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Content

Obsah

ERGONOMICS IN CATIA 3D CAD SYSTEM AND ITS UTILIZATION IN CLOTHING INDUSTRY

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Abstract: *The aim of the article is to refer to a modern method of solving ergonomics using new 3D programs created for such purposes. The meaning is to encourage readers' interest in this issue and inspire them to deeper study, to think about the conditions people work within their professions. The main part of the paper is simulation and analysis of activities, positions and body postures that are performed in a workplace in the operation of sewing lateral seam of short trousers. Simulations of moves are divided into individual positions, in which the RULA Analysis is carried out. The meaning of the solution is to improve and adjust the workplace and working environment and to contribute to work performance increase and to satisfaction within the work executed and creation of conditions for development of a personality.*
Key words*: ergonomic design, ergonomic analysis, human builder, simulations of moves, RULA Analysis.*

1 INTRODUCTION

The importance of persons as creative employees, supervising or managing employees or persons who realize designed projects by their work is still growing. A person must have optimum conditions for work to be able to execute the activities at work as well as outside-employment more effectively. These questions are solved in the scientific field of ergonomics. Ergonomics is an important tool not only for increasing labour productivity but also for creating conditions for personal development.
With regard to history, there are many scientific fields and disciplines that look into humans and their work from various aspects. There are anthropometry, psychology, occupational physiology and sociology among the humanities. There are statistics, construction, standardization, management and cybernetics among technical sciences. Ergonomics comprehensively deals with activities of persons and their connections with machines and environment with the aim to optimize their mental and physical strain and ensure development of their personalities.
A machine is everything that persons use when creating values for use or satisfying needs. Environment surrounds persons, influences their activities. Optimizing of mental and physical strain can be understood as occupational well-being. Person is generally the weakest part of the person – machine – environment system and the task of ergonomics is to make technology as a priority with regard to abilities, capabilities and skills of persons and to respect their limitations in all the phases of development in occupational and non-occupational spheres, e.g. at home, while relaxing, performing sports, etc. [1].

2 APPLICATION OF 3D CAD PROGRAMS FOR THE SCIENTIFIC FIELD OF ERGONOMICS

Since 1960, there have been programs intended for ergonomic purposes. They are used to design and construct machines, arrange them in particular environment and to simulate the entire course of production. Simulation can be performed with virtual models and with risks assessment in the person – machine – environment system.

We can determine person's strain while performing certain activity in a particular workplace during the process of work. In Table 1, there are the main software producers and their products.
Dimensional projecting and correctly set working space are based in somatography. This discipline studies and analyzes working positions and moves by proportional relations of human body using the methods of graphic design depicting of human figure in technical or other documentation. It uses knowledge of human body anatomy, anthropometry and kinesiology. It becomes the basis for scientific study, analysis and determination of demands and functions of a working person with regard to the workplace and production equipment. Somatography works under three sizes of human body - small, medium and large, which determine the limits in the dimensions of the workplace [2].
In this paper, the software of CatiaV5 R19 - Delmia V5 Human module, which allows monitoring of physical capabilities of a virtual model at various work activities within the process of work, is used.

2.1 Ergonomic Design and Analysis Module

Catia (Computer - Graphics Aided Three - Dimensional Interactive Application) and ergonomic module of Human by Dassault Systemes is a 3D software, the main characteristic of which is the option of movement depiction of actions using simulation.
The Dassault Systemes Company offers several versions of Catia with applications for many activities and industrial sectors. Catia V5R19 software is formed of the following modules: **Infrastructure, Mechanical Design, Shape** and **Ergonomic Design and Analysis.**

Ergonomic Design and Analysis includes:
- Human Measurements Editor
- Human Activity Analysis
- Human Builder
- Human Posture Analysis.

Human Measurements Editor – allows definition of the virtual model – name, gender, nationality, height and proportions. It allows working with the entire body or with individual parts. The initial point can be the point of eye, left or right leg, etc. An example of a male virtual model and selected parts of the body that can be edited is in Figure 1. In case of a dimensional change of one part of the body, the other parts are proportionally changed too.

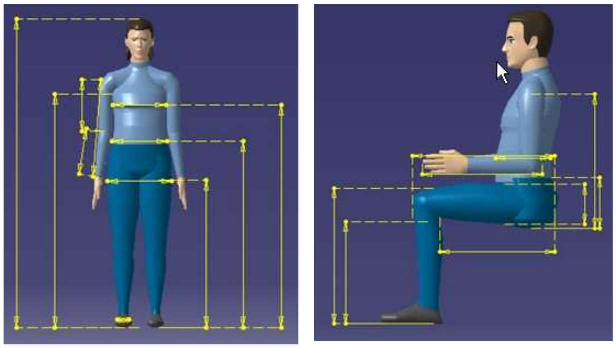


Figure 1 Virtual model and depiction of selected body parts for editing – standing and sitting model

Human Activity Analysis – allows to analyse and to assess performance of persons, their comfort and safety with regard to ergonomics during various activities:
- Rula (rapid upper limb assessment) analysis,
- Lift - lower analysis,
- Push - pull analysis,
- Carry analysis,
- Biomechanics single action analysis.

