 32.0 and 33.0 °C in VAU_{CON} and VAU_{HT}, respectively. In contrast, T_{sk} remained within 33.0-34.0 °C in both MAR_{CON} and MAR_{HT}. For both genders, no statistical significant difference in T_{sk} was obtained between VAU_{CON} and VAU_{HT}, and between MAR_{CON} and MAR_{HT} ($p > 0.05$).

The 4th toe (T_{toe}) and foot temperatures (T_{feet})

The development of the left 4th toe temperature (T_{toe}) and the left foot temperature (T_{feet}) throughout the exposures is presented in figure 3 and figure 4, respectively. In general, the T_{toe} and T_{feet} in MAR_{HT} and VAU_{HT} became relatively stable after 30 min, whereas T_{toe} and T_{feet} in VAU_{CON} and MAR_{CON}, for both male and female subjects, dropped almost

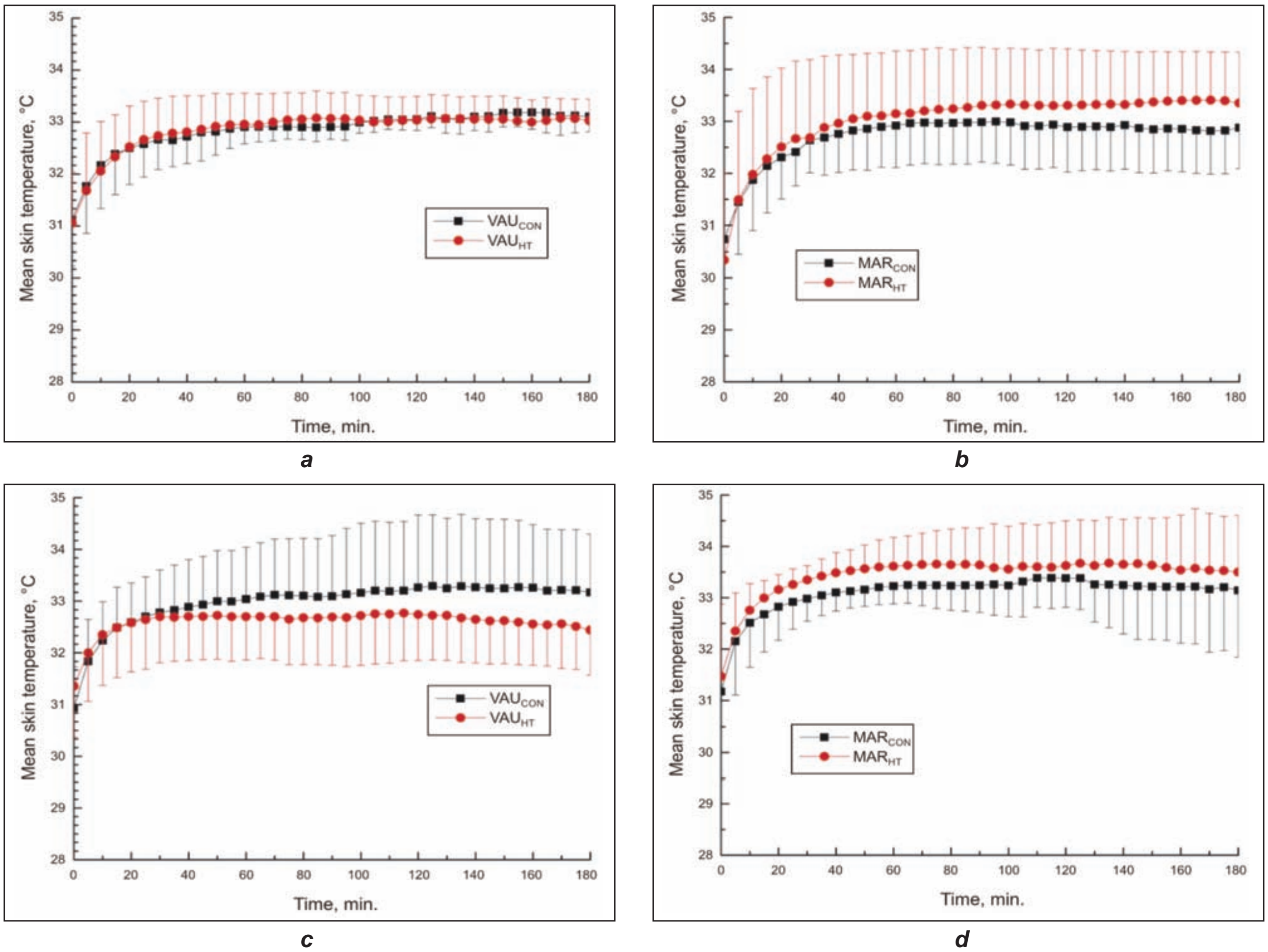

Fig. 2. Evolutions of the mean skin temperature on male and female subjects:
a – females in VAU; *b* – females in MAR; *c* – males in VAU; *d* – males in MAR. $^*p$<0.05

linearly throughout the entire testing period and the main time effect was detected ($p<0.05$).

For female subjects in VAU_{CON}, T_{toe} and T_{feet} fell from 25.4 °C and 29.2 °C to 18.0 °C and 23.2 °C, respectively. Similarly, T_{toe} and T_{feet} in MAR_{CON} dropped from 24.8 °C and 28.3 °C to 15.4 °C and 22.6 °C, respectively. Significant differences in T_{toe} between VAU_{CON} and VAU_{HT} were observed from the 135th min to the end of test. Also, there were significant differences in T_{toe} between MAR_{CON} and MAR_{HT} from the 95th min of the exposure to the end of the exposure ($p<0.05$). Significant differences in T_{feet} between VAU_{CON} and VAU_{HT} were detected from the 80th min till the end of the trial. Similarly, there were significant differences between MAR_{CON} and MAR_{HT} from the 145th min to the end of the test ($p<0.05$). It should be noticed that in both MAR_{HT} and VAU_{HT}, the T_{toe} and T_{feet} increased significantly at the beginning of the trial and then became relative stable at around 27.4 °C and 32.0 °C, respectively throughout the remaining test duration.

For male subjects in VAU_{CON}, T_{toe} and T_{feet} fell from approximately 26.3 °C and 29.2 °C to 14.6 °C and 21.5 °C, respectively. Both T_{toe} and T_{feet} decreased from 24.8 °C and 30.4 °C to 14.1 °C and 24.4 °C in MAR_{CON}, respectively. Significant differences in T_{toe} were observed between MAR_{CON} and MAR_{HT} from the 25th min to the end of exposure ($p<0.05$). For T_{feet} in MAR, significant differences were detected from the 15th min to the end of the test ($p<0.05$). In MAR_{HT}, both T_{toe} and T_{feet} increased significantly at the beginning of the test and then they plateaued at 34.2 °C and 35.1 °C, respectively throughout the remaining test period. The concluding T_{toe} and T_{feet} in VAU_{HT} were 22.3 °C and 28.5 °C, respectively.

Blood flow at the 4th toe

The development of blood flow (BF_t) at the 4th toe of each subject in MAR_{CON}, MAR_{HT}, VAU_{CON} and VAU_{HT} is displayed in figure 5 and figure 6, respectively. For all subjects, the BF_t in both MAR_{CON} and VAU_{CON} dropped from different levels to below 0.5 ml/100g/min within the first 20 min and was then maintained at a relatively low level throughout the remaining test period. In contrast, the BF_t in VAU_{HT} and MAR_{HT} fluctuated at a relatively high value with the exception of F1. In addition to the individual values, the averaged BF_t (BFt_{aver}) of the female and male subjects under all test scenarios was also calculated. It was observed that, the steady state BFt_{aver} on females was found between 0.3 to 6.1 ml/100g/min and 0.9 to 9.3 ml/100g/min in VAU_{CON} and

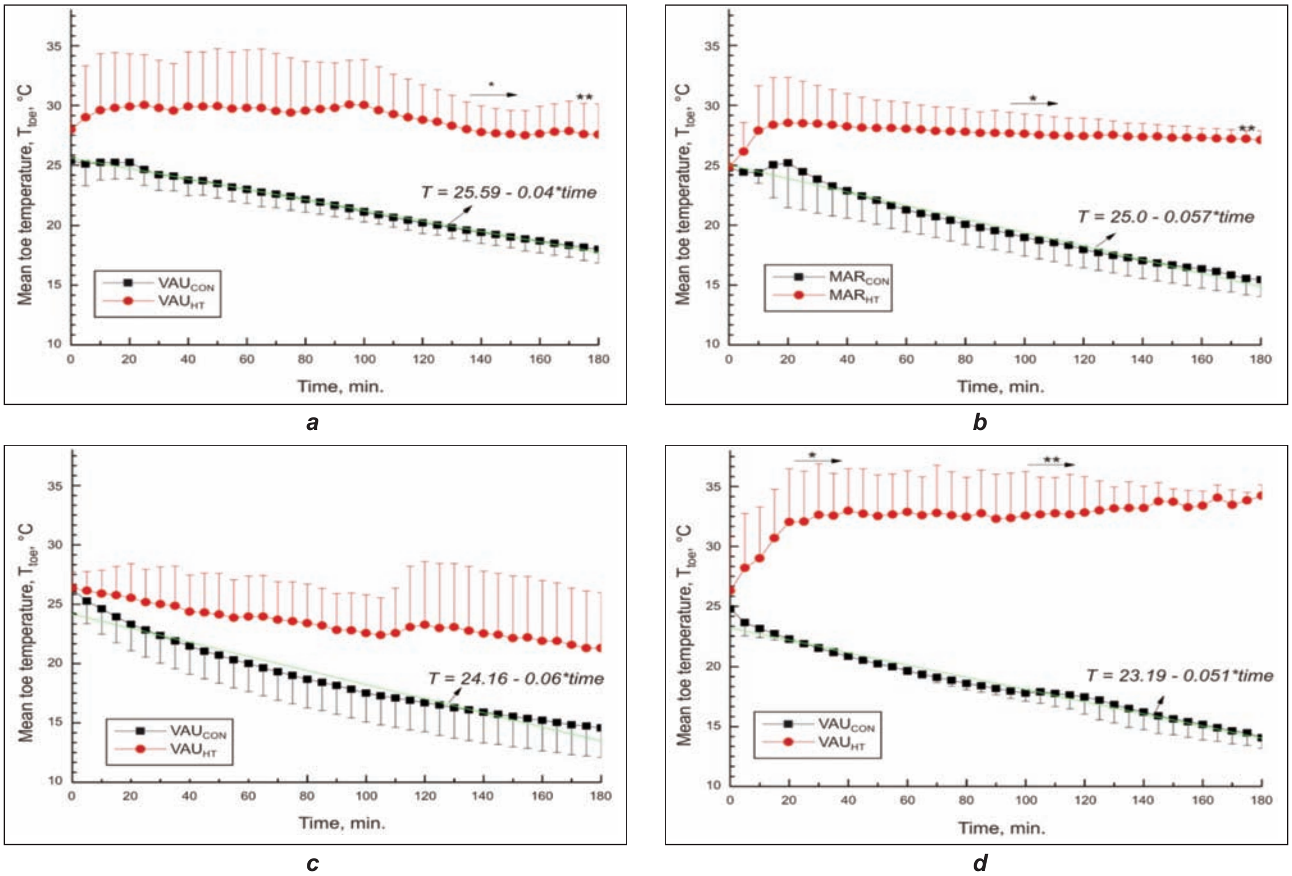

Fig. 3. The development of the 4th toe temperature on males and females: *a* – T_{toe} of female subjects in VAU; *b* – T_{toe} of female subjects in MAR; *c* – T_{toe} of male subjects in VAU; *d* – T_{toe} of male subjects in MAR. *p<0.05

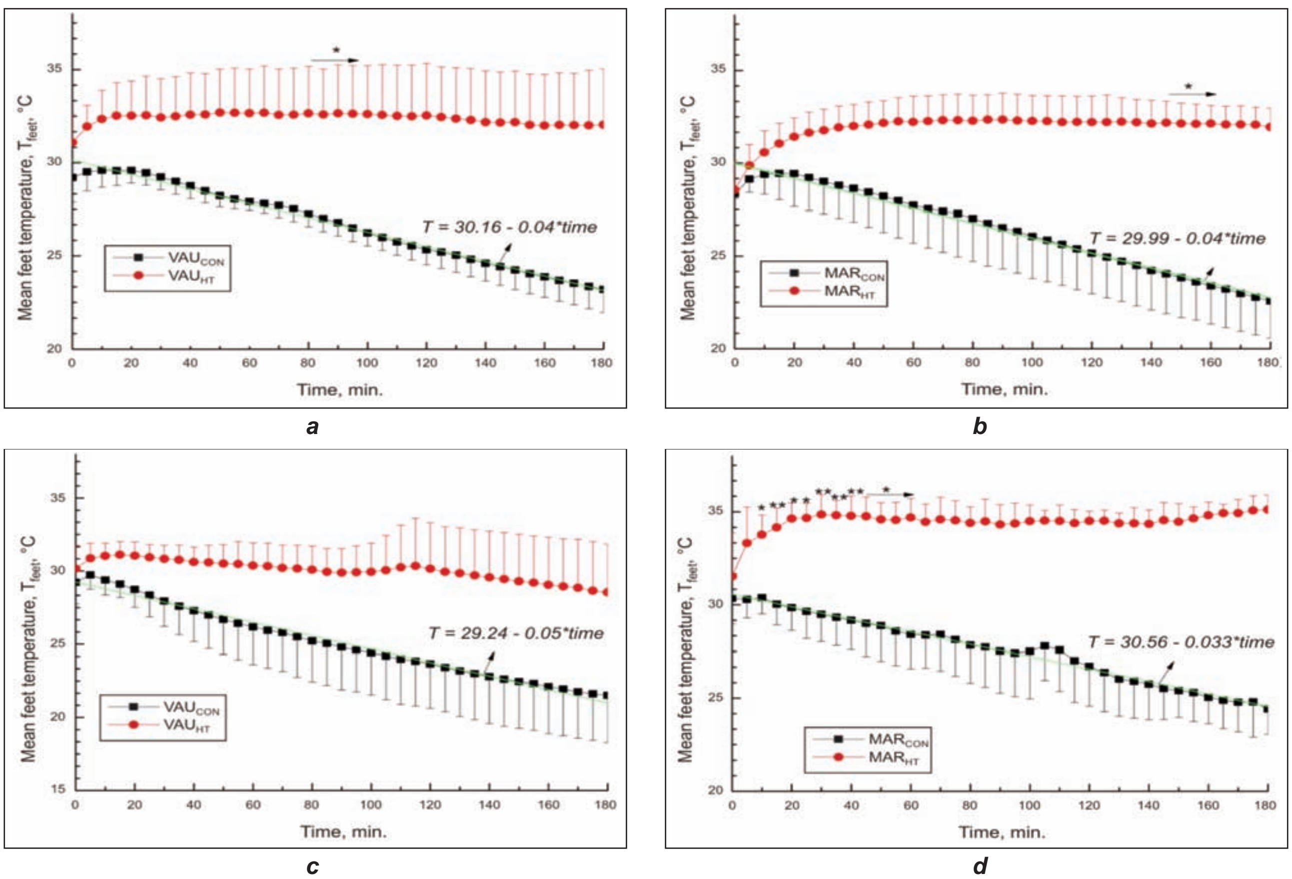

Fig. 4. The development of the left foot temperature on males and females: *a* – T_{feet} of female subjects in VAU; *b* – T_{feet} female subjects in MAR; *c* – T_{feet} of male subjects in VAU; *d* – T_{feet} of male subjects in MAR. *p<0.05

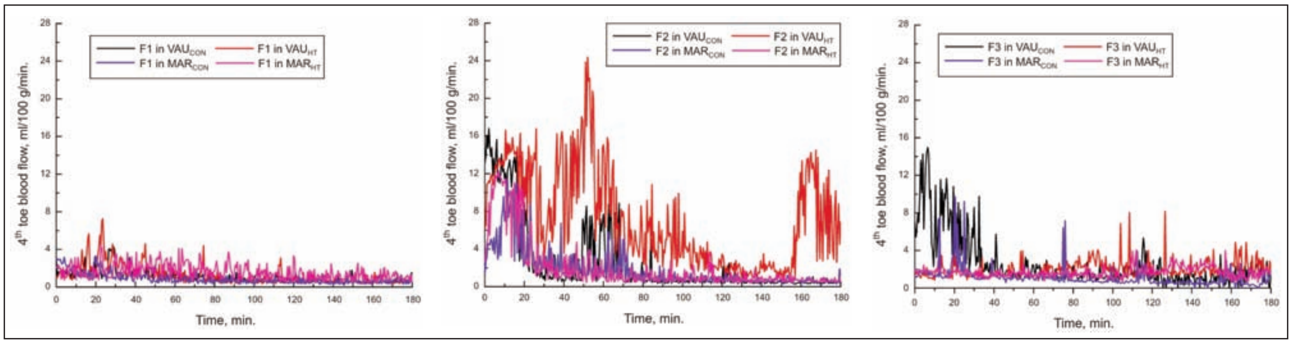

Fig. 5. The development of the 4th toe blood flow (BF_t) on females. F1 to F3 indicates the subject number from 1 to 3

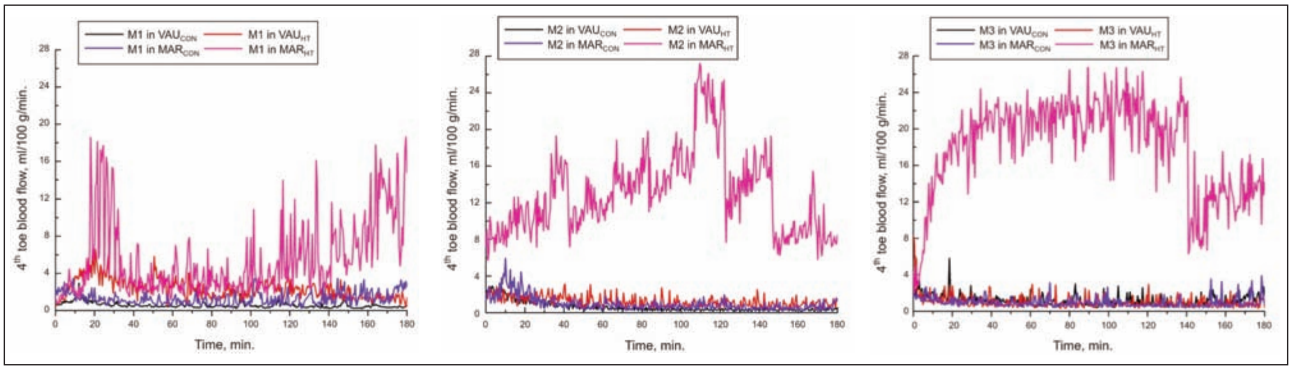

Fig. 6. The development of the 4th toe blood flow (BF_t) on males. M1 to M3 indicates the subject number from 1 to 3

VAU$_{HT}$, respectively. Similarly, the mean blood flow on females in MAR$_{CON}$ and MAR$_{HT}$ fell between 0.3 to 3.9 ml/100g/min and 0.6 to 4.2 ml/100g/min, respectively. For male subjects, the BFt_{aver} fluctuated within the range of 0.2–1.2 ml/100g/min and 0.4–2.7 ml/100g/min in VAU$_{CON}$ and MAR$_{CON}$, respectively, whereas it fell within 0.5–3.4 ml/100g/min and 6.0–19.3 ml/100g/min in VAU$_{HT}$ and MAR$_{HT}$, respectively.

Subjective perceptions

Subjective responses in VAU and MAR are presented in tables 3, 4, 5 and 6, respectively. Almost all subjects had a 'Neutral' rating during the first 20 min of the cold exposure (i.e., TS, CS and SW = 0) with occasionally exceptions (e.g., the TS at the hands on females in VAU$_{CON}$; TS at the feet on males in VAU$_{CON}$ and MAR$_{HT}$).

At the end of the trial, the most significant decrease in TS and CS was observed at the feet in VAU$_{CON}$ and MAR$_{CON}$. The whole body TS had a moderate change on females in MAR$_{CON}$ and on males in VAU$_{CON}$, whereas it had a slightly decrease on females in VAU$_{CON}$ and on male subjects in MAR$_{CON}$. Subjects rated a 'Neutral' or 'Slightly warm' rating at their hands in all four studied scenarios because the hands were always placed closely to the torso. For SW, a 'Neutral' skin wetness sensation was obtained in both the whole body and the feet throughout the tests. A rating of 'Slightly wet' was rated at hands on females in VAU$_{CON}$, VAU$_{HT}$, MAR$_{HT}$, and on males in MAR$_{HT}$.

Table 3

SUBJECTIVE SENSATIONS ON FEMALE SUBJECTS IN VAU$_{CON}$ AND VAU$_{HT}$

Subjective responses		Time	–15 min	0 min	20 min
TS	Feet	VAU$_{CON}$	0±0	0±0	–0.17±0.29
		VAU$_{HT}$	0±0	0±0	0±0
	Hands	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
	Whole body	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
CS	Feet	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
	Hands	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
	Whole body	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
SW	Feet	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
	Hands	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0
	Whole body	VAU$_{CON}$	0±0	0±0	0±0
		VAU$_{HT}$	0±0	0±0	0±0

Table 4

SUBJECTIVE SENSATIONS ON MALE SUBJECTS IN VAU_{CON} AND VAU_{HT}					
Subjective responses		Time	–15 min	0 min	20 min
TS	Feet	VAU_{CON}	0±0	0±0	–0.17±0.29
		VAU_{HT}	0±0	0±0	0±0
	Hands	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
	Whole body	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
CS	Feet	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
	Hands	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
	Whole body	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
SW	Feet	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
	Hands	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0
	Whole body	VAU_{CON}	0±0	0±0	0±0
		VAU_{HT}	0±0	0±0	0±0

Table 5

SUBJECTIVE SENSATIONS ON FEMALE SUBJECTS IN MAR_{CON} AND MAR_{HT}					
Subjective responses		Time	–15 min	0 min	20 min
TS	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
CS	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
SW	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0

Table 6

SUBJECTIVE SENSATIONS ON MALE SUBJECTS IN MAR_{CON} AND MAR_{HT}					
Subjective responses		Time	–15 min	0 min	20 min
TS	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0.17±0.29
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
CS	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
SW	Feet	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Hands	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0
	Whole body	MAR_{CON}	0±0	0±0	0±0
		MAR_{HT}	0±0	0±0	0±0

After the 180 min exposure, 'Cool' to 'Cold' thermal sensations were observed at the feet region on all subjects in VAU_{CON} and MAR_{CON}. In contrast, 'Slightly warm' or 'Neutral' thermal sensations were registered in VAU_{HT} and MAR_{HT}. With regard to the comfort sensations, all subjects rated 'Uncomfortable' or 'Slightly uncomfortable' at the feet at the end of the exposure in both VAU_{CON} and MAR_{CON}, whereas a rating of 'Comfortable' was reported at the feet in VAU_{HT} and MAR_{HT}.

DISCUSSION

In this study, the reported average metabolic rate (around 1.2 ± 0.2 METs) and the mean heart rate (i.e., 60–80 beats/min) of all subjects were close to those of a person lying down quietly at the room temperature [14, 15]. In addition, it has been proven that the linear decrease in both toe (T_{toe}) and feet (T_{feet}) temperatures could result in dramatically cold sensations on both genders (figure 3 and 4) within the 3-hour exposure. Based on the linear regression equations developed for T_{toe} and T_{feet} in VAU_{CON} and MAR_{CON}, it could be estimated that T_{toe} could dropped to below zero in MAR_{CON} after an 8-hour exposure. Thus, our study has reconfirmed that the temperature rating method proposed by the EN 13537 (2012) was inadequate to provide sufficient protection for the human extremities (i.e., the toes and feet). This is in line with the findings of Lin et al. and Huang [5, 8]. Lin et al. observed a linear decrease in T_{toe} on females within the 2-hour exposure under the EN 13537 (2002) defined comfort temperatures [5]. However, no obvious decrease in T_{toe} for male subjects was observed under the defined limit temperatures. In contrast, in this study, a linear decrease in T_{toe} was obtained on both genders in VAU_{CON} and MAR_{CON}. One possible reason for the difference between our findings and Lin et al.'s observation might be due to the different exposure temperatures and durations. It has also demonstrated that the electrically heated sleeping bags could maintain T_{toe} and T_{feet} on both genders within the thermal comfort range (i.e., 24–34 °C) [9].