Table 1 Producers of 3D software for simulation

Country	Company	Program	Virtual model
France	Dassault Systems	Catia	Delmia V5 Human
USA	Siemens PLM Software	Tecnomatix Jack	Jack
Germany	Human Solution GmbH	Human Solution	Ramsis
USA	PTC	Pro/Engineer	Manikin Lite

Human Builder – the module allows moves of virtual model, i.e. moves of limbs, hands including fingers, legs, shoulders and head to sides, up and down and their rotations. We can set lighting of the model and depict model's visual field.

Human Posture Analysis – the module analyses positions and postures of the body for the purpose of ensuring person's comfort while working. It is used to find out human strain in various positions during a work task.

Results of the analyses allow defining criteria requested for given task such as duration and frequency of the researched activity or distance for carrying a load. The analyses request determination of model's initial and final positions or they work with current position of model's body. Results of the analyses are assessed in real time and in a change of person's position. Resulting score is analysed in the RULA Analysis [3].

2.2 Analyses of the Human Builder Module on a virtual model

An important factor for correct ergonomics is awareness of human body mobility. Mobility is capability of performing the move in full range of joint. Normal mobility is determined by physiological range of joints, function of muscles and muscle groups. The degrees of latitude for body moves used in Catia are: Flexion, Extension, Rotation, Lateral Flexion, Elevation, Depression, Abduction, Adduction, Pronation, Supination.

The Human Builder Module allows editing the moves of head, trunk and limbs, including fingers, with depiction of angles of possible ranges of motion and current degree of move angle in certain moment. The following body parts are intended for editing: ARM, CLAVICLE, FOOT, FOREARM, FULL SPINE, HEAD, LEG, LUMBAR, THIGH, THORAX, TOES, HAND, THUMB 1, THUMB 2, THUMB 3, FOREFINGER INDEX 1, 2, 3; MIDDLE FINGER 1, 2, 3, ANNULAR 1, 2, 3, AURICULAR 1, 2, 3 [3].

3 SIMULATION OF THE MOVES OF SELECTED TECHNOLOGICAL OPERATION IN THE PROCESS OF SEWING IN THE CATIA PROGRAM

Application of the methods of scientific analysis, organization and management of labour is important for development of mechanization in the sphere of sewing machines. Based on these methods, each activity needs to be broken down into smaller details first and their importance, performance economy, effectiveness and correctness of sequence need to be assessed. Then individual moves are made easier and shorter, needless moves are excluded, less effective moves replaced with more effective ones, moves are put into the best sequence and entire operation is set.

The thesis solves **simulation of the work operation of sewing lateral seam of short trousers**. The operation consists of three groups of tasks:

- Preparatory works before sewing,
- Sewing,
- Final works after sewing [4].

To execute the analysis and simulation of virtual model's moves and tasks in the process of work the workplace was created in the Autodesk Inventor Professional 2011 and imported to Catia CAD program. It includes the basic industrial sewing machine and chair with backrest - Figure 2. Moves based in MTM (Method Time Measurement) are simulated together with the virtual model.

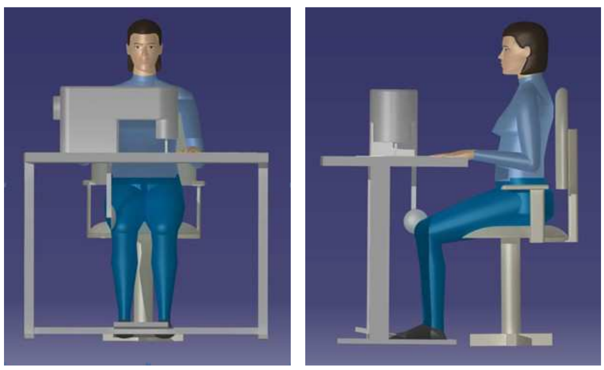


Figure 2 Basic position of the model sitting by the sewing machine – front view and in profile

Simulation of moves on the work operation of sewing the lateral seam of short trousers includes 10 work positions in total [5].

Position 1: Basic position by the sewing machine
Position 2: Rotating trunk and head towards the parts
Position 3: Transferring the parts
Position 4: Placing foot on pedal and lifting the presser foot bar
Position 5: Inserting the part under the presser foot bar
Position 6: Depressing the machine pedal
Position 7: Sewing the parts together
Position 8: Lifting the presser foot bar, removing the parts and lowering the foot
Position 9: Grasping the parts and checking their sewing
Position 10: Transferring the parts to drop space.

Ergonomic intensity is assessed using the RULA Analysis. RULA Analysis of all positions applies to the left and right sides of the body separately. If a person stays in a position for more than 4 seconds, it would be a static position. The analysis score has the basic and extended regimes of depiction. The basic regime depicts resulting numerical score – Table 2. Colour-coding of the necessity of implemented changes is in Table 3 [6].

Table 2 Categories of ergonomic intensity of position in the Catia Program

Segment	Score range	Colour assigned to numerical score					
		1	2	3	4	5	6
Arm	1 – 6						
Forearm	1 – 3						
Wrist	1 – 4						
Wrist rotation	1 – 2						
Neck	1 – 6						
Trunk	1 – 6						

Table 3 Colour-coding of implemented changes

	Changes are not needed.
	Changes should be requested.
	Carry out changes without delay.
	Carry out changes immediately.

In the extended regime of depiction, there are also the results of running score where individual parameters can be changed as needed. Parameters can be changed in arm, forearm, wrist, wrist rotation, neck and trunk. The result of the analysis is then adjusted according to new values [6].
Example of the assessment of the left and right body sides using the RULA Analysis for position 1 is in Figure 3.

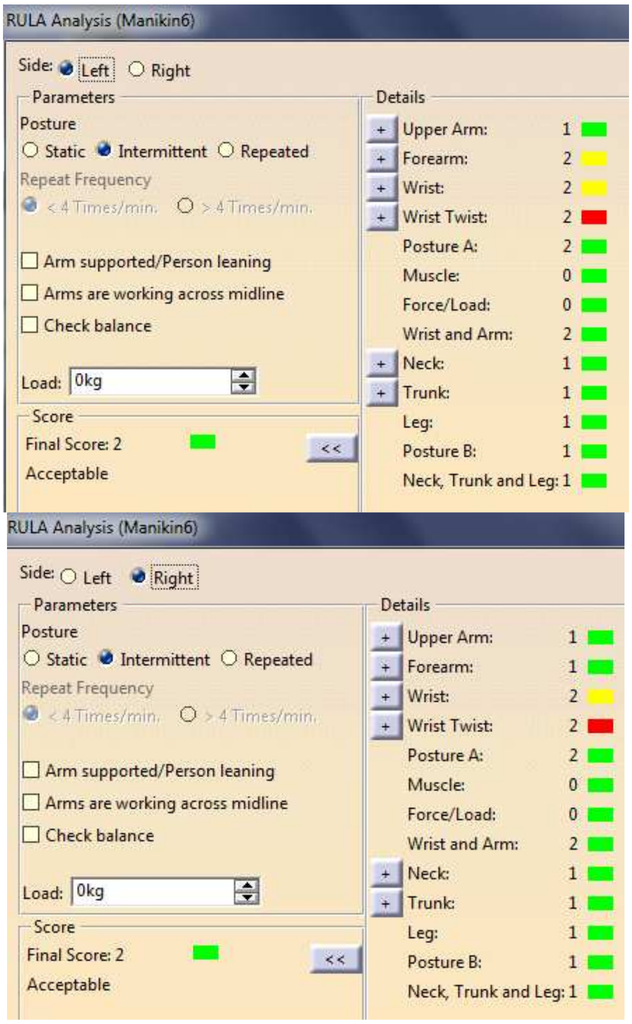


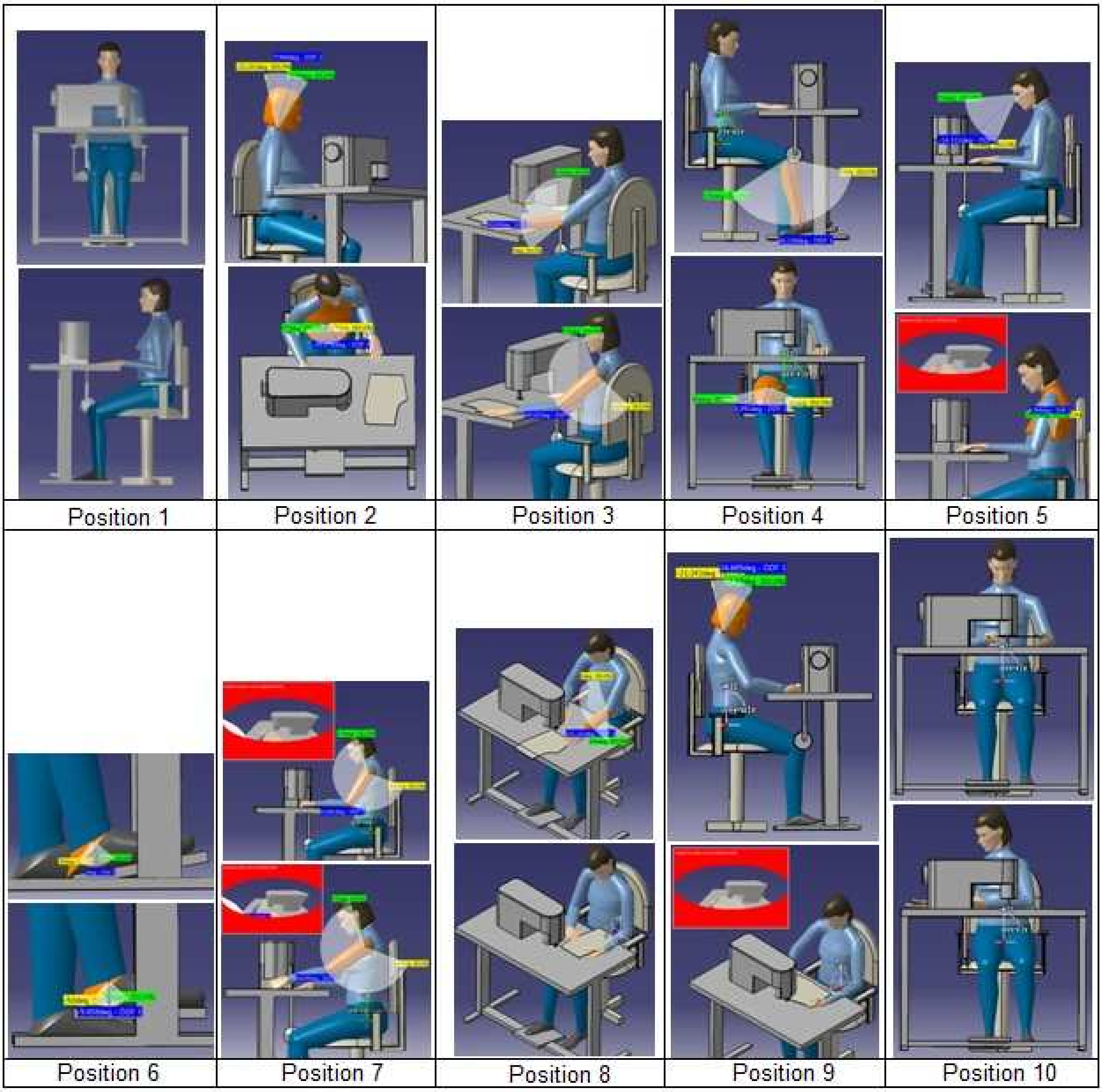
Figure 3 RULA Analysis for position 1 – for the left and right body parts [6]