For most cases in this study, it is evident that heating the feet area could improve the local blood flow at the toes. The BF_t in VAU_{CON} and MAR_{CON} dropped to near zero, whereas much greater BF_t values in both VAU_{HT} and MAR_{HT} were observed. This is in good agreement with the finding of Taylor et al. [10], who described that the blood flow at the foot could drop to 0.2 ml/100g/min under protected cold environments. Meanwhile, the BF_t could increase dramatically to 18 ml/100g/min in warm environments. Similar findings were also reported by House et al. [16]. The mechanism of the changes in the toe blood flow depends on the action mode of arteriovenous anastomoses (AVAs) [17, 18]. The action mode of AVAs depends on the surrounding temperature of the extremities: vasoconstriction and vasodilation occurs upon changes in the ambient temperature [15, 16]. When exposed to cold environments, vasoconstriction occurs at the toes, resulting in BF_t decreased to near zero in VAU_{CON} and MAR_{CON}. In contrast, vasodilation of the toe skin vessel was promoted when the heating was applied in VAU_{HT} and MAR_{HT}. Additionally, a large inter-individual variability in the BF_t on both genders was detected in both VAU_{HT} and MAR_{HT}.

In accordance with the findings of Isik, our study found that heating the feet region had no effect on T_{sk}. [5] . The T_{sk} of all subjects in all test scenarios was well stayed within the thermal neutral range (i.e., 32–34 °C) [20]. It could be suggested that the temperature rating method adopted in EN 13537 (2012) mainly focused on the global thermal comfort, with less attention on the thermal comfort of the extremities.

Physiological and subjective responses were related and interacted with each other. Based on the observed physiological responses, it was reasonable to note that both the TS and CS at the feet in VAU_{CON} and MAR_{CON} decreased significantly at the end of the test. Whole body sensations were affected by the cold sensation at the feet even though there was no decrease in T_{sk}. This finding is in line with that of Fanger, who proposed that cold feelings at the feet could impact the whole body thermal comfort even when the other body parts were properly protected [19]. Thus it could be suggested that the deterioration in the whole body TS and CS in VAU_{CON} and MAR_{CON} was induced by local discomfort. In both VAU_{HT} and MAR_{HT}, significant improvements on TS and CS at the feet region were observed. The TS and CS of the whole body were also greatly improved when comparing the heating scenarios to the control. The present study has reconfirmed that EN 13537 (2012) failed partly to take consideration of local body thermal comfort.

The novel electrically heated sleeping bag was proved to be effective in improving body thermal comfort under cold environments. An important factor affecting the actual usability of the heated bag is the power supply. For the outdoor settings where electric power is not available, a light and portable high capacity lithium-ion battery could be used to supply heat to the sleeping bags. Nevertheless, lithium-ion batteries generally have a limited heating period, and hence they may not be applicable to long-period outdoor activities. Future electrically heated sleeping bag will become smarter. The power supply to the sleeping bag will be automatically adjusted based on the microclimate temperature feedback at the feet region and thereby this helps to save energy as well as to improve the energy efficiency.

Finally, it must be acknowledged that a limited number of subjects and the single sample source of young university students are the limitations of the present study. Though not discussed, it is still meaningful to examine the thermophysiological or psychological differences between the two genders in the heating sleeping bags. More human subjects with wide age distributions should be involved in future studies to investigate the actual effects of the heating sleeping bags as well as the gender differences while using the bags.

CONCLUSIONS

Two heated sleeping bags were developed by incorporating heating pads into the feet region of two traditional sleeping bags. It was found that the electrically heated sleeping bags could dramatically improve the microenvironment at the feet region as well as the blood flow at the toes. The new electrically heated sleeping bags may serve as an alternative for people sleeping outdoors. Nevertheless, power source are required for supplying heat to the sleeping bag. As a portable battery has a limited capacity in providing power to the heated bags, our newly developed sleeping bags may not be applied to extreme settings such as long-time hiking in the wilderness.

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Development of the compositions of chemical agents containing silver nanoparticles for the antibacterial finishing of textiles

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REZUMAT – ABSTRACT

Dezvoltarea compozițiilor de agenți chimici care conțin nanoparticule de argint pentru finisarea antibacteriană a textilelor

Articolul prezintă rezultatele cercetării care implică evaluarea compozițiilor de agenți chimici ce conțin nanoparticule de argint și posibilitatea aplicării lor în procesul de finisare a tricoturilor prin metoda fulardării. Activitățile de cercetare au fost realizate ca rezultat al colaborării cu Amepox Ltd. Fiind pozitiv evaluați în testele organoleptice, compușii agenților chimici și soluțiile coloidale de nanoparticule de argint metalice au fost examinate prin EDS (spectroscopie de raze X cu dispersia energiei) folosind un microscop electronic de scanare VEGA3. Eficacitatea activității antibacteriene a compușilor dezvoltați a fost evaluată pe baza rezultatelor testelor microbiologice ale tricoturilor după finisarea acestora cu aplicarea acestor compoziții.

Cuvinte-cheie: nanoparticule de argint, finisarea textilelor, textile antibacteriene, metoda de fulardare

Development of the compositions of chemical agents containing silver nanoparticles for the antibacterial finishing of textiles

The article presents the results of research involving the assessment of the chemical agents compositions developed containing silver nanoparticles and the possibility of their application in the finishing process of knitted fabrics by the padding method. The research works were realized as a result of cooperation with Amepox Ltd. Positively evaluated in organoleptic tests the compounds of chemical agents and colloidal solutions of metallic silver nanoparticles were examined by EDS (Energy dispersive X-ray spectroscopy) using a scanning electron microscope VEGA3. The effectiveness of antibacterial activity of the compounds developed was evaluated based on the microbiological tests results of knitted fabrics after their finishing with the application of these compositions.

Keywords: silver nanoparticles, textiles finishing, antibacterial textiles, padding method

INTRODUCTION

The issue of antibacterial protection in textiles is of particular importance with reference to fabrics used in direct contact with user's skin. Consumers' requirements and competitiveness on the textile market have resulted in the appearance of a growing number of the assortments of modern clothing fabrics with antibacterial properties. More and more frequently one of the requirements not only for hosiery, hospital bedding, shoe padding, underwear and so-called clothes of the first layer in the multi-layer sports clothing system, but also for protective and working clothes is the protection against the adverse effect of microorganisms and their growth [1–2].

Imparting antibacterial properties to textiles can be carried out in various stages of manufacturing processes. The protection against microorganisms can be achieved, among others things, by means of hygienic finishes consisting in using agents containing bioactive substances or by incorporating these substances into the spinning mass during fibre formation. The development of nanotechnology has created opportunities to use metal nanoparticles, especially silver nanoparticles to obtain antibacterial properties of textiles [3–8].

The essential problem to be solved is to provide antibacterial features resistant to maintenance processes since not all the chemical agents promoted for antibacterial finishes of textiles provide the stability of the protective properties imparted.

The assessment of the action effectiveness of antibacterial agents used in chemical treatment processes, and consequently the effectiveness of their combination with fibre surface, is carried out during microbiological tests. The test methods differ in testing conditions, methods of parameter assessment as well as the bacterial strains used. The choice of an appropriate microorganism strain should depend first of all on the environment, in which the given fabric is to fulfil its bioactive functions [9]. In standardized test methods, Gram-positive and Gram-negative bacteria are most frequently used. Usually, these are bacterial strains existing in man environment, i.e. in the composition of physiological flora of skin, oral cavity and intestines. Most frequently they include: Gram-positive bacteria – *Staphylococcus aureus* and Gram-negative bacteria – *Escherichia coli* (colon bacillus) and *Klebsiella pneumoniae* (Pneumonia bacillus) [1, 9–12].

The Textile Research Institute has experience in imparting specified special properties to textiles, including antibacterial features. Experimental works within this scope were realized with the use of yarns containing bioactive modifiers or special antibacterial chemical agents. The application of antibacterial agents in the finishing process of various fabrics was carried out for metric knitted fabrics by the padding method, while for seamless wear by the method of bath exhaustion [13–18].

The aim of the present study was to assess the various chemical compositions of the compounds developed, containing silver nanoparticles and the possibility of their use in the finishing process by the method of padding knitted fabrics with protective properties against hot thermal conditions and static electricity [19]. The direction of research works resulted from a need for imparting additional features of microbiological activity to the knitted fabrics mentioned.

Research works within this scope were carried out within the Project EUREKA – BATAN, Barrier *textiles and nanomaterials*, additionally financed by the National Centre of Research and Development [20].

EXPERIMENTAL WORK

Composition of the compounds of chemical agents containing silver nanoparticles

The development of the chemical composition of compounds containing silver nanoparticles, designed for antibacterial finishing knitted fabrics by the padding method was preceded by the market analysis in quest for appropriate chemical agents for compounds, to which colloidal solutions of silver nanoparticles were added in the further part of the studies [21]. On account of the planned use of silver nanoparticles, it was decided that the most suitable chemical agents would be those designed for pigment printing. This printing process is based on using water-insoluble dyes, most commonly used solvents and binding agents in the form of proper synthetic resins. Binding agents durably fasten pigments to the fabric surface, thanks to which one can obtain printouts resistant to water and washing [22].

The following chemical agents were selected for tests to establish various antibacterial compounds [23]:

- Pericoat VA 110 – vinyl acetate-based self-cross-linking agent used for coating and pigment printing,
- Acrafix ML – cross-linking agent for pigment printing; aqueous preparation of modified melamine resins,
- Periprint MA conc. – migration inhibitor for pigment dyeing that improves hydrophilic properties of fabrics; polyglycol ether of fatty alcohol,
- Fixative ABN – binding agent for pigment printing, butadiene-acrylonitrile resin,
- Emulgator C – stabilizing-emulsifying agent,
- Texafix HY – binding agent, especially recommended for micro-capsule-based products; its main component is acrylic resin,
- Acramin BPD – acryl-styrene-based binding agent for dyeing by the padding method,
- Texafix PU self-cross-linking aqueous nanodispersion of modified polyether polyurethane,
- Texapret TP – thermoplastic cross-linking agent,
- Texapal RN – wetting agent for dyeing cellulose fibers and their blends; polyglycol ether of fatty alcohols,
- Perlavin NSH – wetting and emulsifying agent for oil and fats; ether of fatty alcohols and polyglycol,
- Emulgator WN – emulsifying and dispersing agent for textile printing; acrylo-polyglycol ether,
- Periprint AC conc. – migration inhibitor for dye and pigments; derivative of polycarboxylic acid,
- Tanaprint ST 2078 – synthetic thickener for pigment printing; acrylic copolymer.

In the first stage of tests, the chemical agents selected constituted the basis for working out mixtures containing: binding agent, thickener, emulsifier, cross-linking agent in different proportion and non-distilled and distilled water. The mixtures with various component contents were used for the preparation of antibacterial compounds containing silver nanoparticles.

The studies on the development of antibacterial compounds were carried out with the co-operation of Amepox Ltd., a manufacturer of nanosilver with various disintegrations and colloidal solutions of silver nanoparticles with specified granulations and types of protective envelopes on the surface of silver particles. As a result of the tests performed, Amepox has developed colloidal solutions of metallic silver particles obtained by the method of thermal decomposition of silver compounds in oxygen-free atmosphere [24]. These colloidal solutions of silver nanoparticles are characterized by the stability of technological properties (viscosity, content of silver nanoparticles, etc.) for a long time and show the features of specific liquid from the point of view of size of dispersed particles in relation to the main solvent. These parameters of colloidal solutions of silver nanoparticles make it possible to use them in technological processes of textile industry [24].

Experimental works on the development of antibacterial compounds designed for the finishing treatment of textiles were directed to obtain the composition stability of the compounds, in which silver nanoparticles do not undergo sedimentation. Tests in this range were carried out with the use of two types of silver colloidal solutions with a silver concentration of 0.1% by wt.:

- silver nanoparticles with dimensions below 10 nm in a paraffin envelope (paraffin coated silver nanoparticles) in petroleum spirits (figure 1, a),
- silver nanoparticles with dimensions 50–60 nm in PVA envelope (PVA – Poly(vinyl alcohol) coated silver nanoparticles) in aqueous medium (figure 1, b),

with the highest purity controlled during the whole production cycle [24].

The size of silver nanoparticles in colloidal solutions made by Amepox was determined by tests with the use of a Malvern laser apparatus according to the standard ISO 22412 ["Particle size analysis – Dynamic light scattering (DLS)"], carried out in Amepox, the

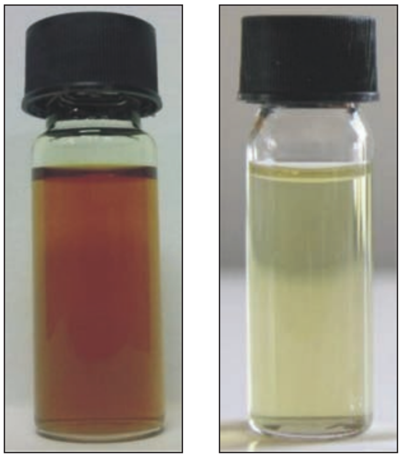


Fig. 1. Colloidal solutions of silver nanoparticles: *a* – in a paraffin envelope, *b* – in a PVA envelope

Polish Academy of Sciences and confirmed at the Oxford University [25].
To each of the 10 mixtures of chemical agents prepared, used for pigment printing, the colloidal silver solutions mentioned were added so as to obtain the concentration of silver nanoparticles about 50 ppm in each of the 20 antibacterial compounds prepared.

Test methods

The pre-assessment of the antibacterial compounds obtained was carried out on the basis of organoleptic assessment, paying particular attention to the state of aggregation, colour and consistence. The tests of silver content in the antibacterial compounds that were accepted by the organoleptic assessment were carried out on the basis of qualitative and quantitative X-ray microanalyses with the use of a VEGA3 electron scanning microscope from TESCAN. The microanalyses were performed in the Scientific Department of Unconventional Technologies and Textiles (Textile Research Institute).
The effectiveness of the antibacterial compounds obtained was assessed on the basis of testing the antibacterial properties of a knitted fabric finished with the use of the compounds mentioned that were positively assessed. The antibacterial activity of the compounds was carried out by the quantitative method, measuring the *R* index of the growth reduction of test bacteria *Staphylococcus aureus* (ATCC 6538). The tests were carried out in the Laboratory of Testing Medical Textiles Fabrics of Textile Research Institute according to American Standard AATCC Test Method 100:2004, using the procedure of calculating bacteriostatic activity S and bactericidal activity L according to Japanese standard JIS L 1902:2008. The method tests both bacteriostatic (S – growth-inhibiting) and bactericidal (L – bacteria-killing) properties on a given antimicrobial materials.
The stability of the antibacterial finish of knitted fabric subjected to wet treatment at a temperature of 40°C, under standardized conditions, was assessed after 1 laundering cycle (according to the standard EN ISO 6330(6A). The basic structural properties of the two-layer knitted fabric, constituting the basis for the assessment of the antibacterial compounds developed, after finishing operation, were expressed with the parameter of surface weight that was determined in the accredited Laboratory of Testing and Textile Raw Materials and Fabrics (Textile Research Institute) according to standards: PN-P-04613-1: 1997 – parameter of surface mass, PN-EN ISO 6330: 2002 – laundering procedure 6A.

RESULTS

The organoleptic assessment of the stability and homogeneity of the systems in their volumes shows that independently of the type of the colloidal silver solution used and the type of water, only four antibacterial compounds are characterized by a uniform system in terms of aggregation state, colour and consistence within their whole volumes (figure 2). Two antibacterial compounds prepared with the use of undistilled water (purified water – made by reverse osmosis method (RO) resistivity = 18,2 MΩ * cm) and two with distilled water were positively assessed. From among the compounds accepted, one was prepared with the use of the colloidal solution of silver containing silver nanoparticles with dimensions below 10 nm in paraffin envelope and three others with the use of silver nanoparticles with dimensions below 50–60 nm in PVA envelope.

Fig. 2. Sample of antibacterial compound containing silver nanoparticles after positive assessment

In the remaining antibacterial compounds, a precipitated silver deposit was observed that resulted from sedimentation. Another unacceptable solution feature was dark colour that could soil fabrics during the padding process (figure 3).
Further tests were continued only with the positively assessed antibacterial compounds that were marked as K1, K2, K3 and K4 with the following compositions of chemical agents:
- **K1:** Fixative ABN, Emulgator C, silver nanoparticles with dimensions below 50–60 nm in PVA envelope, undistilled water.
- **K2:** Texafix PU nano, Texapal RN, silver nanoparticles in paraffin envelope, undistilled water.

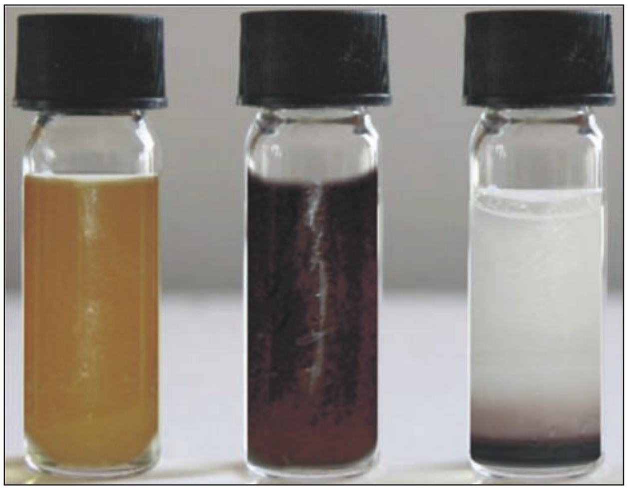


Fig. 3. Samples of antibacterial compounds of chemical agents and silver nanoparticles after negative assessment

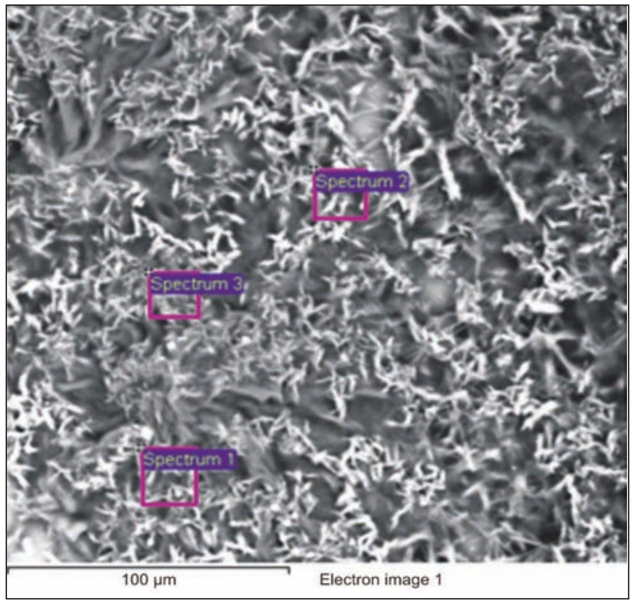


Fig. 4. SEM image of antibacterial composition K2

- **K3:** Acramin BPD, Tanaprint ST 2078, Emulgator WN, Acrafix ML, silver nanoparticle with dimensions below 50–60 nm in PVA envelope. Distilled water.
- **K4:** Texafix PU Nano, Texapret TP, silver nanoparticle with dimensions below 50–60 nm in PVA envelope, distilled water.

X-ray microanalysis of the selected antibacterial compounds

The antibacterial compounds positively assessed in organoleptic tests were subjected to qualitative and qualitative micro-analyses by means of a VEGA 3 scanning electron microscope from TESCAN. This microscope is equipped with a unique system of electron optics enabling observation of various materials with magnification from 4–1,000,000 and a X-ray spectrometer EDS INCA Energy from Oxford Instrument that makes it possible to detect elements [from beryllium (Be) to uranium (U)] of the surfaces of composite materials.

X-ray microanalyses were carried out under condition of low vacuum with the use of the electron beam energy 20 keV, without conductive substance dusting. Figure 4 shows SEM image with marked measurement points (Spectrum) for antibacterial compound K2.

Despite the fact that the antibacterial compounds developed, containing silver nanoparticles at a level of 50 nm, were assessed by organoleptic tests as stable and homogeneous antibacterial systems, the results of X-ray microanalyses indicate a considerable difference in the content of silver particles in the compounds tested (table 1).

The tests performed show that the average content of silver in the compounds tested ranges from 0.06% by wt. for compound K1 to 1.58% by wt. for compound K4. This may indicate non-uniform distribution of silver nanoparticles in a volume unit of the compounds tested. It is worth mentioning that SEM tests use very low volumes of the solutions tested, while

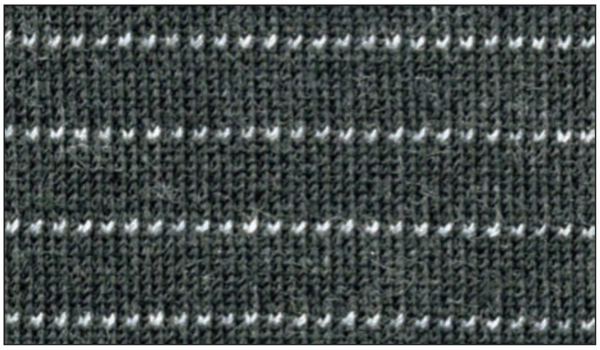
Table 1

Antibacterial composition		K1	K2	K3	K4
Content of silver [%]	Min.	0.09	0.20	0.21	0.08
	Max.	0.10	0.23	0.52	5.98
	Average	0.06	0.21	0.36	1.58

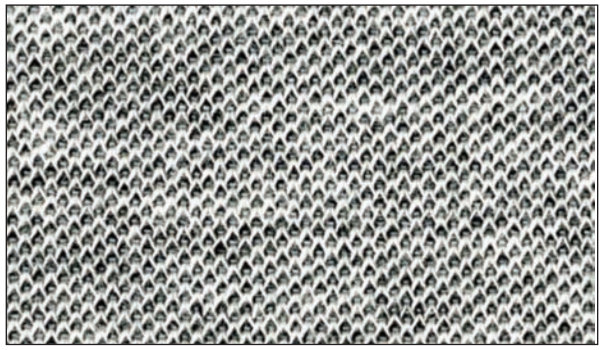
the heterogeneity of the compound tested in a micro scale can affect the read-out of results. Confirmed by tests the silver content in the compounds assessed was the basis for further experimental works.

Experiments with the antibacterial finishing of knitted fabrics

The assessment of the action effectiveness of antibacterial compounds K1, K2, K3 and K4 was carried out on the basis of microbiological tests of a knitted fabric finished with the compound mentioned. The structure of the knitted fabric selected for the antibacterial finishing was worked out within the international research project [14]. The knitted fabric under investigation has been designed for protective clothing with flame-retardant and antistatic properties to be used in direct contact with skin and therefore it was important to impart to it antibacterial feature resistant to laundering. A rib knitting machine from Fukuhara, type LAS, Nu 24, was used to make two-layer rib stitch knitted fabric. The fabric layers were diversified with yarn type and fabric structure so that the one fabric side was made with the use of stitches of basic structure, while the other side had tuck 1×1 loops in course and wale repeat. The external layer of the fabric consisted of a 20 tex metaaramide yarn and a 40 tex blended Rezistat yarn (Vsc FR + PES and carbon compounds), while the internal layer consisted of a 20 tex blended modacryl Protex + cotton. The antistatic Rezistat yarn was incorporated into the knitted fabric structure in a strip system (1 per 10 loop



a



b

Fig. 5. Real appearance of the knitted fabrics structure: *a* – top side, *b* – bottom side

courses). The surface mass of raw knitted fabric was 277 g/m^2. The real appearance of the knitted fabric structure top and bottom sides) is shown in figure 5.

The finishing process of the knitted fabrics under investigation was carried out by the padding method. First, the fabric was washed in a bath containing 1.5 g/l of washing agent (Felosan NFG), 1 g/l of crease preventing agent (Biavin 109) and 1.5 g/l of calcinated soda at a temperature of 50 °C for 30 min. Next, the fabric was rinsed and padded with the compounds containing silver nanoparticles using a laboratory padding machine from Benz, type KLFH 322 I and a laboratory drier Heraeus Function Line. In all the padding operations, the wringing degree was at a level of 80%. After the padding process the knitted fabrics were dried at a temperature of 100 °C, followed by setting for 3 min at a temperature of 150 °C. The knitted fabrics after the padding with the antibacterial compounds denoted as K1, K2, K3 and K4 were denoted as sample 1, sample 2, sample 3 and sample 4, respectively.

The assessment of the antibacterial effectiveness of the compounds developed was carried out on the basis of microbiological tests of the knitted fabrics finished with the compounds under investigation. These tests were performed by the quantitative method according to standard AATCC Test Method 100:2004. *Assessment of Antibacterial Finishes on Textile Materials,* in relation to Gram-positive bacteria *Staphylococcus aureus* (ATCC 6538), showing capability of forming exotoxins that can cause pus changes in skin due to bacterial infections [25].

In order to additionally distinguish bacteriostatic activity from bactericidal activity, there were used the criteria described in standard JIS L 1902: *Testing for antibacterial activity and efficacy on textile products,* according to which the bacteriostatic and bactericidal activities were determined. The test results are listed in table 2.

The calculation of the parameters according to the standards used allowed us to determine the degree of antibacterial activity with reference to bacteriostatic and/or bactericidal properties.