3.1 Simulation of the positions of the work operation of sewing lateral seam of short trousers

Studying ergonomics in the Human Builder Module, **green angle line depicts** the maximum move in positive direction, **yellow** maximum move in negative direction, **blue**

line defines current angle degree of the move in given moment.
Setting the view allows selecting the right or left eye view or both eyes view. The size of the current view window is adjustable and the user can monitor model's field of vision during all the simulation. Monitoring ergonomics in the Human Builder Module is monitoring by both eyes. We can monitor the right and left body sides too.
Simulations of all ten positions are depicted in Table 4 [5].

Table 4 Depiction of monitored positions in the work operation of sewing lateral seam of short trousers



3.2 The RULA Analysis of the positions of work operation of sewing lateral seam of short trousers

The method monitors the risks of arms, forearms, wrists, neck, trunk and legs. The method is useful for frequently repeating, i.e. routine work. It is based on monitoring of several work cycles, from which a work task or posture that is decisive at strain is chosen.

Points are assigned to individual positions of the body, type of work and strain. The assessment includes also the power that considers power and strain spent while working.

Results of the RULA Analysis monitored in the above mentioned positions of the work operation in the left body side are in Table 5 and in the right body side in Table 6 [5].

Table 5 Results of the RULA Analysis for the left body side

	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Position 7	Position 8	Position 9	Position 10
Upper Arm:	1	1	3	2	2	2	3	3	3	3
Forearm:	2	2	2	1	1	2	2	1	3	2
Wrist:	2	2	2	2	2	2	2	3	3	3
Wrist Twist:	2	2	2	2	2	2	2	1	1	1
Posture A:	2	2	4	3	3	3	4	4	4	4
Muscle:	0	0	0	0	0	0	0	0	0	0
Force/Load:	0	0	0	0	0	0	0	0	0	0
Wrist and Arm:	2	2	4	3	3	3	4	4	4	4
Neck:	1	1	1	1	2	2	2	2	2	2
Trunk:	1	2	2	1	2	2	2	2	1	2
Leg:	1	1	1	1	1	1	1	1	1	1
Posture B:	1	2	2	1	2	2	2	2	2	2
Neck, Trunk and Leg:	1	2	2	1	2	2	2	2	2	2

Table 6 Results of the RULA Analysis for the right body side

	Position 1	Position 2	Position 3	Position 4	Position 5	Position 6	Position 7	Position 8	Position 9	Position 10
Upper Arm:	1	3	1	2	2	2	2	2	3	2
Forearm:	1	2	1	1	2	2	2	2	2	1
Wrist:	2	2	2	3	3	3	3	3	3	2
Wrist Twist:	2	2	2	1	1	1	1	2	1	1
Posture A:	2	4	2	3	3	3	3	4	4	3
Muscle:	0	0	0	0	0	0	0	0	0	0
Force/Load:	0	0	0	0	0	0	0	0	0	0
Wrist and Arm:	2	4	2	3	3	3	3	4	4	3
Neck:	1	1	1	1	2	2	2	2	2	2
Trunk:	1	2	2	1	2	2	2	2	1	2
Leg:	1	1	1	1	1	1	1	1	1	1
Posture B:	1	2	2	1	2	2	2	2	2	2
Neck, Trunk and Leg:	1	2	2	1	2	2	2	2	2	2

4 RESULTS AND DISCUSSION

With regard to ergonomics, there is always the demand for the strain of the body and its parts to be as minimal as possible with the aim to decrease the risk of locomotor system damages and to achieve higher labour productivity. Overall overview of the locomotor system and results of the analysis of work operation are in Table 7.

Table 7 Assessment of the RULA Analysis of the work operation of sewing lateral seam of short trousers for left and right body sides

Posture	1		2		3		4		5		6		7		8		9		10	
Details	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**
Upper Arm	1	1	1	3	3	1	2	2	2	2	2	2	3	2	3	2	3	3	3	2
Forearm	2	1	2	2	2	1	1	1	1	2	2	2	2	2	1	2	3	2	2	1
Wrist	2	2	2	2	2	2	2	3	2	3	2	3	2	3	3	3	3	3	3	2
Wrist Twist	2	2	2	2	2	2	2	1	2	1	2	1	2	1	1	2	1	1	1	1
Posture A	2	2	2	4	4	2	3	3	3	3	3	3	4	3	4	4	4	4	4	3
Wrist and Arm	2	2	2	4	4	2	3	3	3	3	3	3	4	3	4	4	4	4	4	3
Neck	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
Trunk	1	1	2	2	2	2	1	1	2	2	2	2	2	2	2	2	1	1	2	2

The resulting score with colour-coded assessment will refer to critical strain of the human body part that needs to be solved immediately or within a short period of time.

Results of the RULA Analysis showed that while carrying out the work operation the persons strain their wrists most and subsequently, when handling material, wrist rotation comes. In upper arm and forearm as well as in posture A and wrist and arm changes of the position should be requested.

The result of the experiment says that it is still necessary to be concerned with correct move of hand and other body parts so that more positive analysis assessment is achieved as soon as possible.

5 CONCLUSION

3D ergonomic program module for design and analysis is a comprehensive system with wide applications. The main characteristic of the module is the option of movement depiction of actions using simulation. It provides a chance for analysis of activities, positions and body posture, moves of head, shoulder, arm, forearm, wrist, hand, including fingers, trunk, thigh, calf, foot, including toes, and moves of person's eyes while working and for assessment of their strain using the RULA Method.

Within the scope of this article, there is an example of solving one workplace created in 3D, which is on the work operation of sewing lateral seam of short trousers using a sewing machine. However, there are many work operations in production of trousers. All operations need to be analysed this way in the product at each workplace and simulation of entire workshop needs to be created; this can be a subject of future solutions and research.

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ERGONOMIE V 3D CAD SYSTÉMU CATIA A JEJÍ VYUŽITÍ V ODĚVNÍM OBORU

Translation of the article

Ergonomics in Catia 3D CAD system and its utilization in clothing industry

Cílem tohoto článku je poukázat na moderní způsob řešení ergonomie využitím nových 3D programů k těmto účelům vytvořených. Smyslem je podnítit zájem čtenáře o tuto problematiku a inspirovat jej k hlubšímu studiu, k zamyšlení, v jakých podmínkách člověk v rámci profese pracuje. Hlavní částí práce je simulace a analýza činností, pozic a držení těla, které jsou provedeny na pracovním místě u operace sešití bočního švu krátkých kalhot. Simulace pohybu jsou rozděleny na jednotlivé pozice a je u nich provedena analýza RULA. Smyslem řešení je zlepšit a upravit pracoviště a pracovní prostředí a přispět ke zvýšení výkonnosti, ale i spokojenosti v rámci vykonávané práce a vytváření podmínek pro rozvoj osobnosti.

PREDICTION OF SIDE EMITTING OPTICAL FIBERS ILLUMINATION LENGTH

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Abstract: *In the side emitting plastic optical fibres (SEPOF) the light leaks out from their surface. The main aim of this contribution is evaluation of SEPOF loss of illumination intensity in dependence on the distance from light source and prediction of real illumination length. The special device for measurement of light intensity on surface and cross section at various distances from light source is used. The dependence of light intensity on the distance from light source is expressed by the linear piecewise function (LLF2 model) composed from two straight line parts with attenuation factor as the rate parameter. The influence of the SEPOF diameter on the real illumination length is quantified.*
Key words: *polymeric optical fibers***,** *side emission, illumination length, light attenuation.*