According to standard AATCC Test Method 100 the degree of bacteria growth reduction **R** is determined by comparing the number of bacterial colonies formed after 24 h contact with the sample containing an active agent and the number of bacteria obtained from the same sample (containing active agent) after

Table 2

Tested samples	Sample 1	Sample 2	Sample 3	Sample 4
A – count of bacteria in contact time “18h ÷ 24h”;	$A - 2.0 \times 10^5$	$A - 5.2 \times 10^7$	$A - 1.6 \times 10^8$	$A - 1.2 \times 10^8$
B – count of bacteria in contact time “0”	$B - 1.8 \times 10^5$	$B - 2.3 \times 10^5$	$B - 1.9 \times 10^5$	$B - 1.8 \times 10^5$
Bacteria growth reduction **R [%]**, $R = 100(B - A)/B$	**0 %**	**0 %**	**18,5 %**	**0 %**
Bacteriostatic factor value **S*** $S = \lg C_t - \lg T_t$	**2.9** $\lg C_t - 8.2$; $\lg T_t - 5.3$	0.5 $\lg C_t - 8.5$; $\lg T_t - 7.7$	**2.8** $\lg C_t - 8.0$; $\lg T_t - 5.2$	0.1 $\lg C_t - 8.2$; $\lg T_t - 8.1$
Bactericidal factor value **L*** $L = \lg C_0 - \lg T_t$	**0,0** $\lg C_0 - 5.3$; $\lg T_t - 5.3$	– 2,4 $\lg C_0 - 5.3$; $\lg T_t - 7.7$	**0,2** $\lg C_0 - 5.4$; $\lg T_t - 5.2$	– 2,8 $\lg C_0 - 5.3$; $\lg T_t - 8.1$

* C_0 – count of bacteria in contact time “0” on control sample (material without antibacterial finishing),
C_t – count of bacteria in contact time “18h – 24h” on control sample,
T_t – count of bacteria in contact time on tested sample (material after antibacterial finishing).

Table 3

Tested sample	Sample 1 after washing process	Sample 3 after washing process
Bacteria growth reduction **R [%]**,	**0 %**	**0 %**
A – count of bacteria in contact time “18h ÷ 24h”;	*A* – 1.7×10^8	*A* – 2.6×10^5
B – count of bacteria in contact time “0”	*B* – 3.6×10^5	*B* – 1.5×10^5
Bacteriostatic factor value **S** $S = \lg C_t - \lg T_t$	– 0.2 $\lg C_t$ – 8.0; $\lg T_t$ – 8.2	**3,1** $\lg C_t$ – 8.5; $\lg T_t$ – 5.4
Bactericidal factor value **L** $L = \lg C_0 - \lg T_t$	– 3.0 $\lg C_0$ – 5.2; $\lg T_t$ – 8.2	**0,0** $\lg C_0$ – 5.4; $\lg T_t$ – 5.4

“0” time of contact with the sample, i.e. calculated immediately after sample inoculation [25].
Additionally, to distinguish bacteriostatic properties from bactericidal features, we used the assessment criteria according to standard JIS L 1902 “Testing for antibacterial activity and efficacy on textile products”. According to these criteria, a fabric show bacteriostatic properties if the value of bacteriostatic factor ***S*** > 2, while bactericidal properties if the bactericidal factor value ***L*** ≥ 0 [12].
The tests determining the antibacterial properties of knitted fabrics padded with compounds containing silver nanoparticles carried out according to appropriate standards did not show any reduction in the growth of bacteria Gram (+) *Staphylococcus aureus* after 24 h contact with the sample tested, in relation to the quantity of micro-organisms determined after “0” time of contact of the sample tested with the bacterial suspension (R = %). The quantity of micro-organisms after 24 h incubation of the sample tested increased compared to the bacterial population determined in the initial suspension at the beginning of the experiment. The best results were obtained for the knitted fabrics denoted as sample 1 and sample 3. The value of the bacteriostatic factor at a level of 2.8 or 2.9 provides protection against the bacterium tested. These knitted fabrics are also characterized by bactericidal factor (L = 0.0 or L = 0.2).
In order to assess the stability of the bacteriostatic properties imparted, knitted fabric sample 1 and sample 3 with the best evaluation in microbiological tests, were subjected to washing at a temperature of 40ºC according to standard EN ISO 6330 (6A) and again their microbiological activities were tested. The test results obtained were listed in table 3.
The results of testing the antibacterial activity of knitted fabric denoted as sample 1 after the washing process indicate that its antibacterial properties imparted with the use of compound K1 are not resistant to laundering. A lack of antibacterial activity of the knitted fabric tested after washing indicates a weak combination of silver nanoparticles with the fibre surface. On the other hand, in the assessment of antibacterial activity of knitted fabric denoted as sample 3, it was found that this fabric showed protective capability against the bacterial strain used and its value of bacteriostatic parameter was S = 3.1, while its bactericidal parameter L = 0.0.
For the two-layer knitted fabric under assessment of the antibacterial compounds developed, its surface mass was determined after conventional finishing including washing and drying that amounted to 300 g/m^2, as well as the same knitted fabric subjected to antibacterial finish by the padding method with the use of compound denoted as K3, which amounted to 317 g/m^2 and after a single laundering, which was not changed in relation to the value obtained for the knitted fabric padded with the antibacterial compound. Changes in the surface masses of two-layer knitted fabric subjected to various variants of finishing ranged from 8% to 12% in relation to the surface mass of raw untreated knitted fabric.

CONCLUSIONS

The research performed to develop a formula of compound containing silver nanoparticles that would allow one to impart antibacterial properties to textiles in the finishing process by the padding method indicate that the planned aim has been accomplished.
The antibacterial compound developed denoted as K3 containing the following chemical agents: binding agent Acramin BPD, thickener Tanaprint ST 2078, emulsifying agent Emulgator WN, cross-linking agent Acrafix ML, and silver nanoparticles in PVA envelope with dimensions below 60 nm is a homogeneous system in terms of colour and consistence in its whole volume. The use of the antibacterial compound developed for finishing fabrics with flame-retardant and antistatic properties allows one to additionally obtain bacteriostatic properties against Gram (+) bacteria Staphylococcus aureus. The properties imparted to textiles are confirmed by the value of bacteriostatic parameter S>2 for the knitted fabric directly after padding with the compound containing silver nanoparticles as well as after the fabric laundering.
The investigation results within the scope of depositing silver nanoparticles on textiles by finishing methods with the use of the antibacterial compound developed constitute the basis for developing an appropriate technology in textile plants equipped with conventional machinery such as padding machine connected to a frame stabilizer.

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Evaluation of decolorisation abilities of some textile dyes by fungal isolates

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REZUMAT – ABSTRACT

Evaluarea abilităţilor de decolorare a unor coloranți textili cu izolate fungice

Nouă tulpini fungice izolate şi identificate anterior din efluenţi rezultaţi în urma etapelor de finisare textilă au fost investigate pentru abilitatea acestora de decolorare a trei coloranţi textili Bemacid, în soluţie apoasă. Izolatele fungice identificate aparţin următoarelor grupuri: Trichoderma parceramosum, Trichoderma reesei, Trichoderma longi, Polyporus squamosus şi Fusarium oxysporum, alături de Aspergillus niger (IMI 45551) folosită ca tulpină de referinţă, de colecţie. Maximele de absorbanţă în regiunea vizibilă, pentru fiecare colorant, au fost determinate spectrofotometric şi reducerea reziduală a concentraţiei coloranţilor a fost determinată la 500 nm pentru Bemacid ROT, 370 nm pentru Bemacid GELB şi 590 nm pentru Bemacid BLAU. Gradul de puritate al coloranţilor a fost determinat prin Cromatografie pe Strat Subţire (TLC), iar testele de decolorare au fost efectuate în substrat nutritiv, în cinci şarje simultane, la 3, 6, 9, 12 şi 15 zile, în triplicat, rezultatele fiind exprimate ca medie a valorilor triplicate pentru fiecare combinaţie de colorant şi tulpină. Analiza cantitativă a decolorării soluţiilor a fost efectuată prin spectrometrie în UV-VIS, cuantificându-se gradul de decolorare de-a lungul perioadei de incubare, la 29°C, concentraţia reziduală a fiecărui colorant variind de la 20,98% la 98,02% pentru Bemacid ROT, 43,5% la 96,06% pentru Bemacid GELB şi 35,68% la 98,38% pentru Bemacid BLAU, promovând astfel abordarea biologică de tratare a apelor uzate cu ajutorul fungilor filamentoşi ca soluţie eficientă, rentabilă şi prietenoasă mediului.

Cuvinte-cheie: decolorare, fungi, lacază, coloranţi textili

Evaluation of decolorisation abilities of natural fungal isolates

Nine previously isolated and identified fungal strains from post-finishing textile effluents were investigated for their decolorisation ability of three Bemacid textile dyes, in aqueous solution. Identified fungal isolates belong to the following groups: Trichoderma parceramosum, Trichoderma reesei, Trichoderma longi, Polyporus squamosus and Fusarium oxysporum, along with Aspergillus niger (IMI 45551), used as a reference collection strain. Maximum absorbance peaks in visible region, for each dye, were assessed spectrophotometrically and dye residual concentration reduction were assessed at 500nm for Bemacid ROT, 370nm Bemacid GELB and 590nm Bemacid BLAU. Purity screening of the dyes was assessed by Thin Layer Chromatography (TLC), and decolorisation assays were carried out in nutritive media, in 5 simultaneous batches, for 3, 5, 9, 12 and 15 days, with each batch run in triplicate, and results expressed as mean of triplicate values for each combination of strain and dye. Quantitative analysis of solutions decolorisation was carried out via UV-VIS spectrophotometry assessment, quantifying decolorisation degree over post-incubation period at 29°C, each dye residual concentration reduction ranging from 20.98% to 98.02% for Bemacid ROT, 43.5% to 96.06% for Bemacid GELB and 35.68% to 98.38% for Bemacid BLAU, thus promoting biological approach of wastewater treatment with the aid of filamentous fungi as an efficient, cost effective and environmental friendly solution.

Keywords: decolorisation, fungi, laccase, textile dyes

INTRODUCTION

Textile industry generates large volumes of wastewater effluents, colorization degree representing the main pollutant parameter of the effluents [1–3]. Textile industry wastewaters present a complex matrix, containing a mixture of dyes with other organic and inorganic compounds, treating processes becoming of great complexity due to residual substances that are very hard to remove by stages of classical mechanical-biological processing [4]. Discharge of untreated textile effluents into main water bodies can often lead to limitation of re-oxygenation capacity of the effluents, modification of sunlight absorption rates which affects photosynthetic activity of aquatic systems, thus leading to high toxicity [5]. Pollution degree of textile effluents increases significantly with the use of wide varieties of textile dyes, strongly influenced by chemical structure of their chromophore groups, with azo-dyes being the largest group of synthetic textile dyes that are widely used and released into the environment, thus leading to need of viable and economical efficient bioremediation techniques.

The presence of dyes in textile industry generated waste waters, even in low concentrations of 1 mg/L, leads to alteration of esthetic and transparence properties of public water effluents, with direct repercussions on the environment [6]. Synthetic dyes used in the textile industry cannot be easily biodegraded, due to their complex aromatic molecular structure, which

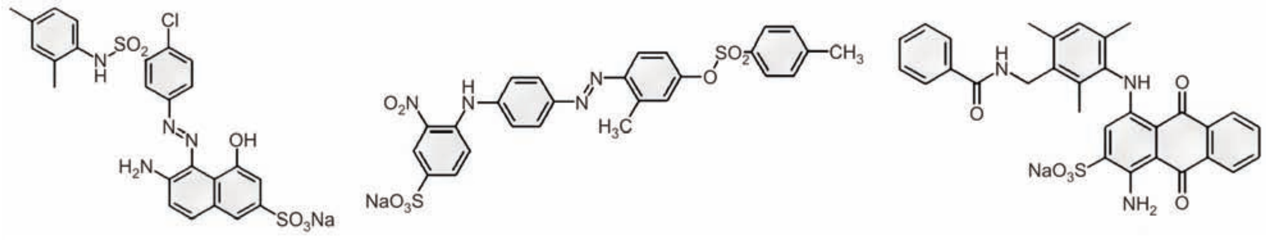


Fig. 1. Bemacid dyes structural formulas

furthermore renders them as resistant to conventional microbial treatment techniques [7]. Due to wide spread of microbial mediated treatment processes, decolorisation of azo-dyes textile effluents using fungi emerges as a new and efficient treatment method, due to their high mineralizing capacity and enzyme mediated oxidizing properties of certain pollutants [8, 9–12].

Microbial decolorisation of textile wastewater effluents is a cost effective and environmental friendly process, representing an efficient tool of controlling pollution generated by textile industry. Biological approach of certain pollutants removal from textile effluents is based on materials transfer from the water to the microbial cell, and the other way around, through interfacial contact or adsorption/desorption governed processes. The adsorbed compounds are involved in enzymatic reaction that takes place in multiple stages [13]. Bioaccumulation of pollutants takes place in metabolically active cells, and involves slow associated processes, with the implication of H^+-ATP-ase as a process mediator [14]. All transfer processes involve chemical interactions with certain functional groups, specific to outer layers of microbial cells: carboxylic groups (-COOH), amino groups ($-NH_2$), amide groups ($RCONR_2$), hydroxyl groups (-OH), sulfhydryl groups (-SH) and phosphate groups ($PO3^{4-}$) [15]. Fungal enzymes have an important role in increasing the activity rate of microorganisms in stages of bioremediation, and to mediate decomposing of organic matter by hydrolytic and oxidation-reduction processes, and further usage as nutritive substrates for microbial populations used in the treatment processes [16–17]. Enzymes act as biochemical catalysts, increasing the rate of chemical reactions that occur in all biological purification stages [18]. Biotechnological stages of microbial or enzymatic treatment of wastewaters are effective alternatives for treating effluents with high content of azo-dyes using a variety of microorganisms, such as bacteria, fungi, yeasts, actinomycetes and algae [19–20].

EXPERIMENTAL WORK

Materials and methods

Fungal strains

Nine fungal strains were used in the decolorisation experiments, most of them being isolated from a wastewater source resulted from textiles finishing processes and previously identified, by molecular methods, as following: I1, I2 and I3 belong to *T.parceramosum/T.reesei/T.longi group; I4 = Aspergillus niger IMI 45551* (ATCC 6275)*; I5 = Polyporus squamosus; I6 = Fusarium oxysporum; I7 and I8 =* yeast-like unidentified strains; I9 = *Trichoderma atroviride* [21]. Fungal strains were grown on Czapek-Dox broth from Fluka Analytical (30 g/L sucrose, 3 g/L sodium nitrate, 0.5 g/L magnesium sulfate, 0.5 g/L potassium chloride, 1.0 g/L potassium phosphate dibasic, 0.01 g/L ferrous sulfate, *p*H 7.3 at 25°C), incubated at 28°C for 14 days, before mixing with the dyes, and all samples run in triplicates.

Textile dyes

Three industrial azo-dyes were used in the decolorisation experiments, respectively Bemacid ROT N-TF(CAS EINECS: 276-115-7), $C_{24}H_{20}ClN_4NaO_6S_2$, M = 583.0 g/M (7), Bemacid GELB N-TF(CAS EINECS: 235-406-9), $C_{25}H_{19}N_4NaO_8S_2$, M = 590.56 g/M (8) and Bemacid BLAU N-TF(CAS EINECS: 267-224-0), $C_{31}H_{28}N_3NaO_6S$, M = 593.63 g/M (9), produced by BEZEMA AG Company, with structural formulas shown in figure 1.

Two stock solutions were prepared for the assays, for each dye, one stock solution for calibration curves, with concentration of 200 mg/L, and one stock solution for decolorisation assays, with concentration of 5 g/L. Both stock solutions were prepared by stirring the dye, at 500 rpm, in 1000 mL Czapek-Dox nutritive broth at 30°C for 3 hours, and then sterilized at 121°C for 15 minutes. Maximum absorbance of dyes was measured with Lambda 950 UV-VIS spectrophotometer and selected to plot the calibration curves used to quantitatively evaluate the decolorisation induced by microorganisms. In order to calculate the dye concentration with a greater accuracy, two calibration curves were carried out (data not shown), by splitting the concentration domain of 0–200 mg/L into two ranges for each dye, respectively from 0 to 50 mg/L, in six points, and from 50 to 200 mg/L, in four points, instead of raging the 0–200 mg/L interval in 4 standard points, thus obtaining correlation factors above 0.9892 for the lower range interval and above 0.9969 for the higher range interval.

Methods and analysis

Decolorisation studies

For decolorisation studies, microbial strains were grown for 14 days at 28°C and allowed to reach metabolic maturity. Stock dye solution, of 5 g/L, concentration, was prepared in nutritive broth, and sterilized at 121°C for 15', and afterwards 2 mL of stock solution was pipetted into the Erlenmeyer flasks, with strains, for a final volume of 50 mL and final dye concentration of 200mg/L, and samples were further incubated at 28°C. All run samples were run in triplicate, in five batches (corresponding to the 3rd, 5th, 7th, 12th and 15th day) for each microbial strain. After incubation period, for each batch, the microbial cells were removed by filtration, filtered through 20 μm membrane filter. 3 mL of each filtrate were extracted with a syringe, and sampled in quartz cuvettes. Dye concentration in aqueous solutions was measured spectrophotometrically at 500 nm for Bemacid ROT, 370 nm for Bemacid GELB, and 590 nm for Bemacid BLAU, and the decolorisation percentage was calculated using the percentage decolorisation formula:

$$\text{Decolorisation Activity (\%)} = \frac{(\text{Initial dye concentration} - \text{Dye concentration after bio-activity})}{\text{Initial dye concentration}} \cdot 100$$

All samples were run in triplicate, and mean value was used for calculation of decolorisation activity.

Thin Layer Chromatography

TLC analysis was used to asses dye purity and type of dye biodegradation products. 5 μL of each stock dye solution (200 mg/L) and biodegradation products extracted in ethyl alcohol were spotted on aluminum plate (200 × 200 mm) covered with 0.25 mm silica gel 60F254 supplied by Merck (Germany) using a micro syringe. A mixture of t-butanol: acetone: water: ammonia-(5:5:1:2) vol/vol. was used as mobile phase.

Laccase activity

Enzymatic activity was determined for two microbial isolates: I2 (*T.parceramosum/T.reesei/ T.longi*) and I5 (*Polyporus squamosus*), in 7 sets, respectively after 1 day, 2 days, 3 days, 4 days, 5 days, 6 days and 15 days of cultivation. Fresh cultures were grown for 7 days in 50mL flasks, and dye concentration was set at 200mg/L for each strain. Laccase activity was assessed according to method of Desai, using guaiacol (2mM) as substrate, in sodium acetate buffer (10 mM *p*H 5.0) based on its oxidation by laccase, and spectrophotometric dosage of enzymatic activity at 450 nm, after incubation 30°C for 15' [22–23]. Reaction mixture was composed of 1 mL guaiacol, 3 mL acetate buffer and 1mL of enzyme source, which was represented by mixture of strain, dye and nutritive broth, and enzyme blank, was considered 1mL of deionized water. Enzyme activity is expressed in International Unites (IU), where 1 IU is defined as the amount of enzyme that is needed to oxidize 1 micro-mole of guaiacol/minute, and the laccase activity, in U/mL is calculated with the aid of extinction coefficient of guaiacol as follows:

$$E.A. = \frac{A \times V}{t \times e \times v}$$

where: *E.A.*= Enzyme Activity; *A* = absorbance at 450 nm, *V* = total volume of reaction (mL); *t* = incubation time (minutes); *e* = extinction coefficient (12,100 $M^{-1} \times cm^{-1}$); *v* = enzyme volume.

RESULTS

Thin Layer Chromatography

TLC technique was used for assessment of qualitative dye purity, which may be an important factor in decolorisation efficiency, being an easy and versatile method due to high sensitivity and good reproducibility. Regarding the purity, according to TLC, the purest was Bemacid ROT dye, compared to Bemacid GELB and Bemacid BLAU, which it seems that they present multiple isomers, visualized as 3 bands for Bemacid GELB, and 4 bands for Bemacid BLAU, respectively (figure 2,*a*). Also, TLC was run for assessment of bioaccumulated dye purity (figure 2,*b-c*), compared to control, thus resulting that the accumulated dye, by fungal biomass, is identical to the initial dye, due to resulted color and migration distance.

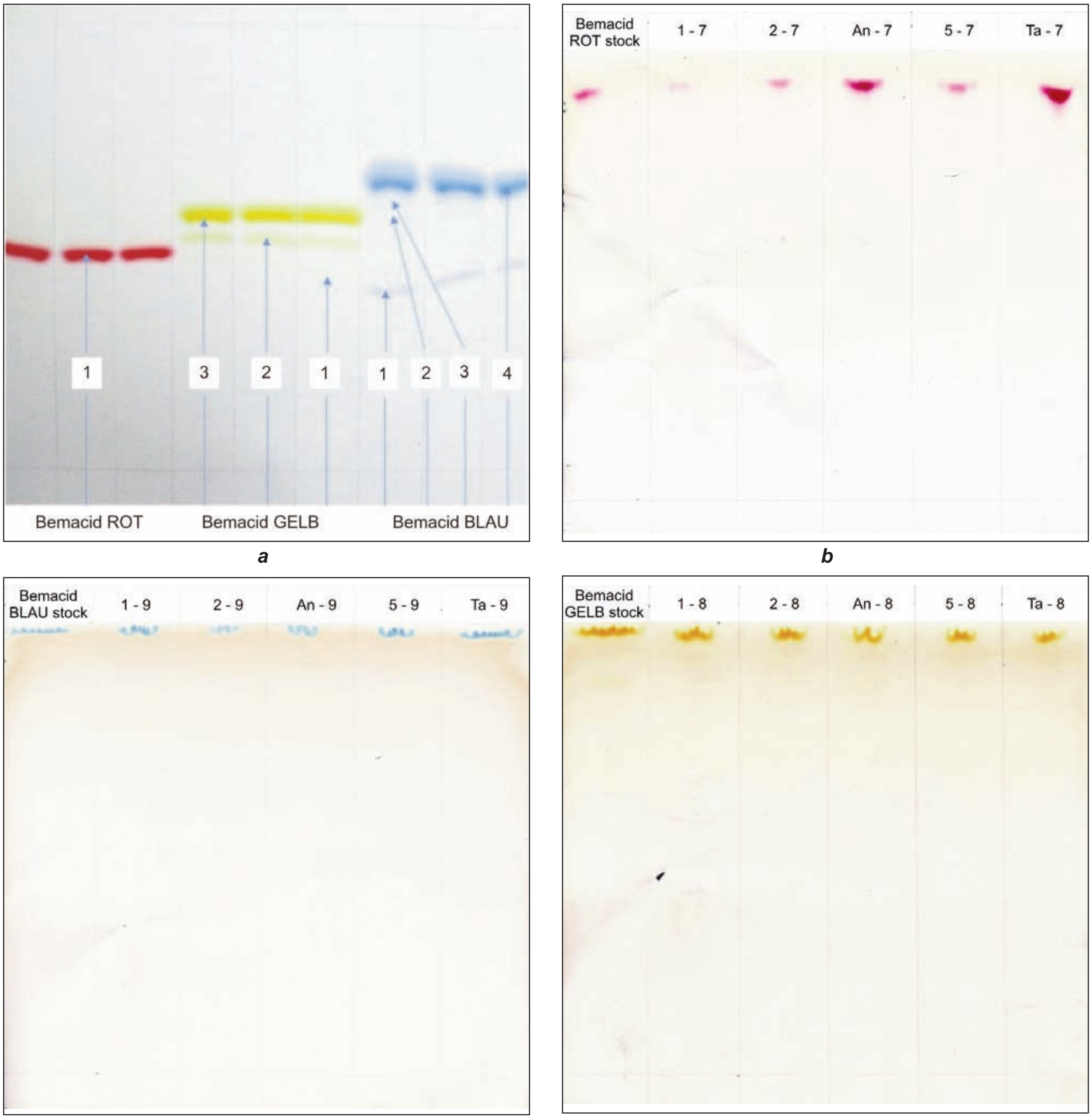
This aspect could have an important influence over the degradative expression of each strain, and can be correlated with higher overall residual dye concentration reduction rates of all strains on Bemacid ROT dye, due to a high purity, seconded by Bemacid BLAU and Bemacid GELB.

UV-VIS spectrophotometry

The UV-VIS spectra of the aqueous solutions of stock dyes, recorded on 200–800 nm, showed the following maximum absorbance peaks: 500 nm for Bemacid ROT, 370 nm for Bemacid GELB and 590 nm for Bemacid BLAU. Three main peaks were observed for all dyes, the strongest absorption bands (243 nm, 277 nm and 280 nm) corresponding to the chromophore group, the diazo-group. The bands of Bemacid ROT are shifted to longer wavelengths due to extended conjugation of aromatic rings (Bemacid GELB) and polycyclic aromatic ring (Bemacid BLAU).

Dye decolorisation

In the present study, the microbial strains were grown in Czapek-Dox nutritive broth, selected due to low nutritive value, forcing the selected microbial strains to use the dyes as nutrients. According the quantitative determinations of the residual dyes during incubation with selected microbial strains, significant degradation rates were detected. The results obtained with Bemacid ROT used as nutritive source in the minimal culture medium indicated strong increasing of dye decolorisation for all tested samples, with minimum of 72.77% decolorisation rate, achieved in 3rd day by the isolate I1, and maximum of 98.02% achieved by isolate I6 in the 15th day (table 1). Except the strain



a *b* *c* *d*

Fig. 2. Bemacid dyes TLC (the arrows indicate the possible isomers of the dyes)

Table 1

RESIDUAL DYE CONCENTRATION REDUCTION OF SELECTED STRAINS AGAINST BEMACID ROT														
I	**mg/L**	**R%**	**II**	**mg/L**	**R%**	**III**	**mg/L**	**R%**	**IV**	**mg/L**	**R%**	**V**	**mg/L**	**R%**
7I1	54.46	72.77	**7I1**	51.93	74.03	**7I1**	22.06	88.97	**7I1**	16.67	91.66	**7I1**	9.67	95.16
7I2	48.41	75.79	**7I2**	27.42	86.28	**7I2**	17.32	91.34	**7I2**	15.07	92.46	**7I2**	6.01	96.99
7I3	23.79	88.10	**7I3**	17.07	91.46	**7I3**	14.54	92.73	**7I3**	7.32	96.34	**7I3**	5.96	97.02
7I4	20.98	89.51	**7I4**	11.06	94.47	**7I4**	10.25	94.87	**7I4**	7.87	96.06	**7I4**	5.64	97.18
7I5	51.20	74.40	**7I5**	20.66	89.67	**7I5**	11.82	94.09	**7I5**	9.97	95.01	**7I5**	6.78	96.61
7I6	35.13	82.43	**7I6**	13.13	93.43	**7I6**	7.97	96.01	**7I6**	7.52	96.24	**7I6**	3.95	98.02
7I7	46.04	76.98	**7I7**	38.67	80.66	**7I7**	37.39	81.30	**7I7**	21.64	89.18	**7I7**	21.43	89.28
7I8	39.64	80.18	**7I8**	14.46	92.77	**7I8**	12.16	93.92	**7I8**	8.35	95.82	**7I8**	6.24	96.88
7I9	42.65	78.67	**7I9**	23.27	88.36	**7I9**	21.51	89.24	**7I9**	12.32	93.84	**7I9**	7.36	96.32

Table 2

RESIDUAL DYE CONCENTRATION REDUCTION OF SELECTED STRAINS AGAINST BEMACID GELB														
I	**mg/L**	**R%**	**II**	**mg/L**	**R%**	**III**	**mg/L**	**R%**	**IV**	**mg/L**	**R%**	**V**	**mg/L**	**R%**
8I1	103.44	48.28	**8I1**	86.18	56.91	**8I1**	79.65	60.17	**8I1**	54.42	72.78	**8I1**	21.27	89.36
8I2	91.40	54.29	**8I2**	84.20	57.9	**8I2**	78.20	60.90	**8I2**	50.21	74.89	**8I2**	34.81	82.59
8I3	193.58	3.20	**8I3**	179.82	10.09	**8I3**	124.83	37.58	**8I3**	55.13	72.43	**8I3**	53.95	73.02
8I4	44.38	77.81	**8I4**	36.87	81.56	**8I4**	26.97	86.51	**8I4**	15.89	92.05	**8I4**	11.86	94.07
8I5	43.50	78.25	**8I5**	36.55	81.72	**8I5**	20.77	89.61	**8I5**	17.47	91.26	**8I5**	14.50	92.75
8I6	157.55	21.22	**8I6**	108.17	45.91	**8I6**	62.84	68.58	**8I6**	39.36	80.32	**8I6**	32.99	83.50
8I7	194.97	2.51	**8I7**	147.93	26.03	**8I7**	110.74	44.63	**8I7**	53.73	73.13	**8I7**	45.55	77.22
8I8	137.67	31.16	**8I8**	83.86	58.07	**8I8**	47.97	76.01	**8I8**	30.72	84.64	**8I8**	22.71	88.64
8I9	148.96	25.52	**8I9**	50.05	74.97	**8I9**	26.92	86.53	**8I9**	25.43	87.28	**8I9**	7.87	96.06

Table 3

RESIDUAL DYE CONCENTRATION REDUCTION OF SELECTED STRAINS AGAINST BEMACID BLAU														
I	**mg/L**	**R%**	**II**	**mg/L**	**R%**	**III**	**mg/L**	**R%**	**IV**	**mg/L**	**R%**	**V**	**mg/L**	**R%**
9I1	163.41	18.29	**9I1**	146.66	26.66	**9I1**	136.47	31.76	**9I1**	107.62	46.30	**9I1**	107.39	46.19
9I2	117.02	41.49	**9I2**	34.31	82.84	**9I2**	23.87	88.06	**9I2**	17.14	91.43	**9I2**	10.54	94.73
9I3	156.66	21.67	**9I3**	54.33	72.83	**9I3**	12.45	93.77	**9I3**	11.82	94.09	**9I3**	11.31	94.34
9I4	35.68	82.16	**9I4**	35.29	82.35	**9I4**	18.07	90.96	**9I4**	8.66	95.67	**9I4**	4.36	97.82
9I5	52.01	73.99	**9I5**	45.20	77.40	**9I5**	17.17	91.41	**9I5**	16.28	91.86	**9I5**	12.46	95.67
9I6	86.58	56.71	**9I6**	35.61	82.19	**9I6**	10.46	94.77	**9I6**	9.94	95.03	**9I6**	3.23	98.38
9I7	55.27	72.36	**9I7**	51.36	74.32	**9I7**	32.07	83.96	**9I7**	23.81	88.09	**9I7**	12.40	93.80
9I8	39.55	80.22	**9I8**	32.39	83.80	**9I8**	13.65	93.17	**9I8**	12.82	93.59	**9I8**	10.41	94.79
9I9	47.23	47.23	**9I9**	53.89	73.05	**9I9**	69.26	65.37	**9I9**	10.06	94.97	**9I9**	8.76	95.62

I7, all the other isolates presented rates of decolorisation over 95%.

Different rates of dye reduction were observed when Bemacid GELB was used as nutrient during the incubation with the selected microorganisms: the results indicated lower values comparing with Bemacid ROT (table 2). Only three out of the isolates were able to induce decolorisation rates over 92%: the isolates I4 (94.07%), I5 (92.75%) and I9 (96.06%).

With Bemacid BLAU as substrate, the selected microbial strains presented different abilities to induce the decolorisation. The degradation process began more difficult for at least half of the microorganisms (isolates I1, I2, I3, I6 and I9) (table 3) but after 6 days of incubation the decolorisation rates were increased over 72% (except the isolate I1). The final results are similar with those run on Bemacid ROT, as strain I1 recorded the lowest decolorisation percentage (46.19%) and strain I6, the highest (98.38%).

Based on these results it could be assumed that the best microbial strains, for ability of decolorisation against all the dyes tested, were the strains designated as I4 (*A.niger)*, I5 (*P.squamosus*) I9 (*T.atroviridae)* and I2 (belonging to *Trichoderma parceramosum/T.reesei/T.longi* group). However, significant degradative properties were also detected in the other strains, at least against Bemacid BLAU and Bemacid ROT. The mechanisms involved in the dyes decolorisation process realized by microorganisms are not clear. Among the possible mechanisms of degradation the most popular are *p*H variation in the culture medium, the accumulation of the dyes in the cells, and the enzymatic activity (intracellular or extracellular enzymes). For this reason, the possible mechanisms involved in the decolorisation activities of the isolate I2 and I5 were analyzed.

The accumulation of the dyes in the microbial cells was observed for the strains I1, I2, I3, I5 and I6, at least for some of the dyes (Bemacid BLAU and Bemacid ROT), proving that cellular mechanisms could be involved in the dye degradation process.

Laccase is a cooper-based polyphenol oxidase enzyme that can show activity on a variety of substrates, and uses molecular oxygen as electron acceptor [24]. Bioremediation of environmental pollutants agents became an active field of laccase exploitation as a biotechnological tool of removal of toxic compounds through oxidative enzymatic coupling of contaminants [28]. Laccase enzyme is able to oxidize both phenolic and non-phenolic compounds and lead to mineralization of synthetic dyes, rendering the

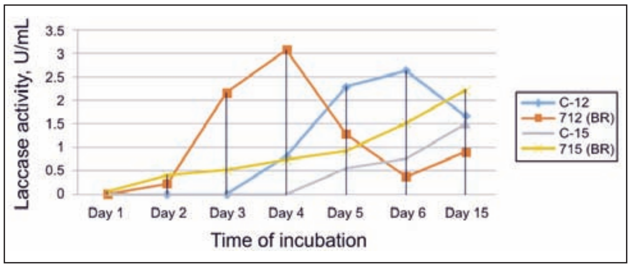


Fig. 3. Laccase activity of I2 and I5 microbial strains with (7) or without Bemacid Rot

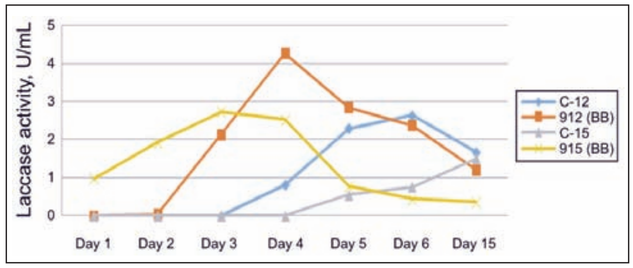


Fig. 5. Laccase activity variation for I2 and I5 + Bemacid BLAU, compared to control

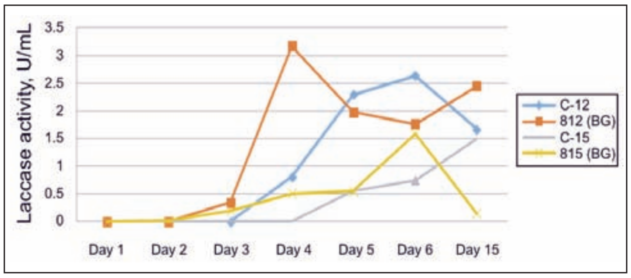


Fig. 4. Laccase activity variation for I2 and I5 + Bemacid GELB, compared to control

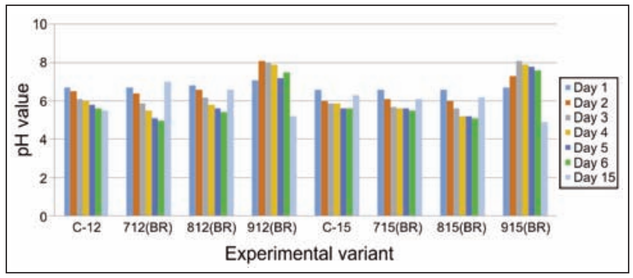


Fig. 6. *p*H variations of microbial cultures in the presence or absence of the dyes

enzyme as a valuable option for efficient, cost effective and environmental friendly bio-treatment method [29–30]. Fungi are important producers of laccase, compared with bacteria, the most important laccase producer strains belonging to white rot fungi [25–26]. Among the fungi able to produce large amounts of laccase are the macromycetes, reason for which *Polyporus squamosus* strain I5 was selected in assessment of the laccase activity, together with the strain I2 (belonging to *Trichoderma parceramosum/T.reesei/T.longi* group) [27]. The laccase activity registered in dye containing samples was compared with control variants (without dye), designated as C-I2 and C-I5, respectively. I2 and I5 microbial strains were previously cultivated in 50 mL culture medium, for 7 days, at 28°C; at the end of the cultivation period, the suspensions were combined with each dye (to a final concentration of 200 mg/L). Differences between microbial strains incubated with the dyes, regarding the enzymatic activity determined at 1, 2, 3, 4, 5, 6 and 15 days of incubation, were observed, comparing with the control variants.

In samples with Bemacid ROT, the laccase activity of the strain I2 increased up to the 4th day, with a maximum of 3.08 U/mL, while the enzymatic activity of the strain I5 increased constantly, with a maximum value at the end of the incubation period (2.22 U/mL), comparing with the controls: maximum of 2.64 U/mL for I2 strain and 1.50 U/mL for I5 (figure 3).

When Bemacid GELB was used as nutrient in the culture medium, the laccase activity of the I2 strain presented similar variations in time as with Bemacid Rot, with a maximum of 3.17 U/mL in the 4th day. The enzymatic activity of the strain I5 was significant lower: the maximum level was detected in the 6th day (1.59 U/mL), followed by a massive drop of activity after 15 days of incubation (figure 4).

In the presence of Bemacid BLAU, figure 5, similar laccase activity variations for the strain I2 were observed, with a maximum of 4.27 U/mL in the 4th day (figure 5). However, differences were detected in I5 strain: the highest value of the laccase activity was registered on the 3rd day (2.73 U/mL), then the activity progressively decreased from day 5 to day 15.

It is known that the *p*H modification of aqueous solutions containing dyes could induce the color modification. For this reason, the *p*H variation during the microbial cultivation in the presence of the dyes was measured and compared with control samples (without dyes) (the initial *p*H of Czapek-Dox broth was 6,8) (figure 6).

It was shown that the dye addition shifted the *p*H values towards the neutral-slightly basic values, respectively 7.45 for Bemacid ROT, 7.34 for Bemacid GELB and 7.27 for Bemacid BLAU. During the incubation period, the overall trend of the *p*H was decreasing, except the samples containing Bemacid Blue: both microbial suspensions exhibited high values of *p*H during the first six days of incubation. However, at the end of the incubation the *p*H values were similar to the control. These results suggest that the decolorisation of the dyes used in experiments is due to other mechanisms than *p*H variation. However, it is possible that the *p*H variations to support other biological mechanisms of degradation.

CONCLUSIONS

Bemacid group N dyes comprises acid dyes with high exhaust properties in neutral medium, good combinability, high build-up properties, good level of wet fastness, good masking of bareness due to kinetic differences within the substrate and rapid fixing under saturated steam conditions, and are widely used in dyeing of PA clothing, sportswear and technical textiles. Decolorisation assays of tested solutions with the aid of living fungi yielded great efficiency by adsorption mechanisms and enzymatic induced processes, which catalyze dye bioremediation stages [31]. Tested fungal strains proved great efficiency in degradation of Bemacid azo-dyes, with best mean of dye residual concentration reduction in aqueous solutions of 95.94% for Bemacid ROT, seconded by Bemacid BLAU, with 90.14% and Bemacid GELB, with 86.35%. Enzymes are widely used in textile fibers modifications [32], including laccase enzymatically treatment of cotton fibers [33]. Laccase enzyme mediated biotechnological processes can be correlated with biological viable alternatives for wastewater effluents treating, which effectively combines both adsorption-biosorption mechanism, and enzymatic treatment of effluents.

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Making an assortment range of textile confections more efficient

ADRIAN TRIFAN ANCA MADAR

REZUMAT – ABSTRACT

Eficientizarea unei game sortimentale de confecţii textile

Considerăm că pentru a realiza o gamă sortimentală adecvată cerinţelor pieţei şi, totodată, o eficienţă maximă a producţiei, confecţionerii de textile trebuie să deţină capacitatea de a îmbina linia modei cu elementele de eficienţă a producţiei industriale sub toate aspectele acesteia. În această lucrare se propune un model matematic care utilizează programarea liniară, pentru eficientizarea unei game sortimentale de confecţii textile realizată de un producător, atât din punctul de vedere al numărului, cât şi al cantităţilor pentru fiecare articol, pe care să-l fabrice, astfel încât să obţină un profit maxim.

Cuvinte-cheie: eficiență, programare liniară, utilizarea costurilor pentru influențarea comportamentelor, cerinţele consumatorilor

Making an assortment range of textile confections more efficient

We believe that in order to achieve an assortment range appropriate to the market requirements and, at the same time, have maximum efficiency in production, the manufacturers of textile confections must be able to combine the fashion line with the elements of industrial production efficiency in all its aspects. In this paper we propose a mathematical model using the linear programming to make an assortment range of textile confections made by a manufacturer more efficient both in terms of number and quantities of each manufactured item, so that the manufacturer should obtain the maximum profit.

Keywords: efficiency, linear programming, using costs for influencing behaviours, consumer demand

INTRODUCTION

Necessity and opportunity of the theme

Based on the results of a previously published article, which had as a result the optimisation of an assortment structure of textile confections in terms of physiological properties relative to the cost of production, in this article the authors propose another type of use of the mathematical models in order to determine, this time, an assortment range efficient both in terms of the number of the items and the optimal quantity of each item to be produced.

To meet the increasing demands of the textiles consumers, firstly, it is necessary to know their demands. The manufacturer of the textile confections must be familiar with both the size typology of the population and the characteristics of such types, depending on age and occupation, aiming to harmonize the fashion line with the typology. Also, the manufacturer of the textile confections must be familiar with the range of the raw materials and the accessories, their manufacturing properties, and the possibilities to purchase those materials.

In our opinion, an important issue that should be taken into consideration when developing an assortment range is the manufacturer's technical possibilities within the existing capacity. This raises the question of establishing the reasonable size of the assortment range of products. The market requirements, in terms of models and designs, are virtually endless. On the other hand, the production, which must satisfy these requests, tends to certain quantitative limitations. The higher the number of the models, the more frequent the changes will be during the production process and the lower the manufacturing series.

The development of an assortment range and the time planning of its launch influence, in principle the possibilities for capitalizing on the textile confections and the related economic results. For example, the number of the different sizes of the garments, significantly influences the labour productivity in the tailoring sections; hence, reducing the number of sizes one can obtain an increase in the production capacity. To achieve a mathematical model to make an assortment range of textile confections more efficient, one must know the elements that define this structure. These are: the number of varieties that can be achieved (skirts, trousers, jackets, etc.), the number of items of each type (differentiated by design, fabric etc.), the fabric types and quantities required, the types and sizes that can be produced.

In turn, each of these elements of the assortment structure depend on a number of other factors, of which the most important are: the demand on the market, the size and strength of the manufacturer, the effectiveness of each item, the possibilities for purchasing the raw materials and their quality, the technical control efficiency, the implementation of the standards from the ISO 9000 series, the fashion trends both for the raw materials and the ready-made

clothes, the destination of the clothes, the production costs necessary to manufacture each item [1].
This chosen structure must be an optimal one, implying a maximum of advantages and a minimum of disadvantages. The synthetic measure of these advantages and disadvantages is the profitability of the production activity, which expresses, in the most concise way, the economic efficiency of the company.

Literature review

The textile confection market is significantly influenced by the fashion trends. Therefore, the demand of this market can change completely in a very short time, being influenced either by certain personalities that may cause a new trend or by introducing a new product by the competitors [2]. Such a demand variation on the market can cause the destabilization of certain companies from this field; therefore, it is necessary to establish some schemes (models) in order to help them to adapt as quickly and effectively as possible to these changes. These schemes can be based on the use of the mathematical models. Their use is a practice in the economy in general and in the textile industry in particular in order to determine how certain variables can influence the size of certain phenomena.
One of the most used mathematical models is the linear programming, which aims to optimise an objective linear function, which is subject to constraints, which are also linear. The linear programming can be used in the textile confection industry in order to determine the optimum way to allocate certain scarce resources, to calculate the profits and the customer satisfaction level or to establish the anthropometrical characteristics [3–5].

A MODEL OF MAKING AN ASSORTMENT RANGE OF TEXTILE CONFECTIONS MORE EFFICIENT

Model description

The general form of a model of linear programming:
Determine $x_1, x_2, \dots, x_n$, to maximize a linear function with the following form:

$$f = c_1x_1 + c_2x_2 + \dots + c_nx_n \qquad (1)$$

satisfying the following conditions:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \dots a_{1n}x_n &\le b_1 \\ &\vdots \\ a_{m1}x_1 + a_{m2}x_2 + \dots a_{mn}x_n &\le b_m \end{aligned} \qquad (2)$$

$$x_1 \ge 0, x_2 \ge 0, \dots, x_n \ge 0 \qquad (3)$$

where: a_{ij}, b_i, c_j are given real numbers.
The relations (1) – (3) can be written in short as follows:

$$\begin{aligned} &\max \sum_{j=1}^{n} c_j x_j \\ &\sum a_{ij}x_j \le b_i,\ i = 1, 2, \dots, m \\ &x_j \ge 0,\ j = 1, 2, \dots, n \end{aligned} \qquad (4)$$

Function (1), the maximum of which should be found, is called the objective function (aim, to be optimised). The system of inequalities (2) represents the constraints of the problem, and (3) is called non-negativity conditions.
On the other hand, if the minimum of the function "f" should be found, the constraints must be satisfied with the ≥ sign, namely:

$$\sum_{j=1}^{n} a_{ij}x_j \ge b_i$$

Understanding the solutions requires their scientific interpretation, their classification. Thus, a system of n real numbers x_j that satisfies (2) and (3) is a feasible (possible) solution. If for the n real numbers satisfying (2), we also have $x_j < 0$, and conditions (3) are not satisfied, the solution is inadmissible (not feasible). A system of m values $x_j \ge 0$ and $n–m$ values $x_j = 0$, which checks the system (2) is called an admissible basic solution. Finally, a basic admissible solution for which the objective function becomes maximum (or minimum) is an optimal solution [6].

Model implementation

The mathematical model starts from the following hypotheses:
– From a certain range denoted by S_i (male jacket designed to be worn in summer) one can produce seven variants (items) denoted by $A_1, A_2, \dots, A_7$.
The first seven variants of the male jacket were taken into consideration, ordered decreasingly according to the value ratio of the production cost/quality, considered the most effective [7];
– The times (t_{jk}) necessary to the operations O_1, $O_2, \dots, O_7$ for manufacturing each item are shown in table 1;
– The total times available for each operation (TT_k) are: TT_1 = 4585 hours, TT_2 = 2125 hours, TT_3 = 1050 hours, TT_4 = 1350 hours, TT_5 = 375 hours, TT_6 = 550 hours, TT_7 = 625 hours;
– The operations necessary to manufacture these items are: O_1 – designing the model, O_2 – drafting the internal norms, O_3 – designing the patterns and templates, O_4 – preparing the fabric, O_5 – tailoring, O_6 – assembling the parts; O_7 – finishing;
– The profit obtained for each item is also known (p_j): p_1 = 43.25 lei, p_2 = 43.35 lei, p_3 = 43.60 lei, p_4 = 43.65 lei, p_5 = 43.75 lei, p_6 = 43.80 lei, p_7 = 45.45 lei;
– The constraints regarding the ongoing contracts are: $5 \le x_1 \le 10$; $x_2 \le 12$; $x_3 \ge 5$; $x_4 \ge 5$; $x_5 \ge 5$; $x_6 \le 20$; $x_7 \ge 10$;
Once the working hypotheses established, we denote $x_1, x_2, \dots, x_7$ the quantities of each item that is to be manufactured.
The constraints that are imposed in the given situation are:

$$\begin{aligned} &60 \cdot x_1 + 60 \cdot x_2 + 60 \cdot x_3 + 60 \cdot x_4 + 58 \cdot x_5 + 58 \cdot x_6 + 58 \cdot x_7 \le 4585 \\ &30 \cdot x_1 + 30 \cdot x_2 + 30 \cdot x_3 + 30 \cdot x_4 + 30 \cdot x_5 + 30 \cdot x_6 + 30 \cdot x_7 \le 2125 \\ &15 \cdot x_1 + 16 \cdot x_2 + 17 \cdot x_3 + 15.5 \cdot x_4 + 12 \cdot x_5 + 14 \cdot x_6 + 13 \cdot x_7 \le 1050 \\ &10 \cdot x_1 + 11 \cdot x_2 + 9 \cdot x_3 + 8 \cdot x_4 + 16 \cdot x_5 + 7.2 \cdot x_6 + 8 \cdot x_7 \le 1350 \end{aligned}$$

Table 1

TIMES NECESSARY TO EACH OPERATION FOR EVERY AND EACH ITEM - hours -							
A \ O	O_1	O_2	O_3	O_4	O_5	O_6	O_7
A_1	t_{11} = 60	t_{21} = 60	t_{31} = 60	t_{41} = 60	t_{51} = 58	t_{61} = 58	t_{71} = 58
A_2	t_{12} = 30	t_{22} = 30	t_{32} = 30	t_{42} = 30	t_{52} = 30	t_{62} = 30	t_{72} = 30
A_3	t_{13} = 15	t_{23} = 16	t_{33} = 17	t_{43} = 15.5	t_{53} = 12	t_{63} = 14	t_{73} = 13
A_4	t_{14} = 10	t_{24} = 11	t_{34} = 9	t_{44} = 8	t_{54} = 16	t_{64} = 7.2	t_{74} = 8
A_5	t_{15} = 5	t_{25} = 5.5	t_{35} = 4.5	t_{45} = 5	t_{55} = 6	t_{65} = 5	t_{75} = 4
A_6	t_{16} = 8	t_{26} = 8	t_{36} = 7.2	t_{46} = 7.8	t_{56} = 8	t_{66} = 7	t_{76} = 6.9
A_7	t_{17} = 7	t_{27} = 9	t_{37} = 8.7	t_{47} = 8	t_{57} = 7	t_{67} = 7.5	t_{77} = 7.3

$$5 \cdot x_1 + 5.5 \cdot x_2 + 4.5 \cdot x_3 + 5 \cdot x_4 + 6 \cdot x_5 + 5 \cdot x_6 + 4 \cdot x_7 \leq 375$$

$$8 \cdot x_1 + 8 \cdot x_2 + 7.2 \cdot x_3 + 7.8 \cdot x_4 + 8 \cdot x_5 + 7 \cdot x_6 + 6.9 \cdot x_7 \leq 550$$

$$7 \cdot x_1 + 9 \cdot x_2 + 8.7 \cdot x_3 + 8 \cdot x_4 + 7 \cdot x_5 + 7.5 \cdot x_6 + 7.3 \cdot x_7 \leq 625$$

The objective function of this model asks to determine the optimal quantities of each item of the range S_i that should be manufactured, so that the obtained profit to be maxim. In mathematical terms, this objective is written as follows:

$$Max\ 43.25 \cdot x_1 + 43.35 \cdot x_2 + 43.60 \cdot x_3 + 43.65 \cdot x_4 + + 43.75 \cdot x_5 + 43.80 \cdot x_6 + 45.45 \cdot x_7$$

By using the QM software for Windows, the following quantities resulted:

$x_1 = 5$, $x_2 = 0$, $x_3 = 5$, $x_4 = 5$, $x_5 = 5$, $x_6 = 0$, $x_7 = 51$.