1 INTRODUCTION

Standard polymer optical fibre (POF) is a dielectric waveguide transferring light or infrared radiation across its axis by the mechanism of total internal reflection on the interface of two materials with different refractive indices [1]. When transmitting light rays are passing through optical fiber, attenuation occurs [1]. It mainly depends on light wavelength, fiber type, fiber structure (i.e. crystallinity and orientation, impurities and dopants, the distance from the source, and also on the outer geometric shape (micro-bends, macro-bends, surface damage). The main requirement for classical POF is to prevent side emission causing loss of transferred light. In the side emitting plastic optical fibres (SEPOF) the light leaks out from their surface. Side emission occurs if the light incidence angle is smaller than critical angle. This effect can be obtained by the increasing of cladding refractive index, decreasing of core refractive index or by the change of incident light angle. It is also possible to use multiple micro-bending of core or cladding; additives causing reflection or fluorescence into core/cladding or to create geometric asymmetry in the core/cladding system [2]. Attenuation as relative decrease of illumination intensity is for standard end emitting optical fibers undesirable. For side-emitting optical fibers is attenuation necessary and mean attenuation rate should ideally be constant [2]. The real illumination length of side emitting optical fibers is defined as distance from light source at which prescribed attenuation or light intensity occurs. The SEPOF can be used for creation of optically active textile structures providing opportunities to highlight people and objects without the need for external light exposure. Due to the transmission loss, the intensity of radiation emitted in any direction decays along the straight fibre axis as a function of distance from the light source [4].
The main aim of this contribution is evaluation of SEPOF loss of illumination intensity in dependence on the distance from light source. The dependence of light intensity on the distance from light source is expressed by the linear piecewise function. The influence of the SEPOF diameter on the mean attenuation rate is quantified.

2 CHARACTERIZATION OF POF ATTENUATION

Due to the transmission loss, the power of radiation emitted in any direction decays exponentially along the fiber axis with increasing distance from the light source of the fiber as observed by Zajkowski [3], while the percentage of light emitted per unit length is uniform over the entire fiber length. The simple model for prediction of this attenuation is proposed.

The attenuation coefficient α [dB] is in fact equal to logarithm of ratio between two powers two powers on the input P_1 and on the output P_2

$$\alpha = 10 \ \log(P_1 / P_2) \tag{1}$$

The Eq. (1) implies that a change in power ratio by one order is corresponding to attenuation change of 10 dB. The mean attenuation rate α_L is defined as the ratio of attenuation coefficient and the distance L between measuring powers P_1 a P_2.

$$\alpha_L = \alpha / L = \frac{10}{L} \ log \ (P_1 / P_2) \tag{2}$$

The unit of the mean attenuation rate is dB per unit length. The mean attenuation rate α_L is ideally constant, but generally may be a nonlinear function of the length L. Theoretical illumination intensity for straight optical fiber is decreasing with increasing distance from source L and can be calculated by rearrangement of Eq. (1) into form [4]:

$$P_2 = P_1 \ 10^{-\alpha_L \ L/10} \tag{3}$$

The real illumination length L_p is the length of the side-emitting optical fiber, in which it can be realistically used. At the end of this length is illuminated power P_{Lp} still sufficient. For the purposes of this work were selected attenuation α_p = 20 and 30 dB. The real illumination length of the optical fiber can be calculated from Eq. (4).

$$L_p = \frac{10}{\alpha_p} \log(P_1 / P_{Lp}) \tag{4}$$

It was found that simple exponential model (3) is practically not able to properly fit the experimental data. The simplest way is to replace decay curve *P(L)* by linear spline i.e. by so called LLF2 model. It is linear piecewise function consist from two different sections created by straight lines. This model is based on the assumption that in short distances from light source there are some no uniformity in side emission due to accommodation to aperture and critical angle. In second phase the illumination intensity is slowly decreasing with distance from source L (system is accommodated). Local slopes of LLF2 are in fact sensitivity coefficients a_1, a_2. Corrected illumination intensity on the fiber input is $P_c(0)$. LLF2 model is described by equation:

$$P(L) = P_c(0) + a_1 L + a_2 (L - L_c)_+ \tag{5}$$

where function $(x)_+$ = 0 if x is negative and if x is positive, function $(x)_+$ = x. The L_c is transition distance between first and second phase. The real illumination length Lp is for LLF2 model derived from Eq. (6)

$$L_p = \frac{\left(10^{(-\alpha_p/10)} - 1\right) + a_1 \ L_c \ / \ P_c(0)}{a_1 \ / \ P_c(0) + a_2 \ / \ P_c(0)} \tag{6}$$

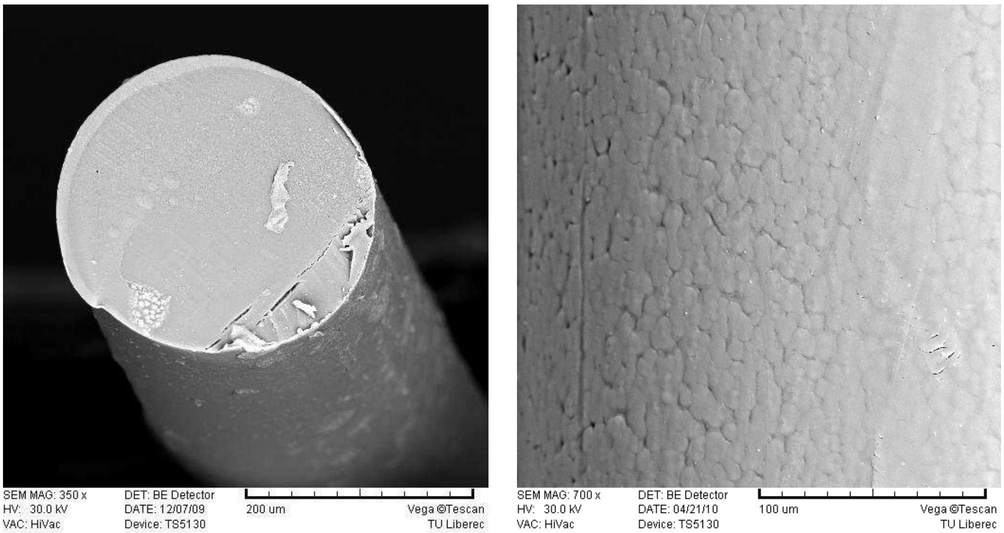
3 EXPERIMENTAL PART

Polymeric side emitting optical fibers “Grace” (produced by company Grace POF Co., Ltd. China) with different diameter were used for measurement of illuminating intensity in straight and bent states (Table 1). Surface of “Grace” fiber and its cross-section is shown in Figure 1.

The POF end connected with light energy source was prepared by heated wire cutting and then by polishing with diamond powder. Illumination system with light emitting diode (LED) was created and used as light source for side emitting optical fibers. Illumination intensity of source was 43.9 W.m^{-2}.

Table 1 Optical fiber specification

core/cladding	PMMA/ polycarbonate
core/cladding refractive index	1.49 / 1.41
numeric aperture/ maximal input angle	0.48 / 57.4º
mass density/ tensile strength	1190 kg.m^{-3} / 78 MPa
wave length/ temperature of use	400-900 nm / 20-70°C
POF diameter [mm]	0.2, 0.3, 1, 1.2



a) cross-section b) surface

Figure 1 Polymeric side emitting optical fiber “Grace”

For measurement of illumination intensity of these fibers the special devices was constructed. This on line measurement device for measurement of intensity illumination changes along straight fiber is shown in Figure 2. Device is composed from light sensor, step driver, control unit, measuring channel and input/ output rolls.

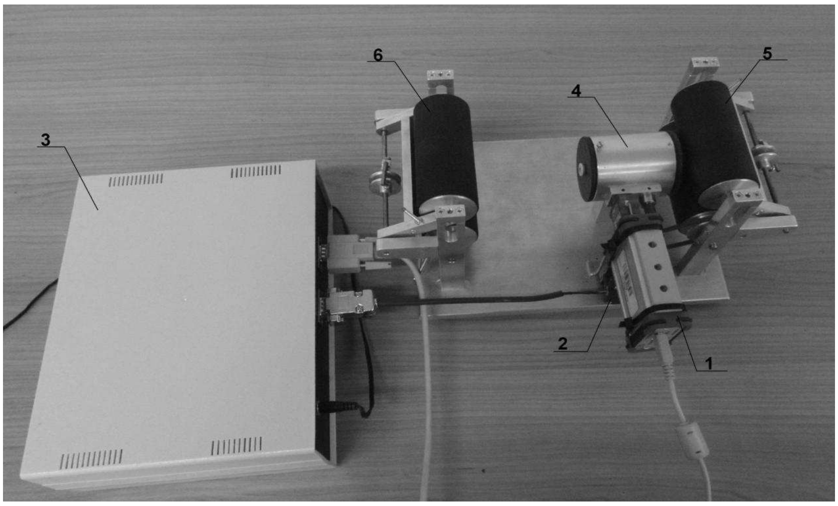


Figure 2 On-line device for measurement of illumination intensity in straight state
1 - light sensor, 2 - step driver, 3 - control unit, 4 - measuring channel, 5 - output rolls, 6 - input rolls

4 RESULTS AND DISCUSSION

Mean value of illumination intensity and 95% confidence interval based on twenty repetition of measurement on polymeric optical fiber „Grace“ with diameter 0.25 mm was calculated by using of statistics for small samples [5]. The mean values as function of distance from source are in Figure 3.

Theoretical illumination intensity can be calculated by rearrangement of Eq. (3) into form

$$P(L) = P(0)\,10^{-\alpha_L\,L/10} \qquad (7)$$

where $P(L)$ is mean value of illumination intensity at the distance from source L, $P(0)$ is mean illumination intensity on the fiber input and α_L is mean attenuation rate. The least square method was used for estimation of model parameters.

The experimental variances were used as weights in regression analysis.

The model curve is shown in Figure 2 as grey curve. The relative bad fit is clearly visible. Black piecewise solid line in Figure 2 is so called LLF2 model given by Eq. (5). By using of special linear regression [3] the following parameters of LLF2 were found:

- Input intensity $P_c(0) = 9\ 10^{-12}$ [W.mm^{-2}]
- First straight line slope $a_1 = -1.64\ 10^{-14}$ [W.mm^{-2}]
- Second straight line slope $a_2 = 1.44\ 10^{-14}$ [W.mm^{-2}]
- Distance $L_c = 359.9$ [mm]

The real illumination lengths of the optical fiber calculated from Eq. (6) as function of attenuation α_p are shown in Figure 4.