For these values of $x_1 ... x_7$, the value of the objective function (the maximum profit to be obtained) is 3181.63 lei.

Results and discussions

The optimal solution is to produce 5 pieces of A_1, 5 pieces of A_3, 5 pieces of A_4, 5 pieces of A_5 and 51 pieces of A_7, and the total profit obtained is 3181.63 lei (table 2).

The data in the column "reduced cost" (table 3) indicate how much the objective function coefficients should change for the values of the variables in the final solution to be positive. For the situation we present, p_2 should be modified with 2.10 lei, and p_6 with 1.65 lei for the values of the variables x_2 and x_6 to be positive. This means that, if the profit for A_2 was increased with 2.10 lei, i.e. it was increased from 43.35 lei to 45.45 lei, and for A_6 it was increased with 1.65 lei, i.e. from 43.80 lei to 45.45 lei, the result of the model would change (x_2 = 12 pieces and x_6 = 20 pieces); hence, the items A_2 and A_6 could be produced.

Table 2

RESULTS OF LINEAR PROGRAMMING										
Specification	x_1	x_2	x_3	x_4	x_5	x_6	x_7		**Constraints**	**Dual value**
Maximize	43.25	43.35	43.6	43.65	43.75	43.8	45.45			
Constraint 1	60	60	60	60	58	58	58	≤	4585	0
Constraint 2	30	30	30	30	30	30	30	≤	2125	1515
Constraint 3	15	16	17	15.5	12	14	13	≤	1050	0
Constraint 4	10	11	9	8	16	7.2	8	≤	1350	0
Constraint 5	5	5.5	4.5	5	6	5	4	≤	375	0
Constraint 6	8	8	7.2	7.8	8	7	6.9	≤	550	0
Constraint 7	7	9	8.7	8	7	7.5	7.3	≤	625	0
Constraint 8	1	0	0	0	0	0	0	≤	10	0
Constraint 9	1	0	0	0	0	0	0	≥	5	–2.2
Constraint 10	0	1	0	0	0	0	0	≤	12	0
Constraint 11	0	0	1	0	0	0	0	≥	5	–1.85
Constraint 12	0	0	0	1	0	0	0	≥	5	–1.8
Constraint 13	0	0	0	0	1	0	0	≥	5	–1.7
Constraint 14	0	0	0	0	0	1	0	≤	20	0
Constraint 15	0	0	0	0	0	0	1	≥	10	0
Solution	5	0	5	5	5	0	50.833		3181.63	

Table 3

ORDERING VALUES					
Variable	**Value**	**Reduced cost**	**Original value (profit per item)**	**Lower bound**	**Upper bound**
x_1	5	0	43.25	– infinity	45.45
x_2	0	2.1	43.35	– infinity	45.45
x_3	5	0	43.60	– infinity	45.45
x_4	5	0	43.65	– infinity	45.45
x_5	5	0	43.75	– infinity	45.45
x_6	0	1.65	43.80	– infinity	45.45
x_7	50.83	0	45.45	43.8	infinity
Constraint	**Dual value**	**Slack/Surplus**	**Original value (restrictions)**	**Lower bound**	**Upper bound**
Constraint 1	0	446.66	4585	4138.33	infinity
Constraint 2	1515	0	2125	900	2317.39
Constraint 3	0	91.66	1050	958.33	infinity
Constraint 4	0	728.33	1350	621.67	infinity
Constraint 5	0	69.16	375	305.83	infinity
Constraint 6	0	44.25	550	505.75	infinity
Constraint 7	0	100.41	625	524.58	infinity
Constraint 8	0	5	10	5	infinity
Constraint 9	–2.2	0	5	0	10
Constraint 10	0	12	12	0	infinity
Constraint 11	–1.85	0	5	0	27.92
Constraint 12	–1.8	0	5	0	41.67
Constraint 13	–1.7	0	5	0	39.58
Constraint 14	0	20	20	0	infinity
Constraint 15	0	40.83	10	– infinity	50.83

The coefficients of the variables x_1, x_3, x_4, x_5 and x_7 should not be modified because they have positive values.

In contrast, the data in the column "slack/surplus" (table 3) provides the values of the auxiliary variables for each constraint. For the given situation, it shows us that there is an inactivity of the production capacity of 446.66 hours for operation 1, 91.66 hours for operation 3, 728.33 hours for operation 4, 69.16 hours for operation 5, 44.25 hours for operation 6 and 100.41 hours for operation 7. This would mean that it would achieve the same result by allocating less time for operations 1, 3, 4, 5, 6, 7. Therefore, the times required by these operations should be reduced.

Finally, the data in the column "dual value" (table 3) provides information on the marginal value of the resources in the optimal solution. The dual value associated with a constraint shows how much the optimum value of the objective function improves at an increase by one unit of the right member from that constraint. In the present circumstances, the dual price of 1,515 lei for constraint (2) shows that for an increase in the length of operation 2 with a unit (from 2125 hours to 2126 hours), the optimum value of the objective function will increase by 1515 lei (from 3181.63 lei to 4698.63 lei).

In addition, if one wants a growth of the total profit, the total times can be increased for operation 2 up to 2317.39 hours and for operation 6 unlimited.

The other operations (O_1, O_3, O_4, O_5, O_6, O_7) having unused capacity have the dual price = 0, which shows that adding one unit to these resources does not improve the value of the objective function.

The values of the variables from "lower bound – upper bound" (table 3) show that for the variation of the coefficients of the objective function in the interval lower bound – upper bound, the optimum solution is unchanged. Specifically, for the variation of the profit within the following limits: $43.25 \le p_1 \le 45.45$; $43.35 \le p_2 \le 45.45$; $43.6 \le p_3 \le 45.45$; $43.65 \le p_4 \le$ ≤ 45.45; $43.75 \le p_5 \le 45.45$; $43.8 \le p_6 \le 45.45$; $p_7 \ge 43.8$, the value of the objective function is 3181.63 lei.

On the other hand, the values of the constraints from "lower bound – upper bound" (table 3) show the fact that the dual price associated with a constraint is valid if the value of the resource (the right member of the inequality) varies within the interval lower bound - upper bound. Applied to our situation, the dual values remain valid if the number of hours allocated for each operation varies within the following limits:

$4138.33 \leq TT_1$; $900 \leq TT_2 \leq 2317.39$; $958.33 \leq TT_3$; $621.67 \leq TT_4$; $305.83 \leq TT_5$; $505.75 \leq TT_6$; $524.58 \leq TT_7$.

CONCLUSIONS AND RECOMMENDATIONS

For the manufacturers of the textile confections, making an assortment range more efficient must take into consideration, first of all, the consumers' demands for the fashion trends, the types and sizes, and the nature of the raw materials. On the other hand, the manufacturers must take into account the real possibilities of making their assortment range, namely: the raw and auxiliary materials supply possibilities, the technological capacity, the human resources etc. Last but not least, they must think about the efficiency of their activity and about achieving an as high as possible profit which, however, should not affect the quality of the product and the consumers' interests. To meet all these requirements the present paper suggests using the linear programming.

Along with this proposed mathematical model, the authors recommend the manufactures of textile confections, as a complement, to also use the costs for influencing the behaviours within the company.

It is known that the analysis of the deviations from the standard cost is used in assessing the performance of departments and employees, in wage setting, etc., thus influencing behaviours. It should be avoided, however, the danger of turning the control through the standards system into a tool for identifying culprits for adverse deviations and reward favourable deviations without a meaningful analysis of the existing situation outside its obvious appearance.

The process of deviation analysis involves calculating the differences between the actual costs and the standard ones for the real level of the activity, followed by the identification and the study of the possible causes of the identified deviations. Another essential element of this process is to analyse only the deviations controlled by the managers, because the uncontrollable ones spirals out of their control.

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WEB PORTAL FOR CUSTOMIZED PRODUCTION OF CLOTHING FOR OVERWEIGHT AND ELDERLY PEOPLE

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GEORGETA POPESCU
ALEXANDRA MOCENCO

REZUMAT – ABSTRACT

Portal web pentru producţia personalizată de îmbrăcăminte pentru persoane supraponderale şi vârstnice

Această lucrare prezintă proiectul de cercetare GarmNet derulat în cadrul programului EUREKA de către următorii parteneri: INCDTP, DATSA TEXTIL SRL, MAGNUM SX SRL – România și Institutul de Cercetare în domeniul textil din Lodz – Polonia. Studiul Institutului de Cercetare în domeniul textil a fost realizat ca proiect internațional Eureka E! 8056 GarmNet finanțat de NCBiR din Polonia.

La nivel global, aproximativ 39% dintre adulții cu vârsta de peste 18 ani au fost supraponderali în 2014. Producția de masă a îmbrăcămintei este construită pentru persoanele cu dimensiuni ale corpului și postură standard. Proiectul are ca scop dezvoltarea unei platforme web cu o arhitectură modulară, care conține datele necesare pentru proiectarea și fabricarea de îmbrăcăminte personalizată pe baza datelor antropometrice specifice ale persoanelor supraponderale, obeze și vârstnice. Modulele platformei web sunt: tabele cu dimensiuni care conțin datele antropometrice necesare pentru a proiecta tipare; set de informații pentru măsurarea directă a corpului destinat persoanelor care nu au acces la scaner 3D; clasificarea tipurilor de corp; tiparele de bază, în conformitate cu tabelele de dimensiuni și tipul de corp; catalog cu modele de îmbrăcăminte corelate cu tipurile de corp și un ghid on-line pentru utilizarea portalului web.

Cuvinte-cheie: obezitate, date antropometrice, personalizare, îmbrăcăminte, platformă web

Web portal for customized production of clothing for overweight and elderly people

This paper presents the GarmNet project research in EUREKA program in collaboration with the following partners: INCDTP, DATSA TEXTIL SRL, MAGNUM SX SRL –Romania and Textile Research Institute Lodz – Poland. The study of Textile Research Institute was conducted as an international project Eureka E! 8056 GarmNet financed by polish NCBiR.

Globally, around 39% of adults aged 18 and over were overweight in 2014. Mass production of clothing is constructed for people with standard body dimensions and posture. The project aims to develop a web platform with a modular architecture that contains the necessary data for designing and manufacturing the customized clothing based on specific anthropometric data of overweight, obese and elderly people. The modules of web platform are: the sizes tables with the anthropometric data necessary to design patterns; the set of information for direct body measurement aimed at people who have no access to the 3D scanner; the classification of body types; the basic patterns in conformity with size tables and body type; clothing models catalog correlated with body types and an online guide for use the web portal.

Keywords: obesity, anthropometric data, customization, clothing, web platform

INTRODUCTION

The goal of the project is to develop a web platform as a new, innovative and interactive clothing production system and business model able to respond to several aspects of customized products for obese and elderly people.

Mass production of clothing is constructed for people with standard body dimensions and posture.

Obesity is today a global phenomenon that affects all countries, all types of societal collectives regardless of age, sex and income. In the actual context of unstoppable increasing prevalence of obesity and metabolic syndrome, the adipose tissue became the main target tissue for research, as its inflammatory reaction on different tissues, in different degrees, are considered to be the substrate of decrease in insulin sensitivity, explaining the cardiovascular complications [1].

Today, 2.1 billion people – nearly 30% of the world's population – are either obese or overweight, according to a new, first-of-its kind analysis of trend data from 188 countries. During 1980-2013 the rates of overweight and obesity among adults have increased for both men (from 29% to 37%) and women (from 30% to 38%). In developed countries, men had higher rates of overweight and obesity, while women in developing countries exhibited higher rates. Also in developed countries, the peak of obesity rates is moving to younger ages [2].

According to anthropometric survey results conducted in Romania in 2010 the overweight and obesity in the adult people (20–65 of age) is 45% respectively 22% for men and 24% respectively 17% for women. The average value of relative body mass index (BMI) has increased, which indicates an increasing obesity problem in the Polish population.

This is accompanied by changes in the fatty tissue distribution resulting in fat accumulation on abdomen and in hip regions. From generation to generation, one can observe a growing fraction of persons of extremely high body weight. In the Polish group of women (19–59 age), 35% are overweight and 63% are obese.

The population ageing is most advanced in Europe and North America, but it will soon begin, in all the major areas of the world. Globally, the share of older people (aged 60 years or older) increased from 9 per cent in 1994 to 12 per cent in 2014, and is expected to reach 21 per cent by 2050 [3].

On the other hand, the EU promotes the active inclusion and full participation of obese and elderly people in society, in line with the EU human rights. Clothing products for these target people is governed by a number of different needs and restrictions.

The problems of obese and elderly people and their needs will be identified in the project in order to design the most appropriate and comfortable clothes, that allow them to do daily activities. The project will address two directions, design and manufacturing the clothing of target people: customized clothes using the table dimensions from web platform and individual clothing for people that can be measured by scanning or manually. The specific anthropometric reference data of this target population is necessary and essential. Nowadays, laser scanning technology has revolutionized the traditional collection and application of anthropometric data.

So, digital fitting systems are more and more used for evaluating the fit of garment without making actual patterns or actual garments. In a digital fitting system, a virtual garment is made using virtual patterns, and the fit of actual garment on an actual human body is assessed by draping a virtual garment on a virtual body or a virtual dress-making dummy. In the project we will use digital fitting systems in order to improve the fit of garments on the body and the fit of customized garments for the target group.

EXPERIMENTAL

The acquisition of anthropometric data

The acquisition of anthropometric data of the target group in both countries was made with Vitus XXL scanner equipped with Anthroscan Professional software using 3D scanning technology as shown in figure 1 [4].

In Romania anthropometric survey of older and obese people was conducted on about 1500 subjects at the National Institute of Diabetes, Nutrition and Metabolic Diseases “Prof. Dr. N. Paulescu”. In Poland tests have been conducted on about 314 subjects, at the Textile Institute in Łódź, Weight Loss and Nutrition Center in Łódź and Sanatorius Resort in Ustroń – south part of Poland.

This technology has pushed anthropometric research towards a digitalized environment, which allows researchers to conveniently access and study the anthropometric data and can bridge many professional disciplines such as medicine, CAD/CAM, engineering and e-commerce applications. By this technology, 3D digitized anthropometric data can easily be collected in a few seconds and accessed immediately from anywhere in the world through the internet.

The Research Methodology

The research methodology consists in 3D anthropometric data collection, statistical analysis, design and development of anthropometric databases of target people, characterization of body types, types of obesity and clothing sizes [5].

The main indicators of overweight/obesity used currently in practice are waist circumference, hip circumference and body mass index [6–7]. An additional anthropometric parameter to be associated with the degree of obesity is neck at base circumference [1].

The 150 primary anthropometric data were filtered by gender (women and men), by age and they were subjected to statistical analysis to select the target groups and the anthropometric data necessary for design of patterns and body type defining.

Analysis of the female obesity figures shows diverse body fat distribution, figure 2.

The statistical analysis was processed on the principal anthropometric parameters according to the formulas described in the specialty literature, allowing these determinations:

- Arithmetic-media selection, trend parameter Mean (X), to the dimensions of each gender group;
- Limits number of variables (Xmin and Xmax), Standard deviation (Sx), Dispersion (Variance, S2x) and coefficient of variation (Cv);

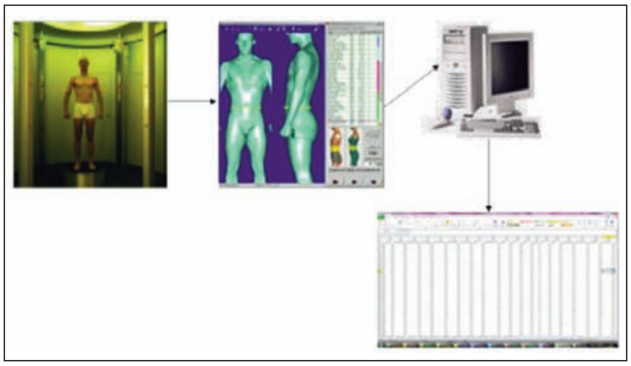


Fig. 1. Anthropometric data collecting system

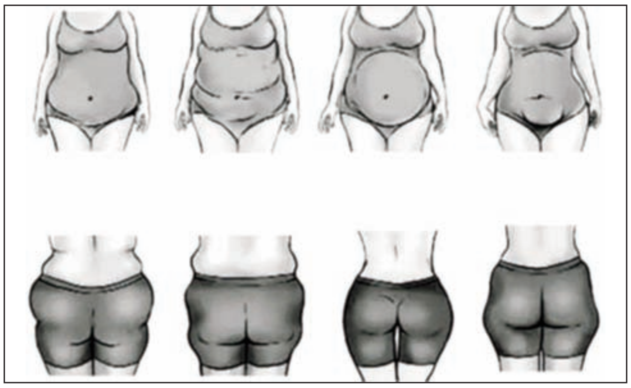


Fig. 2. Diverse body fat distribution in women

– The error limit of the mean sample (Δ) and average test selection (txm).

To establish dimensional typology (establishing the body's variants to be included in the size tables or table of anthropometric dimensions) the relative frequency in the investigated sample of the different values of the main dimensions must be taken into account.

In determining the types of body the relative frequency analysis of the difference between Ps (hip area) and Pb (bust area) for women and Pt (waist perimeter) and Pb (chest area) for men has been considered.

For the table of anthropometric dimensions, size clothing and body type the relative frequencies exceeding 5% were selected.

In the present study, we carried out the analysis of the basic measurement data and attempt to work out basic body dimensions on the basis of the measurement results of persons scanned during the study for women with minimal hip circumference amounting to 104 cm and for men with minimal waist circumference of 96 cm.

The results of statistical analysis provide information necessary for developing modules of GarmNet web portal.

Within the modules there is all information for the manufacture of the garments for obese and elderly people. The network makes the connection between producers, customers and market.

RESULTS AND DISCUSSION

The architecture of web portal, figure 3, was designed to integrate the following modules: tables with 3D anthropometric data and clothing size of the obese and elderly people; a set of anthropometric measurement tools, easily and inexpensively, delivered via Web platform to people that have not access to the 3D scanner (an alternative to scan measuring); a special library with fashion models correlated with the body type; a library with basic patterns; a library with specific body type of this target people; a database with fabrics and their characteristics suitable for target people. The network has a producer and customer interface.

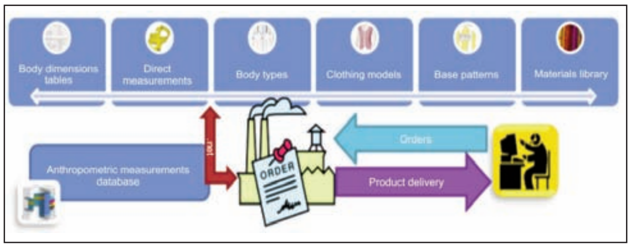


Fig. 3. GarmNet web portal and the Network

Module of body dimensions and clothing size

Within this module there are the tables with sizes of body height, the summary table with bust perimeter, hip perimeter, body types and sizes of clothing. Corresponding to each size clothing and body type there is the table with approximately 37 body dimensions necessary for design patterns. The module contains this type of tables for each target group: obese women, obese men, elderly women and elderly men.

In order to help the garment manufacturers this module contains information regarding the percentage of height, bust and hips perimeters and body type within each target groups. Example of the tables dimensions for obese women (tables 1, 2, 3, 4) and the frequency of these dimensions among sample studied (figures 4, 5, 6).

Table 1

BODY HEIGHTS (Ic) AND THE RANGES			
Body height (cm)	**Range** (cm)	**Body height** (cm)	**Range** (cm)
152	148 – 155,9	168	164 – 171,9
160	156 – 163,9	176	172 – 180,0

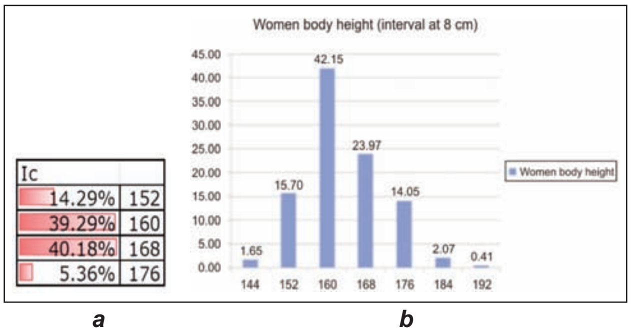


Fig. 4. Frequency percentage of Body height (Ic) distribution: *a* – in Romania, *b* – in Poland

Table 2

BUST PERIMETERS (Pb) AND RANGES			
Bust (cm)	**Range** (cm)	**Bust** (cm)	**Range** (cm)
104	102 – 105,9	122	118 – 123,9
110	106 – 111,9	128	124 – 129,9
116	112 – 117,9		

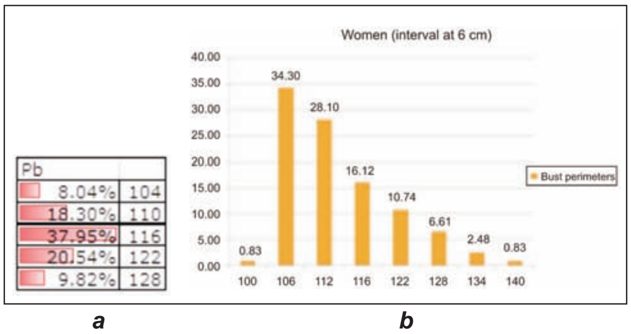


Fig. 5. Frequency percentage of bust perimeters (Pb) distribution: *a* – in Romania, *b* – in Poland

Direct measurements of the body module

In this module there are images accompanied by explanations for the direct measurement way.

Table 3

SUMMARY TABLE WITH THE BUST AND HIPS PERIMETERS, CLOTHING SIZE AND BODY TYPE						
Body type	**Pş–Pb**	**Clothing size**				
		o52	**o54**	**o56**	**o58**	**o60**
		Pb				
		104	**110**	**116**	**122**	**128**
		Pb				
oA	–8	-	-	108	114	120
oB	–4	-	106	112	118	124
oC	0	104	110	116	122	128
oD	4	108	114	120	126	132
oE	8	112	118	124	130	136
oF	12	116	122	128	134	140
oG	16	120	126	132	138	-
Range		**6 cm**				

Body types module

This module comprises the description and the images of the body types for each target group. Table 5 shows the body types for Romanian obese women and men [8].

In Poland the analysis of the data calculations has shown that 56% of women represent the pear structure type, while 44% – the apple structure type. Thus, there is a decisive majority of the pear structure type among women, figure 7.

Clothing models module

This module is a fashion catalogue which correlates the clothing models with the body type. The database of this module will be permanently updated with the current fashion trends, each partners will upload on web platform its own catalogue [9].

Table 4

PRIMARY, SECONDARY AND ADDITIONAL DIMENSIONS FOR BODY TYPE A				
Cod	**Body type oA**	**o56**	**o58**	**o60**
4510	Bust/chest girth	116	122	128
7525	Hip girth	108	114	120
5020	Across back width (armpit level)	39.9	41.0	42.1
9551	Ankle girth right	25.9	26.6	27.4
7540	Belly circumference	106.7	112.2	117.7
0170	Breast height	109.0	110.4	111.7
4081	Bust point to neck	33.6	34.7	35.9
4030	Bust points width	21.9	22.7	23.6
7520	Buttock girth	107.6	113.5	119.4
9541	Calf girth	37.1	38.7	40.3
3010	Cross shoulder over neck	44.7	45.9	47.1
6010	Cross shoulder over neck	77.9	80.9	83.9
6011	Crotch length, front	39.1	40.8	42.6
0040	Distance neck to hip	56.0	56.3	56.6
8541	Forearm girth right	26.9	27.5	28.2
9021	Inseam right	70.2	72.2	74.1
9521	Knee girth right	38.5	40.5	42.4
0110	Knee height	42.1	42.9	43.7
1510	Mid neck girth	39.8	41.1	42.4
1520	Neck at base girth	44.1	45.4	46.6
1010	Neck diameter	13.5	13.9	14.2
0030	Neck height	134.9	136.7	138.5
5051	Neck right to waist back	45.1	45.8	46.5
4040	Neck right to waist over bust	48.0	49.0	50.1
5030	Neck to across back width (armpit level)	15.9	16.2	16.6
5040	Neck to waist center back	41.1	41.6	42.1
9036	Sideseam at waist right	96.5	98.0	99.5
9511	Thigh girth right (horizontal)	56.9	59.5	62.1
2510	Total torso girth	167.0	171.8	176.6
8911	Upper arm diameter right	12.4	13.1	13.7
8521	Upper arm girth right	31.4	32.6	33.7
6510	Waist girth	104.4	110.0	115.6
4020	Width armpits	48.8	52.1	55.3
8551	Wrist girth right	17.7	18.2	18.6
8030	Arm length left	51.5	52.3	53.1
3030	Shoulder width	15.2	15.6	16.0
1530	Head circumference	59.5	59.9	60.3
9800	Weight	75.9	85.0	94.0
4520	Underbust circumference (horizontal)			

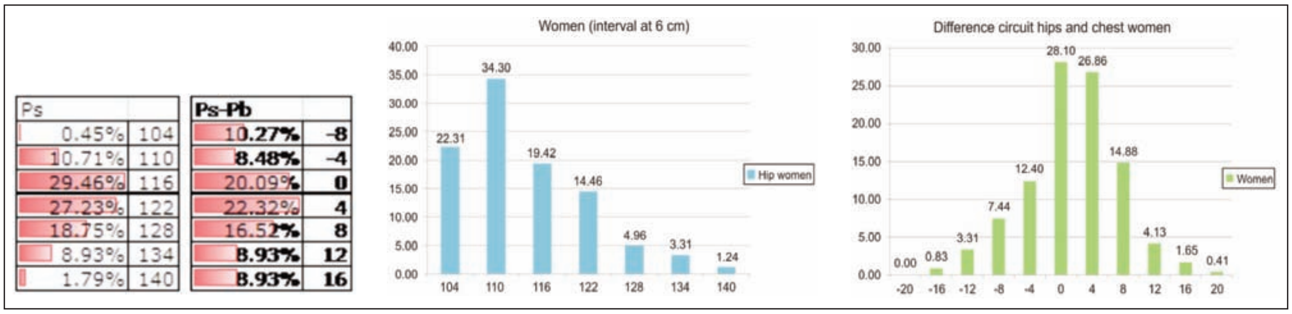


Fig. 6. Frequency percentage of bust perimeters (Pb) and body type distribution: *a* – in Romania, *b* – in Poland

Table 5

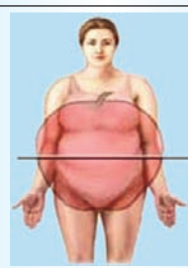
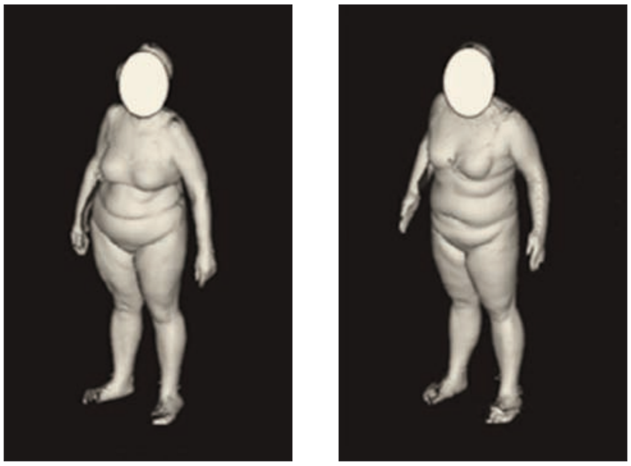
BODY TYPES FOR OBESE WOMEN				
Characteristics	**Body type name**	**Usual body type name**	**Characteristics**	**Body type name**
Women			**Men**	
oC: Pş–Pb= 0			oF: Pt–Pb= 0	
	Rectangular	Hourglass Rectangular		Rectangle
oA: Pş–Pb= –8 oB: Pş–Pb= –4			oA: Pt–Pb= –20 oB: Pt–Pb= –16 oC: Pt–Pb= –12 oD: Pt–Pb= –8 oE: Pt–Pb= –4	
	Inverted Triangular	Apple body		Inverted Triangular Trapezium
oD: Pş–Pb= 4 oE: Pş–Pb= 8 oF: Pş–Pb= 12 oG: Pş–Pb= 16			oG: Pt–Pb= 4	
	Triangular	Pear body		Triangular
Pt > Pş and Pb			Pt > Pş and Pb	
	Rounded/Diamond	Apple body		Oval

Fig. 7.



a *b*

Fig. 7. Body figure: *a* – pear, *b* – apple

Base patterns module

Design of clothing patterns for the overweight and obese people cannot be achieved easily with existing CAD systems on the market because they are working on algorithms build for proportional bodies. On the other hand, personalized design algorithms must be calculated for each subject, which is difficult to put into practice. In this context we have developed specific rules processing algorithms design patterns for atypical bodies having layers of excess fat in various areas of the body.

The database with basic pattern for each body type and each size is owned by each partner of the project [10].

Materials and accessories module

This module will contain recommendations/suggestions for the limit values of the technical characteristics of fabrics used in clothing products for the elderly and obese people.

Customer interface

Uniform products as a result of mass production will not satisfy target groups people demands. The combination of existing products and services and the new ones with a change in their characteristics will be absolutely necessary to provide customers with competitively priced customized products and services that meet as closely as possible the requirements of each user. The web portal contains a Customer and a Producers interface. Through this interface the customers who want individualized products and the retailers can order them to SMEs involved in the project.

CONCLUSIONS

All partners have interests in achieving the results and expand the new paradigm in design and production of clothing with added value, for obese and elderly people and winning these market niches. The innovative technology is based on the latest IT solutions and represents major leaps in manufacturing clothing for this target group.

According to statistical analyses of the primary anthropometric data of sample survey the following resulted:

- for Romanian obese women sample seven body types were established (Ps–Pb = –8, –4, 0, 4, 8, 12, 16 cm), four standardized values for body height (152,160, 168, 176 cm) and five standardized values for the chest girth (104, 110, 116, 122 and 128 cm);
- for Polish obese women sample five bodies type were established (Ps–Pb = –8, –4, 0, 4, 8 cm), four standardized values for body height (152,160, 168, 176 cm) and five standardized values for the chest girth (104, 110, 116, 122 and 128 cm);
- for Romanian obese men sample we established seven body types, six standardized values for body height (168, 172, 176, 180, 184, 188 cm), five standardized values for chest girth (112, 116, 120, 124 and 128 cm) and eight standardized values for waist girth (92, 96, 100, 104,108, 112, 116 and 120 cm);
- for Polish obese men sample we established six body types (Pt–Pb = –20, –16, –12, –8, –4 and 0), five standardized values for body height (168, 172, 176, 180, 184 cm), five standardized values for chest girth (112, 116, 120, 124 and 128 cm) and seven standardized values for waist girth (96, 100, 104, 108, 112, 116 and 124 cm);
- for Romanian sample group ‘elderly women’ we established five body types (Ps–Pb = –4, 0, 4, 8, 12 cm), three standardized values for body height (152, 160, 168 cm), seven standardized values for the bust girth (96, 100, 104, 108, 112, 116 and 120 cm) and seven standardized values for hip (96, 100, 104, 108, 112, 116 and 120 cm);
- for Polish sample group ‘elderly women’ we established five body types (Ps–Pb = –4, 0, 4, 8, 12 cm), three standardized values for body height (152, 160, 168 cm) and eight standardized values for the bust girth (96, 100, 104, 108, 112, 116 , 120 and 124 cm), six standardized values for hip (100, 104, 108, 112, 116 and 120 cm);
- for Romanian sample group ‘elderly men’ we established five body types (Pt–Pb = –12, –8, –4, 0 and 4 cm), six standardized values for body height (164, 168, 172, 176, 180, 184 cm) and seven standardized values for chest girth (100, 104, 108, 112, 116, 120 and 124 cm) and eight standardized values for waist girth (92, 96, 100, 104, 108, 112, 116 and 120 cm);
- for Polish sample group ‘elderly men’ we established five body types (Pt–Pb = –16, –12, –8, –4, 0 cm), five standardized values for body height (164, 168, 172, 176, 180 cm) and eight standardized values for chest girth (100, 104, 108, 112, 116,

120, 124 and 128 cm) and seven standardized values for waist girth (92, 96, 100, 104, 108, 112 and 116 cm).

The interactions between body shapes, pattern shapes and fabric properties can create an exponential number of possible fitting issues to be resolved.

These results will contribute and will increase the quality of life for target people with disproportionate body, various degrees of obesity, asymmetric posture, deficient spinal, deficient joints, by developing daily clothing with a better fitting and functionality.

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Knowledge and economic rationality in productive/reproductive environment in textile and leather industry in Romania

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REZUMAT – ABSTRACT

Cunoaștere și raționalitate economică în mediul productiv/reproductiv din industria textilă și pielărie în România

Articolul abordează probleme legate de cunoștințele economice în sistemele de producție/reproducție, în industria textilă și pielărie. Este descris sistemul conceptual al problemelor manageriale, vizând modelarea comportamentului economic în rândul celor care organizează și conduc agenți economici cu producție pe baze științifice avansate, precum în industria textilă și pielărie din România. Rezultă că modelarea economică a comportamentului managerial în rândul celor care organizează și conduc companii, întreprinderi, organizații etc. are contribuție decisivă la operaționalizarea conștientizării sociale și stabilirea căilor către bunăstarea economică.

Cuvinte-cheie: industria textilă și pielărie, fundamente economice, raționalitate, noua economie, producție/reproducție, cunoștințe economice

Knowledge and economic rationality in productive/reproductive environment in textile and leather industry in Romania

The article dealt with issues relating to economic knowledge in production/reproduction systems, in the textile and leather industry. There are described the managerial issues about shaping economic behaviour among those who organize and lead advanced productive economic entities in the textile and leather industry in Romania. It follows that economic modelling of managerial behaviour among those who organize and lead companies, enterprises, organizations etc. give a conclusive contribution to the operationalization of social awareness and economic welfare.

Keywords: the textile and leather industry, economic fundamentals, rationality, new economy, production/reproduction, economic knowledge

INTRODUCTION

Romania's contemporary knowledge economy is one of the fundamental processes of the spirit of participants in production/reproduction, which requires the existence of a custom system for staff training/workforce for the future in the textile and leather industry. Knowledge is the first that reality and consciousness itself appears in the subject, relating to the self and the world. The essence of knowledge is to reproduce inside of other subjectivity, through self-awareness and awareness with a bias binding reality it can act, experiment, evaluate and decide on the consequences. In context to achieve the commitment of human resources in this alignment of fundamental support of economic production/reproduction, move to resume within the subjectivity of employees in both the public and the private sphere, another subjectivity marked by conviction and acceptance of immersion in a particular training process, other than traditional organizational learning, using borderless telecommunication and information technologies. The term "knowledge economy" is used to designate an activity arising organizational learning through knowledge production/reproduction, and results of this work. In the first sense there are considered the employee's knowledge capacity and functionality, and in the second instance, there are considered ready constituted knowledge, concepts, judgments, economic theories [5]. In enterprises of all types in Romania (i.e. in the textile and leather industry) one can manifest interest to the factors involved in the production of knowledge production/reproduction, analysis and final results of these actions.

EXPERIMENTAL WORK

Economic knowledge in production systems for raising/breeding in the textile and leather industry

Knowledge of economic awareness aimed at identifying, describing and controlling the shape, property or event production/reproduction, separation and conceptual understanding of causality criteria that allow the emergence and development of different objects, properties, shares and conditioning the economic reality in which they operate companies from Romania. The concept of knowledge in the context analysed in relation to the requirements of the Romanian economy indicators (GDP, inflation, employment, etc.) can have multiple meanings. It can be characterized as knowledge state of a computer system (not related to the new knowledge economy) in economic reality (the national and European economy), and in this way you can build modal representations and predictive strategies on economic dynamics and can develop actions in the societal model. In this interactive perspective, knowledge of economics can be a relationship perceptual- gestural, linguistic or mixed human resources system in relation to economic reality. Eventually, the economic reality in Romania can be defined as interactive space, defined by structure, property and event correlation (production/ reproduction). The composition of economic knowledge performance defines the set of components with stable border. However, events such as production/breeding have movements and connections between border movements in the economic and societal productive area of Romania. We note that, in fact, cognitive causation (theories, methodologies, etc.) defines criteria for structured, interactive invariant, fundamental, resulting in all shapes and type events of production/reproduction. On the other hand, individualized property modal, structural or behavioural components of economic reality in which they operate companies, enterprises, organizations etc. show a certain level of quality for the competitiveness of the European economic space in integrated operation. The first organizational knowledge – knowledge management through the senses, is retained as obscure, and the second – economic knowledge through intellect, is authentic. The reason the opposition senses managerial-economic intellect, apparently the essence of analysed management-knowledge production/ reproduction. Economic superior science aiming operation of companies in the Knowledge and manifests itself nowadays through a pre-aggression evolving from knowledge through the senses of managerial conventional world on productive sensitive to knowing intellect economic true life works companies, enterprises, organizations etc. Based on our theoretical and methodological research, it is considered that the amount of economic knowledge or good economic foundation of knowledge, may be commonly determined with reference to the epistemological sources and paths that were obtained from conventional sources. Knowledge to awareness of Romanian economic competitiveness is authentic if and only the product validation sources of value added in production/ reproduction are competitive. In this context, one can use the term "economic rationalism" for the view that the economic rationale or intellect constitutes genuine sources of economic knowledge.

MODELING OF ECONOMIC MANAGERIAL BEHAVIOR AMONG THOSE WHO ORGANIZE AND LEAD PRODUCTIVE ECONOMIC ENTITIES IN THE TEXTILE AND LEATHER ADVANCED INDUSTRY

The behaviour of managers, their selection is found that by using information technologies in the field of producing influences from various factors, which may be classified as:

– Socio-demographic factors (geographical distance reasons for termination);
– Socio-economic factors (lower costs of production);
– Psychological factors (des-inhibition communication/by telecommunication widespread production and the market);
– Institutional factors (companies, enterprises, organizations etc. generate competitive programs production/reproduction).

It notes that complexity manifests rational choice economic decision (meta-decisions) in terms of contemporary organizational learning without borders. Essentially, complex economic decisions characterize different value systems production/breeding for certain arrangements for accelerated societal advance [4]. The case study below shows the options transitive production/reproduction relative to corporate preferences of Knowledge Economy. As such, there are the following cases:

1. Axiom hierarchy comparison and customer preferences and producer/consumer: an example, the two sets of formulas A and B production/reproduction will choose one of three possible variants (exemplary) (X_1, X_2, X_3):

* prefer A front of B, ($A \succ B$);
* prefer B front of A, ($B \succ A$);

} Preferably relationships

* It is indifferent to the two types production/reproduction, considering them equivalent, ($A \sim B$).

$\Longrightarrow$ Indiference realtionships

2. Transitivity option a type of production / breeding: Sort different sets production manager/breeding pair and compares them:

$$\text{If } A \succ B \text{ and } B \succ C \rightarrow A \succ C \tag{1}$$

3. Axiom greed: if there are two sets of formulas A (X, 2Y) and B (X, Y): $A \succ B$.

In this context, managers prefer a larger number of formulas production/reproduction using valuable intangible assets. Most preferable set of formulas of production/breeding aware assume the highest level of satisfaction or utility. Utility is an initial category in the theory of economic behaviour manager. The utility can be defined as the ability of a program production/breeding high quality to satisfy a particular need of a result. This involves a subjective notion.

1. Addressing the cardinal (classical) utility. Under the approach “cardinaliste”, usefulness of program production/reproduction subjected to awareness among managers and performers (HR) can be measured by a number of abstract units (useful).

2. Ordinal approach (neoclassical). For ordinal approach it is characteristic the utility of the combinations of formulas ordering production/breeding measured by ordinal scale (first, second, third, etc.). In other words, the manager ordered their (rank) rational preferences in relation to the total satisfaction management, which aims to be achieved [3]. Total awareness usefulness in providing a program of production/reproduction is achieved by using sequences satisfaction successive management of a real productive system in a given period. Total usefulness of the function has the following general formula:

$$TU = f(Q_{X_i}) \quad (2)$$

Marginal utility is the additional satisfaction felt by manager by calling one additional unit of a program production/reproduction. The relationship of calculation of marginal utility is:

$$MU(Q_{X_i}) = \frac{\Delta TU}{\Delta Q_{X_i}} \quad (3)$$

To be expressed in mathematical terms, the marginal utility may be defined as the partial derivative of order 1 of the utility function. So:

$$MU(Qx) = (TUx)' \quad (4)$$

Size of marginal utility in ensuring awareness program production/reproduction is influenced by different factors:

- The volume or amount of management effort expended in program production/breeding respectively.
- The importance of program production/reproduction in relation to the requirements of the Romanian economy indicators and the intensity with which manifests different needs.
- Reproductive conditions given system of program production/reproduction.

We find that consuming an amount of management effort in a program production/reproduction, modification of marginal utility and usefulness of the total quantities are interdependent. Law of Diminishing Marginal Utility (Gossen's first law) implies that, in fact, consume more as a manager of a program production/breeding ($x_1, x_2, \ldots, x_i$), so you get a lower marginal utility by the consumption of additional units of the general economic framework, namely [2]:

$$MU_{X_1} > MU_{X_2} \ldots > MU_{X_i} \quad (5)$$

Each manager tends to maximize overall utility consumption organizational knowledge/managerial purchased. Meanwhile, managers and contractors are interested efficient use of their resources for learning/economic organizational knowledge. The second law of Gossen supposed to maximize total utility manager/contractor must distribute effort production/breeding economy, society, so that the marginal utility price-weighted assets are equal:

$$\frac{MU_X}{P_X} = \frac{MU_Y}{P_Y} = \ldots = \frac{MU_Z}{P_Z} \quad (6)$$

In behaviour research manager/performer indifference curves have an important place. They represent graphic illustration preferences manager/performer organizational realized. Indifference curve reflects the preferences and shows alternative combinations of economic formula awareness of organizational learning, allowing two (manager, executor) to achieve the same level of utility (TU). The graphical interpretation, in fact, indifference curve, is the locus of points whose details show combinations of formulas production/breeding creates utilities and is equal no matter what combination (figure 1) of formulas to choose [1]. Indifference curve, farthest from the origin of the coordinate axes, expresses a higher level of utility and is preferable for the manager; i.e. $U1 < U2 < U3$.

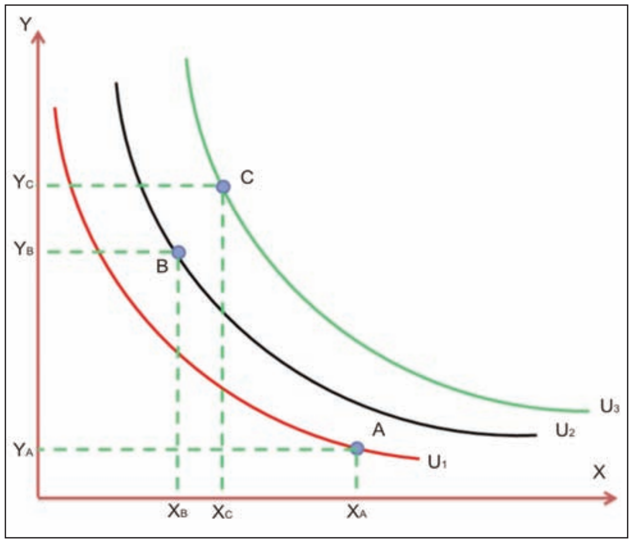

Fig. 1. Indifference curve describing a consumer preference for certain goods
(*Source*: Statistics EUA, 2010)

The fundamental problem lies in the manager of the contemporary optimal economy use of the available production/breeding conditions existing in market competition, based on individual preferences. The conclusion to this line, it is inferred that economic modelling managerial-behaviour among those who organize and lead companies, enterprises, organizations etc. conclusive contribution to operationalize social awareness and economic welfare.

RESULTS AND DEBATES

Development of scientific economic knowledge in the textile and leather advanced industry

Theme rationalistic knowledge based economy is assumed by putting in contrast the knowledge that is rooted in reason, which comes from managerial senses. First steps in economic metaphysics, giving early elements of the constitution can be made by separating managerial intellect economic senses. Economic rationale used for awareness can penetrate things (the system of production/reproduction) as they are, while managerial knowledge derived from the senses is a confusing quasi-economic knowledge. Rational economic knowledge allows access to truths that can sustain awareness insurer production system/reproduction. As regards economic knowledge for proper awareness, this should be limited to the modern world and the economic phenomena and processes operationalizing of production/reproduction. The fundamental forms of knowledge of economic reality for awareness are common knowledge and scientific knowledge. The Economic Community referred to the knowledge that combines elements of cognitive with the management, which sometimes leads to a low degree of rigor and systematization. Economic scientific knowledge is constituted under the joint as a result of increased specialization of economic research, the use of effective methods and means of investigation, with a strong abstract, systematically, methodically [4]. Knowledge is expressed in scientific economic concepts, laws, hypotheses

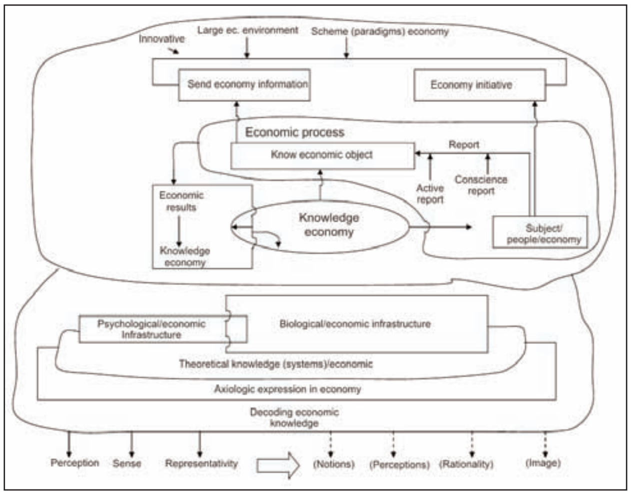

Fig. 2. Final decoding of economic knowledge

and scientific theories, formulated in the language of the different economic disciplines (figure 2).

Analysing the structure of modern economic knowledge admits that it is presented as a relationship between two components which are irreducible to one another, namely subject and object of knowledge. The nature and content of the two components of cognitive relationship and the very nature of that, but may be defined differently from different perspectives in New contextual knowledge economy. For economic idealism, the objective of economic knowledge is accessible worldwide in processing managerial awareness senses. A veritable economic knowledge is achieved through contemplation of the world economic ideas of organizational learning, using more diverse forms of commitment to training companies, enterprises, organizations etc. Before being run through filters economic management, economic knowledge is purely objective.

RESULTS

The real issue about the nature of economic knowledge to raise awareness of safeguarding production/reproduction competitive is actually one that relates to why there are so many types of economic interpretation that are subjective, when knowledge is purely objective. The answer could be that managers, decision makers in companies, enterprises, organizations etc. luggage have different experiences that produce different economic visions. When managers and performers are exposed to new economic information, they analyse it automatically and are always subjective, to make it conform to the knowledge base/consequences, operation can in turn completes a cycle that was beginning to launch production/breeding and which has continued ever since with every new aspect that came in contact with. Common Fund economic knowledge is composed of professional, moral-ethical principles and language. All these have an impact on how to interpret any new economic information.

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Time optimization of the textile manufacturing process using the stochastic processes

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REZUMAT – ABSTRACT

Optimizarea timpilor procesului de fabricație textilă folosind procesele stochastice

Existența, cu siguranță, a unui număr determinat de etape în dezvoltarea procesului de fabricație textilă face ca optimizarea acestui proces să fie adecvată prin utilizarea teoriei procedurilor stochastice. În această lucrare s-a proiectat un lanț Markov care modelează producția şi care poate fi aplicat pentru identificarea timpilor de fabricație estimativi. În același timp, se descrie software-ul de calculator pe care s-a realizat procesarea datelor numerice practice din acest caz specific.

Cuvinte-cheie: fabricație textilă, procese stochastice, optimizarea timpilor

Time optimization of the textile manufacturing process using the stochastic processes

The existence of a certainly determined number of steps in the textile manufacturing process development makes adequate to approach the optimization of this process with stochastic procedures theory. In this paper we design a suitable Markov chain that shapes the production and we show how it can be applied for finding the estimate manufacturing times. At the same time, we describe the computer software that we made to process the practical numerical data from this specific case.

Keywords: textile manufacturing, stochastic processes, time optimization

INTRODUCTION

One of the current problems in the textile industry is to produce manufacturing articles with high quality in a definite time. For this purpose it is necessary to monitor and control the products and the equipment during the entire process. For example, Das offers a detailed description of the classical statistical procedures, like hypothesis testing or significance tests, which can be applied in the quality control [1]. Other authors, such as C.D. O'Donoghue and J.G. Prendergast, give some directions on optimization in production planning and scheduling by using the computerized maintenance management systems [2]. They are underlining the importance of the planning equipment maintenance which plays a decisive role in minimization of the production costs or of the production time. Hsu also investigate the scheduling yarn-dyed textile manufacturing problem [3]. They minimize the total delay of customer orders by a genetic algorithm solving a mixed integer programming problem which models a multi-stage production. On the other hand, a good manufacturing control of process time is required by the necessity of fulfilling the energy and utility management needs. Ngai et all. present a soft system methodology approach to design and develop an energy and utility management support system [4]. At the same time, Radulescu et all. consider that the nature of the fibers material can have an influence on the risk of dysfunctions appearance and so it is necessary to have a more careful quality control of the process [5–6]. Otherwise, there are in the specialized literature another approaches of the textile process optimization, these research apply the intelligent systems and fuzzy decision support theory to monitoring the time delivery in textile industry [7–9].

Our paper is concerning the manufacturing time control and offers a Markov chains approach which can be applied to minimize the business losses that result from customer dissatisfaction or delay penalties. In the next section we present some basic definitions and in Section 3 we design proper Markov chain to model the data from a specific textile process. At the same time we provide the significant subroutines that describe our computer software. The last section provides some further directions, conclusions which are useful in the design implementation.

NOTATIONS AND DEFINITIONS

The stochastic processes are mathematical procedures designed to model the practical processes that essentially depend on the time parameter [10–11].

For our case study we consider a Markov chain $\{M(t), t \in T\}$. If St_i, where $i = 1,n$, are the stages of the process, then $M(t) = St_i$ means that the stochastic process is in stage St_i at the moment t.

We denote the pass probabilities with p_{ij} and it is the conditioned probabilities:

$$p_{ij} = P(M(t+1) = St_j \mid M(t) = St_i)$$

Proposition 1. Let a Markov chain $\{M(t), t \in T\}$ with stages space $S = \{St_i\}$, $i = 1,n$ and $S = S' \cup S''$ where

S' is the absorbent stages set formed with stages St_i, which has $p_{ii} = 1$ and S'' is the unabsorbent stages set formed with the rest of the stages [12]. The average numbers of transitions to absorption corresponding to a start from stage i, denoted by τ_i, are solutions for the following equations system:

$$\tau_i = 1 + \sum_{j\in S'} p_{ij}\tau_j\,,\ i\in\ S'' \qquad (1)$$

and the probabilities that the process be absorbed in stage $j \in\ S'$ if it starts from stage $i \in\ S''$, denoted β_{ij} are solutions for the following equations system:

$$\beta_{ij} = p_{ij} + \sum_{k\in S''} p_{ik}\beta_{kj}\,,\ i\in\ S'' \qquad (2)$$

Observation (see [12]). If i is absorbent stage then $\tau_i = 0$, $\beta_{ii} = 1$ and $\beta_{ij} = 0$ for $j \neq i$.

THE STOCHASTIC PROCESS FOR TEXTILE MANUFACTURING TIME

Our considerations refer to a research concerning a sub-branch of textile industry, namely the knit-goods industry. For this purpose we worked with a set of real data from a Romanian factory. We observed a total number of knitwear products units of 1145 which pass the process phases. These products represent four assortments of knitwear goods (A_1,A_2,A_3,A_4). The manufacturing process involves a set of intermediary production steps or phases for which we design the following stochastic stages:

St_1: Acquisition of yarn-raw material. In the end of this stage it can be an amount of total or partial waste yarn. This one is replaced using a future transport and so the manufacturing process is delayed;

St_2: Knitting process. At the end of this stage the knit-goods pieces are obtained using a specialized program according with the customer ordered model;

St_3: Technical quality control. The knit-goods are subject of a quality control, a part of them pass in the next stage, another part are declared rejected and the rest must take again the knitting process;

St_4: Ironing;

St_5: Knit-goods manufacturing. This phase consists in assemblage of the knitting pieces made in the second phase;

St_6: Final ironing;

St_7: Final quality control. A part of goods pass in the next stage, a part are declared rejected, another part must take again the knit-goods manufacturing process (the 5th phase) and the rest must take again the 6th phase;

St_8: Labeling and packing;

St_9: Delivery;

St_{10}: Rejected;

St_{11}: Delivered.

For our statistical design the stages set is $S = \{1,2,3,...,11\}$, the absorbent stages set is $S' = \{10,11\}$ and the unabsorbent stages set is $S'' = \{1,2,3,...,9\}$. We denote the times for each intermediary phases with: $\theta_1,\theta_2,...,\theta_9$.

The data obtained from observing of the knitwear products evolution are presented in table 1 – table 4 which correspond respectively with St_1, St_3, St_7 and St_9. For the other stages all products pass in the next stage and continue the manufacturing process. In figure 1 we present data distribution for the units that pass in the next stage.

For our case study we estimate the stochastic pass probabilities with the relative frequencies π_{ij} which are computed in the following way:

π_{ij} = Number of units that pass from stage i to stage j / Number of units that reached stage i.

The computed values of these frequencies for stages St_1, St_3, St_7 and St_9 are presented in the last column from table 1 – table 4, for the other stages we have:

$$\pi_{2,3} = \pi_{4,5} = \pi_{5,6} = \pi_{6,7} = \pi_{8,9} = \pi_{10,10} = \pi_{11,11} = 1$$

Further on, we compute the average time of a product until it leaves the process as good or as rejected. For this purpose we first determine the average number of transitions to absorption corresponding to a start from stage 1,τ_1 and then using the phases times θ_i, $i = 1{,}9$ we compute the average time.

For the absorbent stages we have $\tau_{10} = \tau_{11} = 0$ and for the unabsorbent stages we use the relation 1 and solve the system with 9 equations:

$$\tau_i = 1 + \sum_{j\in\{1,2,...,9\}} \pi_{ij}\tau_j\,,\ i\in\ \{1,2,...,9\}$$

or

$$\tau_i = 1 + \pi_{i1}\tau_1 + \pi_{i2}\tau_2 + ... + \pi_{i9}\tau_9\,,\ i\in \{1,2,...,9\} \quad (3)$$

Using the data from table 1 – table 4 and a C++ software we find the following solutions for the system 3: $\tau_1 = 7.086$, $\tau_2 = 6.079$, $\tau_3 = 5.079$, $\tau_4 = 4.057$, $\tau_5 = 3.056$, $\tau_6 = 2.055$, $\tau_7 = 1.060$, $\tau_8 = 2.012$, $\tau_9 = 1.012$.

The numerical value which we fallow is τ_1, so we find that the average number of transitions to absorption for a product is 7.086. Taking into account that for a product the optimum process number of transitions is 9, meaning that the unit had crossed all the intermediary process phases without any stage repetition or rejection.

Concerning the manufacturing time T, we can calculate the time for a unit that cross the process as:

$$T = \theta_1 + \theta_2 + ... + \theta_7 + 0.086\times\theta_8$$

and this value can be compared with the ideal time for a unit that completes the process development.

$$T_{opt} = \sum_{i=1}^{9}\theta_i$$

On the other hand we establish the probability that a unit leaves the process as good. For this purpose we use the relation (2) to compute the probability for a unit which begins the process from the stage ST_1 and finishes as a good product.

Table 1

THE NUMBER OF PRODUCTS ASSORTMENTS THAT GO THROUGH STAGE I						
Assortments	**A1**	**A2**	**A3**	**A4**	**Total**	**Relative frequencies**
The units number that pass in the next stage	298	189	321	329	1137	$\pi_{12} = \frac{1137}{1145} = 0.993$
The units number that repeat the stage	2	0	1	5	8	$\pi_{11} = \frac{8}{1145} = 0.007$
The units number that continue the manufacturing process	300	189	322	334	**1145**	

Table 2

THE NUMBER OF PRODUCTS ASSORTMENTS THAT GO THROUGH STAGE III						
Assortments	**A1**	**A2**	**A3**	**A4**	**Total**	**Relative frequencies**
The units number that pass in the next stage	296	185	312	327	1120	$\pi_{34} = \frac{1120}{1145} = 0.978$
The units number that repeat the stage II	4	3	9	5	21	$\pi_{32} = \frac{21}{1145} = 0.018$
The units number that are declared rejected	0	1	1	2	4	$\pi_{3,10} = \frac{4}{1145} = 0.004$
The units number that continue the manufacturing process	300	188	321	332	**1141**	

Table 3

THE NUMBER OF PRODUCTS ASSORTMENTS THAT GO THROUGH STAGE VII						
Assortments	**A1**	**A2**	**A3**	**A4**	**Total**	**Relative frequencies**
The units number that pass in the next stage	293	184	311	324	1112	$\pi_{78} = \frac{1112}{1141} = 0.975$
The units number that repeat the stage V	4	2	8	4	18	$\pi_{75} = \frac{18}{1141} = 0.016$
The units number that repeat the stage VI	1	1	0	3	5	$\pi_{76} = \frac{5}{1141} = 0.004$
The units number that are declared rejected	2	1	2	1	6	$\pi_{7,10} = \frac{6}{1141} = 0.005$
The units number that continue the manufacturing process	298	187	319	331	**1135**	

Table 4

THE NUMBER OF PRODUCTS ASSORTMENTS THAT GO THROUGH STAGE IX						
Assortments	**A1**	**A2**	**A3**	**A4**	**Total**	**Relative frequencies**
The units number that pass in the next stage	298	187	319	317	1121	$\pi_{9,11} = \frac{1121}{1135} = 0.988$
The units number that repeat the stage	0	0	0	14	14	$\pi_{9,9} = \frac{14}{1135} = 0.012$
The units number that complete the process	298	187	319	331	**1135**	

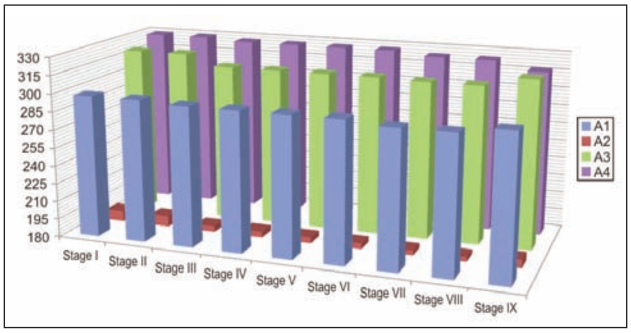

Fig. 1. The data distribution for the units that pass in the next stage

The searched probabilities are the solutions of the equations system:

$$\beta_{ij} = \pi_{ij} + \sum_{k\in\{1,2,...,9\}} \pi_{ik}\,\beta_{kj}\,,\; i\in\{1,2,...,9\}$$

or

$$\beta_{ij} = \pi_{ij} + \pi_{i1}\,\beta_{1j} + \pi_{i2}\,\beta_{2j} + ... + \pi_{i9}\,\beta_{9j}\,,\quad i\in\{1,2,...,9\} \tag{4}$$

We note that the probabilities β_{ij} = for i an absorbent stage, $i\in\{10,11\}$ are:

$$\beta_{10,10} = \beta_{11,11} = 1 \text{ and } \beta_{10,11} = \beta_{11,10} = 0.$$

Solving the system (4) with the data from table 1 – table 4 we obtained the following solutions:

$$\beta_{9,11} = 1,\ \beta_{8,11} = \beta_{9,11} = 1,\ \beta_{7,11} = 0.99,$$
$$\beta_{4,11} = \beta_{5,11} = \beta_{6,11} = \beta_{7,11} = 0.987,\ \beta_{3,11} = 0.985,$$
$$\beta_{2,11} = 0.984 \text{ and } \beta_{1,11} = 0.991.$$

The value of the probability that a unit of knit-good which starts the manufacturing process, finishes as a good product in other words, as delivered product, is 0.991.

The obtained results were calculated with C++ subroutines that we made for this case study. For example to calculate the average time to absorption we used: cout<<endl; for (i=1;i<=durata; i++) cout<<”-t[“<<i<<”]*tau[i]=”<<t[i]<<endl; where t defines the array that stores the stage times and τ the array for transitions average.

CONCLUSIONS AND FURTHER DIRECTIONS

As a conclusion, we can say that our manufacturing process analyzing method is more efficient than the classical method used in present for productivity study. In comparison with these, the use of Markov chain approach has the advantage to offer simultaneously a correct approximation of the manufacturing time by taking into account the replayed stages and emphasize the critical stages in which waste or remediable units can appear.

In the ideal situation in which all goods pass through the intermediary manufacturing phases, and thus any mistakes or rejects do not appear, we can determine the optimum total time for the integer process. This one represents the needful time for a product to pass through all the manufacturing stages and can be computed by adding the needful times that correspond to each phase of the manufacturing process.

Using our model the following can be determined:

- the real times because we take into account the situations when a product takes again certain phases;
- the comparison of the average times to absorption with the optimum manufacturing time leads to finding of the process yield;
- by analyzing the pass probabilities we can find the critical stages that must be careful watched or improved by increasing of the stage productivity (renewing the equipment, adjusting or employed training), stages that are representing steps remade.

Concerning the results interpretation of our study case we underlie that the value of the unit probability to finish the process as a good product is 0.991 that means that the manufacturing process has a big probability to give good products and the number of rejected units are small.

Despite of this result we cannot conclude that the process has an optimum development because the average number of transitions to absorption for a product is 7.086 and this value is really distant from the optimum time value of 9.

Optimal value (9) > Real value (7.086)

That situation shows two aspects:

- the rejected units can appear from the beginning of the process, in the 3rd stage;
- there is a relatively big amount of products which repeat certain stages and increase the manufacturing time.

Roughly speaking, a value of the average number of transitions to absorption that exceed the optimum value is according with a process with a small number of rejected units and very large number of units that repeat the intermediary stages. On the other side, a value that is far below the optimum value is according with a process with a large number of rejected units.

“What is the optimal proportion of rejections number and of units’ number with repeated phases in the process time value?” is our further research question. Knowing our model’s real time of production, the repeated stages and the rejected units at this moment we offer a tool to review the technological process. The extension of the model that we intend to do, to calculate the optimal report between the repeated stages and rejections will give a second tool to the production managers to prioritize the improvement of the technology stages. Furthermore, we are interested in the production costs optimization and in the supply improving using the proportion of rejections number and units number with repeated phases in the process time value.

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Textile manufacturers' decisions optimization using informational energy modeling

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REZUMAT – ABSTRACT

Optimizarea deciziilor producătorilor de textile utilizând modelarea energiei informaționale

În cadrul prezentului articol, autorii și-au propus să evidențieze modalitatea prin care deciziile referitoare la optimizarea producției și vânzărilor pentru un producător de textile pot fi fundamentate și cu ajutorul modelării energiei informaționale aplicabile comenzilor unor clienți interni și externi. Analizele statistice sunt fundamentate pe metoda drumului factorilor și metodei Onicescu, bazată pe conceptul energiei informaționale. Conceptul de energie informațională propune o viziune dinamică asupra fenomenelor din economie, putând fi adaptat cu succes la o multitudine de situații concrete referitoare la procesele de producție, distribuție și desfacere a produselor și serviciilor.
Deși concluziile preliminare demonstrează relevanța aplicării modelării energiei informaționale în domeniul industriei textile, considerăm că rezultatele obținute reprezintă doar un prim pas în optimizarea modelelor de predictibilitate a managementului comenzilor, în cazul producătorilor de textile.

Cuvinte-cheie: responsabilitate socială, atitudini, standarde, satisfacție în consum, motivații de consum, imagine corporativă

Textile manufacturers' decisions optimization using informational energy modeling

In the present article, authors have proposed to highlight the way in which the decisions referring to the production and sales optimization for a textile producer can be optimized also with the help of informational energy modeling, corresponding to information referring to internal and external customers' orders. The statistical analysis is grounded on the factorial path method and the Onicescu's method, based on the informational energy concept. The informational energy concept proposes a dynamic vision on phenomena from economy, being easily adapted to a multitude of concrete situations referring to production, distribution and sale processes for products and services.
Although the preliminary conclusions are showing the relevance for applying modeling of informational energy in the field of textile industry, we believe that the results are only a first step in optimizing orders management predictability patterns in the case of textile producers.

Keywords: social responsibility, attitudes, standards, consumer satisfaction, consumer motivations, corporate image

INTRODUCTION

The production, distribution and sales processes represent for any type of textile producer essential elements of its business strategy and constant effort to adapt to the dynamics of the market.

The managerial decisions optimization necessity that is referring to the management of these processes is also a constant of the management activity and the natural condition for achieving objectives on a long run. Within a modern business vision, production processes will correlate with those referring to sales or order management in the context of what specialists are calling – the supply chain. The concept of supply chain has known a tremendous development in the scientific literature and also at the level of economic practice in the last 25 years, different authors highlighting the characteristic of concept being related with series of activities or relationships among different partners (suppliers, manufacturers, distributors, retailers) that are dealing with planning, coordinating, controlling the transformation of raw materials into final products [2, 16, 17].

The complexity of markets and the consumers' trends impose as a tendency the fact that the future is reserved to competition between supply chain networks and not merely between organizations [4, 10]. At the same time in the majority of business fields supply chains have become more dispersed and dynamic, the members being separated geographically. Because the globalization influencing factors and mass customization tendency, many producers have developed built-to-order supply chains in order to become more flexible and responsive to the market. Thus, in order to achieve flexibility and responsiveness within their supply chain, many organizations have tried to develop strategic alliances based on core competencies and incorporation of information technology [7].

As product life cycle has accelerated environmental complexity and volatility has increased so the textile manufacturers have to develop the capacity of sales forecasting in order to predict the sufficient quantity to

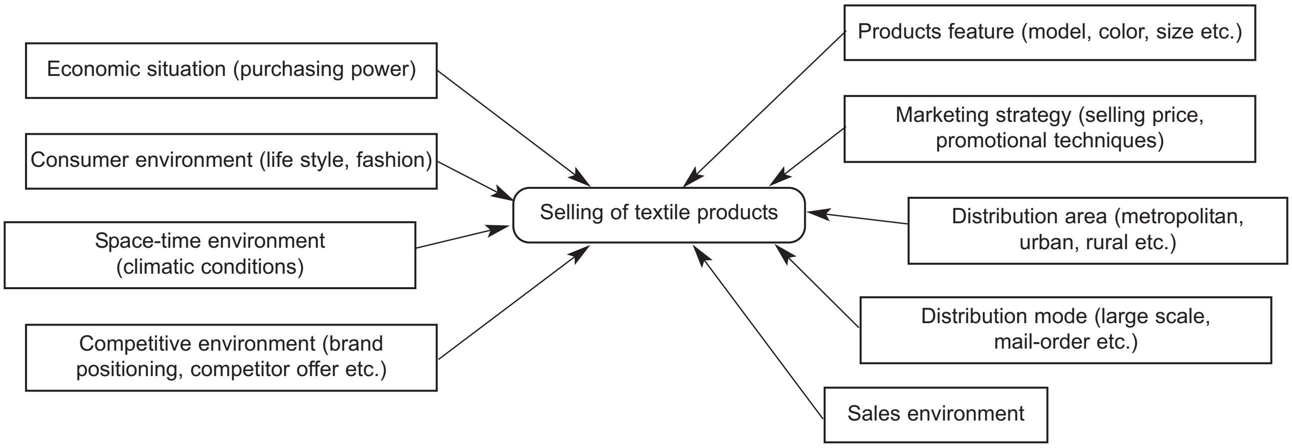

Fig. 1: Variables influencing the selling outcomes

Source: Thomassey, S., Happiette, M., & Castelain, J.M. (2002), An automatic textile sales forecasting using fuzzy treatment of explanatory variables, *Journal of Textile and Apparel, Technology and Management*, 2(4), p. 3

produce. Also it is true that the degree of optimization of the supply chain management is correlated with the forecast quality of the final product sales [6].

An optimized forecasting system in case of textile producers has the following characteristics:

– The capacity of reaction in case of variations of the market and new trends.
– The capacity to identify random events.
– Forecasting performance on short historic sales data.
– The capacity to integrate into the forecast the influence of explanatory variables [5].

At the level of the textile industry environment the events that can influence the forecasting process are not strictly controlled and identified. The textile products are too various and the global lead-time is too long in order to make assumptions about the production reactivity. At the same time, the textile markets in general are one of the most instable markets. There are a large amount of factors that can influence the selling process as we can see in the figure 1.

All these variables can be correlated with each other that make the effort to appreciate their effect harder.

In the context of textile industry, the life cycle of the products will be quite short and also the diversity of them. Taking into account also the fact that the profit margins are pretty low, the production based on small series and the creation of stocks having small amount of quantities does not represent a viable solution on a long run. Thus the textile producers have to be able to operate with a sufficient speed depending on the customers' requests [3].

Having the possibility to optimize decisions regarding the orders that have to be completed first and making the efforts to determine the costs of opportunity associated to these options becomes crucial for any textile producers.

If we consider the producers, its customers and their relationship as an informational system, the concept of informational energy can be of help in order to determine the quality and nature of relationship seen in this case from the perspective of orders and the selling effort.

The concept of informational energy was introduced by Onicescu in an attempt to define a finer measure of dispersion distribution than Shannon's information entropy. Onicescu proved that information entropy increases when informational energy decreases Sen (2011). A study developed by Pardo (1985) highlights the `information energy' provided by a fuzzy event, by integrating the statistical uncertainty resulting from the occurrence of events. In this context, the fuzzy event's functional information energy is similar to the Onicescu's information energy. According to Kent and Williams (1999), informational energy describes the uniformity or diversity of a system, process or phenomenon related to computer science, being more sensitive than Shannon's entropy to modification of a system. In a study developed in the field of social entropy Rizescu and Avram (2014) outlines that informational energy uses as source of data the normal statistical measurements in order to characterize the evolution of a society, an economy, a group of countries.

Thus the model of informational energy can be used to validate the evolution of a system and offers the certainty that the changes within the structure of relations within the system are valid.

RESEARCH METHODOLOGY AND RESULTS

Our research will analyse the distribution of a textile producer orders coming from domestic and foreign clients during the period 2008–2014, in order to determine the optimised future decisions regarding the management of orders and production.

The results of the data analysis will allow us to draw certain conclusions about the statistical validation of the tendencies encountered within the data set analysed.

Based on the data from the table 1, we could calculate the values of the manufacturer orders coming from domestic and foreign clients, in the period 2008–2014, and we can determine the evolution of

Table 1

THE DISTRIBUTION OF ORDERS' VALUES RECEIVED BY THE ANALYSED TEXTILE MANUFACTURER DURING THE PERIOD 2008–2014			
Years	Value of orders from domestic and foreign clients		
	Value of orders from domestic clients (thousands of euro)	Value of orders from foreign clients (thousands of euro)	Total (thousands of euro)
2008	43	1254	1297
2009	87	1496	1583
2010	167	1846	2013
2011	378	1933	2311
2012	598	2164	2762
2013	744	2380	3124
2014	900	2463	3363

Source: internal reports textile manufacturer

Table 2

THE SHARE OF ORDERS COMING FROM DOMESTIC AND FOREIGN CLIENTS AND ADJUSTED INFORMATIONAL ENERGY EVOLUTION BETWEEN 2008 AND 2014								
Years	Orders				f_1^2	f_2^2	Informational energy $E_i = \sum_{i=1}^{2} f_i^2$	Adjusted informational energy
	Orders from domestic clients (f_1)		Orders from foreign clients (f_2)					
		(%)		(%)				
2008	0,0332	3,32	0,9668	96,68	0,00110224	0,93470224	0,93580448	0,87160896
2009	0,0550	5,50	0,9450	94,50	0,00302500	0,89302500	0,89605000	0,79210000
2010	0,0830	8,30	0,9170	91,70	0,00688900	0,84088900	0,84777800	0,69555600
2011	0,1636	16,36	0,8364	83,64	0,02676496	0,69956496	0,72632992	0,45265984
2012	0,2165	21,65	0,7835	78,35	0,04687225	0,61387225	0,66074450	0,32148900
2013	0,2382	23,82	0,7618	76,18	0,05673924	0,58033924	0,63707848	0,27415696
2014	0,2676	26,76	0,7324	73,24	0,07160976	0,53640976	0,60801952	0,21603904

the informational energy, in the same time period, which is reflected in table 2.

Applying the Factors Path Method, our goal is to analyse the dynamics of the adjusted informational energy:

$$E_{iaj} = \frac{\sum_{i=1}^{2} f_i^2 - \frac{1}{2}}{1 - \frac{1}{2}} = 2 f_1^2 + 2 f_2^2 - 1$$

where:

E_{iaj} = adjusted informational energy;

f_1 = Orders from domestic clients;

f_2 = Orders from foreign clients.

If we assign $f_1 = x$ and $f_2 = y$, then the indicator concerning the adjusted informational energy will be based on the formula:

$$E_{iaj} = 2x^2 + 2y^2 - 1 = \varphi_{(x,y)}$$

Also, we will assign x_1 for the current year 2014 and with x_0 the basic year 2008.

In the case of geometrical decomposition for the dynamics of E_{iaj} indicator through "Factors Path Method", we will obtain the factorial indexes:

$$I_{1/0}^{\varphi(x/y)} = e^{\int_{(P_0 P_1)} \frac{\varphi'_{x(x,y)}}{\varphi_{(x,y)}} dx}$$

$$I_{1/0}^{\varphi(y/x)} = e^{\int_{(P_0 P_1)} \frac{\varphi'_{y(x,y)}}{\varphi_{(x,y)}} dy}$$

$$\varphi'_{x(x,y)} = 4x$$

$$\varphi'_{y(x,y)} = 4y$$

Then:

$$I_{1/0}^{\varphi(x/y)} = e^{\int_{(P_0 P_1)} \frac{4x}{2x^2 + 2y^2 - 1} dx}$$

$$I_{1/0}^{\varphi(y/x)} = e^{\int_{(P_0 P_1)} \frac{4y}{2x^2 + 2y^2 - 1} dy}$$

In order to calculate the factorial indexes, we must set the type of function reflected by the path from

Table 3

THE COEFFICIENT OF VARIATION IN CASE OF THE ADJUSTED LINEAR FUNCTION, IN THE ASSUMPTION OF THE LINEAR EVOLUTION OF ORDERS FROM DOMESTIC CLIENTS, IN THE PERIOD 2008–2014						
Years	**The weight of the orders from domestic clients (x_i)**	**Linear trend**				
		t_i	t_i^2	$t_i x_i$	$x_{t_i} = a + bt_i$	$\lvert x_i - x_{t_i} \rvert$
2008	0,0332	–3	9	–0,0996	0,022110713	0,0111
2009	0,0550	–2	4	–0,1100	0,065078570	0,0101
2010	0,0830	–1	1	–0,0830	0,108046428	0,0250
2011	0,1636	0	0	0	0,151014285	0,0126
2012	0,2165	1	1	0,2165	0,193982142	0,0225
2013	0,2382	2	4	0,4764	0,236949999	0,0012
2014	0,2676	3	9	0,8028	0,279917856	0,0123
TOTAL	1,0571	0	28	1,2031	1,057099993	0,0948

each factor, X, respectively Y, between P_0 and P_1. In this sense, if we apply the coefficients method in order to study the variation (a real method concerning the selection for the best trend model), we will consider the year from the middle of the series for each factor, as origin of calculation, while through the substitution $\sum_{i=-m}^{m} t_i = 0$, we will obtain the relevant parameters for the factors embedded in the study.

In the case of the X factor if we formulate the null hypothesis H_0^*: which mentions the assumption of a trend model related to X factor = *the weight of orders from domestic clients,* as being a linear function $x_{t_i} = a + b{\cdot}t_i$, then the parameters a and b for the adjusted linear function will be calculated through the system:

$$\begin{cases} n \cdot a = \sum_{i=-m}^{m} x_i \\ b \cdot \sum_{i=-m}^{m} t_i^2 = \sum_{i=-m}^{m} t_i \cdot x_i \end{cases}$$

Using the statistical data from table 3 in order to adjust the linear function, we will have the following values for the parameters a and b: a = 0,151 and b = 0,043.

The variation coefficient in case of the adjusted linear function will be:

$$v_I = \left[\frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{I} \rvert}{n} : \frac{\sum_{i=-m}^{m} x_i}{n} \right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{I} \rvert}{\sum_{i=-m}^{m} x_i} \cdot 100$$

$$\Rightarrow v_I = \frac{0{,}0948}{1{,}0571} \cdot 100 = 8{,}97\%$$

In the situation of the alternative hypothesis H_1^* which specifies the assumption of the existence for a trend model concerning X factor = *the weight of the orders from domestic clients,* as being the quadratic function – $x_{t_i} = a + b \cdot t_i + ct_i^2$, parameters a, b and c of the adjusted quadratic function will be determined through the system:

$$\begin{cases} n \cdot a + c \cdot \sum_{i=-m}^{m} t_i^2 = \sum_{i=-m}^{m} x_i \\ b \cdot \sum_{i=-m}^{m} t_i^2 = \sum_{i=-m}^{m} t_i \cdot x_i \\ a \cdot \sum_{i=-m}^{m} t_i^2 + c \cdot \sum_{i=-m}^{m} t_i^4 = \sum_{i=-m}^{m} t_i^2 \cdot x_i \end{cases}$$

Therefore, using the calculated data for the adjustment for the quadratic function, the parameters a, b and c will have following values: A = 0,1533, b = 0,0429, c = –0,0058

The coefficient of variation in case of the adjusted quadratic function will be calculated, based on the results highlighted within table 4:

$$v_{II} = \left[\frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{II} \rvert}{n} : \frac{\sum_{i=-m}^{m} x_i}{n} \right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{II} \rvert}{\sum_{i=-m}^{m} x_i} \cdot 100$$

$$\Rightarrow v_{II} = \frac{0{,}0956}{1{,}0571} \cdot 100 = 9{,}04\%$$

In the case of the alternative hypothesis H_2^*: which describes the assumption of a trend model of the X factor = *the weight of the orders from domestic clients as being the exponential function* $x_{t_i} = ab^{t_i}$, then the parameters a and b belonging to the adjusted exponential function will be determined through the system:

$$\begin{cases} n \cdot \lg a = \sum_{i=-m}^{m} \lg x_i \\ \lg b \cdot \sum_{i=-m}^{m} t_i^2 = \sum_{i=-m}^{m} t_i \cdot \lg x_i \end{cases}$$

Table 4

THE COEFFICIENT OF VARIATION IN THE CASE OF THE ADJUSTED QUADRATIC FUNCTION, IN THE HYPOTHESIS OF THE PARABOLIC EVOLUTION OF THE ORDERS FROM DOMESTIC CLIENTS IN THE PERIOD 2008–2014							
Years	**The weight of the orders from domestic clients (x_i)**	**Quadratic trend**					
		t_i	t_i^2	t_i^4	$t_i^2 x_i$	$x_{t_i} = a + bt_i + ct_i^2$	$\lvert x_i - x_{t_i} \rvert$
2008	0,0332	–3	9	81	0,2988	0,01920002	0,014
2009	0,0550	–2	4	16	0,2200	0,06507858	0,0101
2010	0,0830	–1	1	1	0,0830	0,10979286	0,0268
2011	0,1636	0	0	0	0	0,15234286	0,0113
2012	0,2165	1	1	1	0,2165	0,19472858	0,0218
2013	0,2382	2	4	16	0,9528	0,23595002	0,0022
2014	0,2676	3	9	81	2,4084	0,27700718	0,0094
TOTAL	1,0571	0	28	196	4,1795	1,05710010	0,0956

Table 5

THE COEFFICIENT OF VARIATION VALUE IN CASE OF THE EXPONENTIAL ADJUSTED FUNCTION, IN THE HYPOTHESIS OF THE EXPONENTIAL EVOLUTION OF THE STRUCTURE OF THE ORDERS FROM DOMESTIC CLIENTS DURING THE PERIOD 2008–2014						
Years	**The weight of the orders from domestic clients (x_i)**	**Exponential trend**				
		$\lg x_i$	$t_i \lg x_i$	$\lg x_{t_i} = \lg a + t_i \lg b$	$x_{t_i} = ab^{t_i}$	$\lvert x_i - x_{t_i} \rvert$
2008	0,0332	–1,478861916	4,436585749	–1,396027366	0,040176549	0,0070
2009	0,0550	–1,259637311	2,519274621	–1,238578009	0,057732716	0,0027
2010	0,0830	–1,080921908	1,080921908	–1,081128652	0,082960497	0,0000
2011	0,1636	–0,786216700	0,000000000	–0,923679295	0,119212200	0,0444
2012	0,2165	–0,664542099	–0,664542099	–0,766229938	0,171305009	0,0452
2013	0,2382	–0,623058242	–1,246116486	–0,608780581	0,246161097	0,0080
2014	0,2676	–0,572513890	–1,717541673	–0,451331224	0,353727460	0,0861
TOTAL	1,0571	–6,465755066	4,408582020			0,1934

Therefore, in case of the adjusted exponential function, the coefficient of variation is calculated based on the results highlighted within the table 5, and it will have the value:

$$v_{exp} = \left[\frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{exp} \rvert}{n} : \frac{\sum_{i=-m}^{m} x_i}{n} \right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} \lvert x_i - x_{t_i}^{exp} \rvert}{\sum_{i=-m}^{m} x_i} \cdot 100$$

$$\Rightarrow v_{exp} = \frac{0{,}1934}{1{,}0571} \cdot 100 = 18{,}29\%$$

We notice that:

$$v_I = 8{,}97\% < v_{II} = 9{,}04\% < v_{exp} = 18{,}29\%$$

Therefore, *the path followed by the X factor, implicitly the weight of orders from domestic clients, during the period 2008–2014, from P_0 to P_1, is a linear trend* having the form $x_{t_i} = a + b \cdot t_i$, with other words the null hypothesis H_0^* is confirmed.

The case of Y factor

In the situation where we formulate the null hypothesis H_0^{**}: according to which, it is presumed a trend model of the *Y* factor = the weight of the orders from foreign clients as being a linear function $y_{t_i} = a + b \cdot t_i$, then the parameters *a* and *b* of the adjusted linear function will be determined through the formula (30 and 31):

$$a = \frac{\sum_{i=-m}^{m} y_i}{n} \quad \text{and} \quad b = \frac{\sum_{i=-m}^{m} t_i \cdot y_i}{\sum_{i=-m}^{m} t_i^2}$$

Using the data from table 6, calculated in order to adjust the linear trend, we will obtain the following values for the parameters *a* and *b*: $a = 0{,}849$ and $b = –0{,}043$

So, the coefficient of variation in case if the adjusted linear function will be:

Table 6

THE COEFFICIENT OF VARIATION IN CASE OF THE ADJUSTED LINEAR FUNCTION, IN THE HYPOTHESIS OF THE LINEAR EVOLUTION OF THE ORDERS STRUCTURE FROM FOREIGN CLIENTS BETWEEN 2008 AND 2014						
Years	**The weight of the orders from foreign clients (y_i)**	**Linear trend**				
		t_i	t_i^2	$t_i y_i$	$y_{t_i} = a + bt_i$	$\lvert y_i - y_{t_i} \rvert$
2008	0,9668	–3	9	–2,9004	0,977889285	0,0111
2009	0,9450	–2	4	–1,8900	0,934921428	0,0101
2010	0,9170	–1	1	–0,9170	0,891953571	0,0250
2011	0,8364	0	0	0	0,848985714	0,0126
2012	0,7835	1	1	0,7835	0,806017857	0,0225
2013	0,7618	2	4	1,5236	0,763050000	0,0013
2014	0,7324	3	9	2,1972	0,720082143	0,0123
TOTAL	5,9429	0	28	–1,2031	5,942899998	0,0949

$$v_I = \left[\frac{\sum_{i=-m}^{m} |y_i - y_{t_i}^I|}{n} : \frac{\sum_{i=-m}^{m} y_i}{n} \right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} |y_i - y_{t_i}^I|}{\sum_{i=-m}^{m} y_i} \cdot 100 = \frac{0,0949}{5,9429} \cdot 100 = 1,60\%$$

If the alternative hypothesis H_1^{**} is formulated, it would presume the existence of the trend model of the Y factor = the weight of the orders from foreign clients as being the quadratic function $y_{ti} = a + b \cdot t_i + ct_i^2$, then the parameters a, b and c belonging to the adjusted quadratic function will be calculated through the formula:

$$a = \frac{\sum_{i=-m}^{m} t_i^4 \cdot \sum_{i=-m}^{m} y_i - \sum_{i=-m}^{m} t_i^2 \cdot \sum_{i=-m}^{m} t_i^2 \cdot y_i}{n \cdot \sum_{i=-m}^{m} t_i^4 - \left(\sum_{i=-m}^{m} t_i^2\right)^2}$$

$$b = \frac{\sum_{i=-m}^{m} t_i \cdot y_i}{\sum_{i=-m}^{m} t_i^2}, \quad c = \frac{n \cdot \sum_{i=-m}^{m} t_i^2 \cdot y_i - \sum_{i=-m}^{m} t_i^2 \cdot \sum_{i=-m}^{m} y_i}{n \cdot \sum_{i=-m}^{m} t_i^4 - \left(\sum_{i=-m}^{m} t_i^2\right)^2}$$

Using the statistical data determined in order to adjust the quadratic function, from the table 7, parameters a, b and c will have the values: a = 0,847; b = –0,043 and c = 0,001.

The coefficient of variation in case of the adjusted quadratic function will be:

$$v_{II} = \left[\frac{\sum_{i=-m}^{m} |y_i - y_{t_i}^{II}|}{n} : \frac{\sum_{i=-m}^{m} y_i}{n} \right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} |y_i - y_{t_i}^{II}|}{\sum_{i=-m}^{m} y_i} \cdot 100 = \frac{0,0927}{5,9429} \cdot 100 = 1,56\%$$

If we formulate the alternative hypothesis H_2^{**}: by which there is presumed the trend model of the factor Y as evolving as an exponential function $y_{ti} = ab^{t_i}$,

Table 7

THE COEFFICIENT OF VARIATION IN THE CASE OF THE ADJUSTED QUADRATIC FUNCTION, IN THE HYPOTHESIS OF THE PARABOLIC EVOLUTION OF THE ORDERS FROM FOREIGN CLIENTS BETWEEN 2008 AND 2014							
Years	**The weight of the orders from foreign clients (y_i)**	**Quadratic trend**					
		t_i	t_i^2	t_i^4	$t_i^2 y_i$	$y_{t_i} = a + bt_i + ct_i^2$	$\lvert y_i - y_{t_i} \rvert$
2008	0,9668	–3	9	81	8,7012	0,980800000	0,0140
2009	0,9450	–2	4	16	3,7800	0,934921428	0,0101
2010	0,9170	–1	1	1	0,9170	0,890207142	0,0268
2011	0,8364	0	0	0	0	0,846657142	0,0103
2012	0,7835	1	1	1	0,7835	0,804271428	0,0208
2013	0,7618	2	4	16	3,0472	0,763050000	0,0013
2014	0,7324	3	9	81	6,5916	0,722992858	0,0094
TOTAL	5,9429	0	28	196	23,8205	5,942899998	0,0927

Table 8

THE COEFFICIENT OF VARIATION IN CASE IF THE ADJUSTED EXPONENTIAL FUNCTION, IN THE HYPOTHESIS OF THE EXPONENTIAL EVOLUTION OF THE STRUCTURE OF THE ORDERS FROM FOREIGN CLIENTS BETWEEN 2008 AND 2014						
Years	**The weight of the orders from foreign clients (y_i)**	**Exponential trend**				
		lg y_i	**t_i lg y_i**	**lg y_{t_i} = lg a + t_i lg b**	**$y_{t_i} = ab^{t_i}$**	**$\mid y_i - y_{t_i}\mid$**
2008	0,9668	–0,0147	0,0440	–0,0073	0,9834	0,0166
2009	0,9450	–0,0246	0,0491	–0,0293	0,9347	0,0103
2010	0,9170	–0,0376	0,0376	–0,0514	0,8885	0,0285
2011	0,8364	–0,0776	0	–0,0734	0,8445	0,0081
2012	0,7835	–0,1060	–0,1060	–0,0954	0,8027	0,0192
2013	0,7618	–0,1182	–0,2363	–0,1175	0,7630	0,0012
2014	0,7324	–0,1353	–0,4058	–0,1395	0,7252	0,0072
TOTAL	5,9429	–0,5138	–0,6173	*	5,9420	0,0911

then the parameters a and b of the adjusted function, will be expressed by formula:

$$\lg a = \frac{\sum_{i=-m}^{m} \lg y_i}{n} \quad \text{and} \quad \lg b = \frac{\sum_{i=-m}^{m} t_i \cdot \lg y_i}{\sum_{i=-m}^{m} t_i^2}$$

Therefore, with the help of the quantified data in the situation of the adjusted exponential function, which is presented in the table 8, we will have: lg a = –0,073 and lg b = –0,022.

So, in case of the adjusted exponential function, the coefficient of variation will be:

$$v_{exp} = \left[\frac{\sum_{i=-m}^{m} \left| y_i - y_{t_i}^{exp} \right|}{n} : \frac{\sum_{i=-m}^{m} y_i}{n}\right] \cdot 100 =$$

$$= \frac{\sum_{i=-m}^{m} \left| y_i - y_{t_i}^{exp} \right|}{\sum_{i=-m}^{m} y_i} \cdot 100 = \frac{0,0911}{5,9429} \cdot 100 = 1,53\%$$

We can notice that:

$$v_{exp} = 1,53\% < v_{II} = 1,56\% < v_I = 1,60\%$$

In conclusion, the path followed by the Y factor, the weight of the orders from foreign clients from P_0 la P_1, is an exponential trend having the form $y_{ti} = ab^{t_i}$, in other words H_2^{**} is confirmed.

Data analysis

Because the X factor = the weight of the orders from domestic clients evolves according to a linear function, $x_{t_i} = A + B \cdot t_i$, then in the situation of the *geometrical decomposition* of the adjusted informational energy dynamics, in the period 2008–2014, the influences of the variation of the orders from domestic clients, respectively the orders from foreign clients reflect the conditions:

$$x(0) = A \quad \text{and}$$

$$x(1) = A + B = x(0) + B \Rightarrow B = x(1) - x(0) = \Delta_{1/0}^{x}$$

Thus we will obtain:

$$x = x(0) + \Delta_{1/0}^{x} \cdot t \Rightarrow \mathrm{d}x = \Delta_{1/0}^{x} \cdot \mathrm{d}t$$

Proving in the analogy mode, we will have:

$$y = y(0) + \Delta_{1/0}^{y} \cdot t \Rightarrow \mathrm{d}y = \Delta_{1/0}^{y} \cdot \mathrm{d}t$$

Taking into consideration that $x + y = 1$, we will have:

$$\int_{(P_0P_1)} \frac{4x}{2x^2 + 2y^2 - 1}\,\mathrm{d}x = \int_{x(0)} \frac{4x}{(2x-1)^2}\,\mathrm{d}x =$$

$$= 4\int_0^1 \frac{[x(0) + \Delta_{1/0}^{x} \cdot t] \cdot \Delta_{1/0}^{x}}{2[x(0) + 2\Delta_{1/0}^{x} \cdot t - 1]^2}\,\mathrm{d}t =$$

$$= 4\,x(0) \cdot \Delta_{1/0}^{x} \int_0^1 \frac{\mathrm{d}t}{[2\Delta_{1/0}^{x} \cdot t + 2x(0) - 1]^2} +$$

$$+ 4\,(\Delta_{1/0}^{x})^2 \int_0^1 \frac{t}{[2\Delta_{1/0}^{x} \cdot t + 2x(0) - 1]^2}\,\mathrm{d}t =$$

$$= 1.080340458 + (-0.697440877) = 0.382899581$$

The influence in relative dimensions of orders from domestic clients dynamics over the variation level of the variation of the adjusted informational level, in the case of textile manufacturer analysed, in 2014 compared with 2008, will be:

$$I_{1/0}^{\varphi(x/y)} = e^{\int_{(P_0P_1)} \frac{4x}{2x^2 + 2y^2 - 1}\mathrm{d}x} = e^{0.382899581} \cong$$

$$\cong 1.4665 \quad \text{or} \quad 146,65\%$$

Doing the requested calculations we will obtain the following result for the influence in relative dimensions of the structure modification of the orders from foreign clients in 2014 compared with 2008, in the particular case of the analysed textile manufacturer:

$$I_{1/0}^{\varphi(y/x)} = e^{\int_{(P_0P_1)} \frac{4x}{2x^2 + 2y^2 - 1}\mathrm{d}y} = e^{-1.777781338} \cong$$

$$\cong 0.1690 \quad \text{or} \quad 16,90\%$$

So, under the conditions where the path described by of the X factor = the weight orders from domestic clients follows a linear trend model and the way of the Y factor = the weight of orders from foreign clients follows an exponential trend model, the value of the adjusted informational energy value has increased by 46,65% under the influence of the structure modification for the weights of orders from domestic clients in the year 2014 compared with 2008, and as a result of the variation of the weights of orders from foreign clients, the level of the adjusted informational energy has decreased by 83,10, in the same time period.

The influence in absolute dimensions of the change of the structure of weights of orders from domestic clients over the dynamics of the adjusted informational energy, in the case of analyzed textile manufacturer, in 2014 compared to 2008, will be: $\Delta_{1/0}^{\varphi(x/y)} = \int_{(P_0P_1)} \varphi'_x \, dx = 4 \int_{(P_0P_1)} x \, dx$ and for the influence of the change of the structure of weights of orders from foreign clients over the dynamics of the adjusted informational energy will be: $\Delta_{1/0}^{\varphi(y/x)} = \int_{(P_0P_1)} \varphi'_y \, dy = 4 \int_{(P_0P_1)} y \, dy$.

Summarizing, because X factor and Y factor vary linearly, respectively exponentially, the influence in absolute dimensions of the change of *the weight orders from domestic clients* and the variation of *the weight orders from foreign clients* over the dynamics of the adjusted information energy in 2014 compared with 2008, there has been an increase by 0,141, respectively a decrease by – 0,797.

CONCLUSIONS

Analyzing the orders from domestic clients, respectively foreign clients, in the case of the textile manufacturer analyzed, in the period 2008–2014, we can observe that the adjusted informational energy values are decreasing.

The decreasing tendency of the adjusted informational energy levels automatically outlines the increase of the entropy, which reflects a negative reaction from economical point of view. The increase of the entropy within a given system – in this case production of textile products, involves the consumption of multiple resources and energy. The high levels of the entropy mean high level of internal disorder of the system of reference.

This fact appeared as a result of the bigger weights of the orders from domestic clients compared with the orders from foreign clients of the textile manufacturer.

The effects of the adjusted informational energy, reflected in this case study undertaken in a real context, consist of developing in-depth statistical analyses, which reflect both statistical data structure: the weights of orders from domestic clients and the weights of orders from foreign clients in the period 2008–2014, following in dynamics their levels, the influence of key factors upon them, as well as the interconnections between them.

The trend of the orders that has been validated with the help of informational energy analysis can be used as a starting point for the optimization of the orders management. This data should be correlated with the information from supplementary marketing qualitative research that is able to determine the factors that are influencing the orders not only from the perspective of organizational buyers (retailers) but also from the perspective of final consumers – buying motives, buying power etc.

The analyzed manufacturer has to implement the following sets of activities in order to optimize decisions regarding production and distribution:

– Analyzing the demand from domestic clients in terms of volume and structure of requested products for individual organizational clients.
– Determining the frequency of the orders and adjust the product stock accordingly for every major domestic client.
– Analyzing the individual profitability of the external clients in order to assess the future competitive advantages.
– Processing various sets of information in order to determine the production structure (individual product lines sales, fashion trends, etc.).
– Maintaining the costs for the distribution network on the national market and improving the order communication system with the domestic clients.

The demand management and forecasting represent a complex business process that in case of textile products can offer the possibility to achieve business goals in an efficient manner. The demand management process can be integrated in the sales and operations planning or the integrated business planning process at the level of the entire economic entity. Having a reliable statistical analysis upon a set of data like the one presented, allows the decisional factors to elaborate a customer demand planning process.

The process will involve assessing the information related to sales volume, the trends confirmed with the help of informational energy analysis with information related to the factors that can influence these outputs.

In the case of the textile products manufacturers similar to the one analyzed, the process of decisions optimization should involve:

- Organizing a reliable data collection system (external and internal sales reports, prediction or demand simulations from the retailers).
- Processing the data (data analysis, forecast, simulations).
- Adapting the production system to the output of the analysis (types and lines of products, stock management adjusted for the clients types etc.).
- Comparing the results with the objectives stated before and make necessary adjustments.
- Integrating the results as data for future analysis and next production stage decisional process.

The modeling of informational energy in the context of orders management offers a base for statistical reliability of the conclusions and can be useful to assist the complex decisions that are integrating all sorts of data, besides the statistical ones.

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