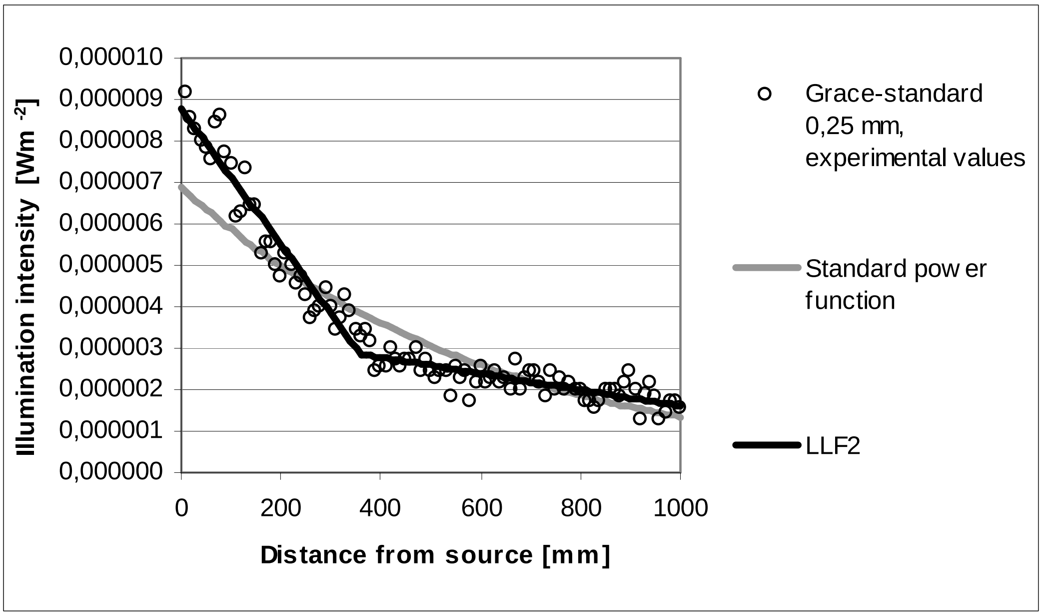


Figure 3 Illumination intensity as function of distance from source

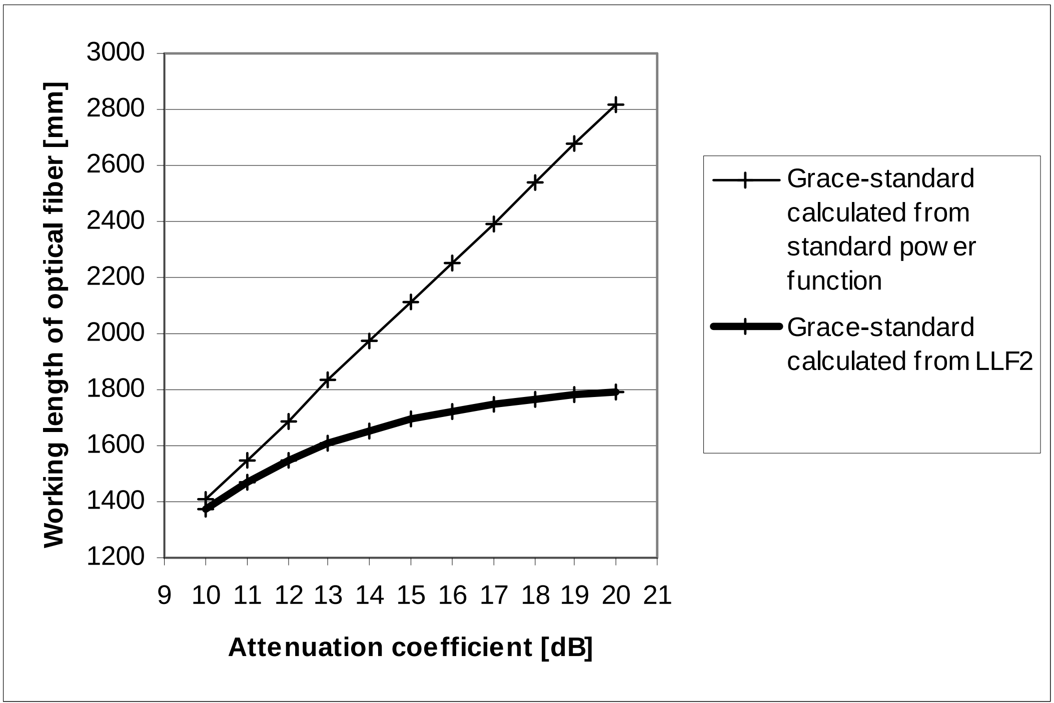


Figure 4 Real illumination length of optical fiber calculated for attenuation from 10 to 20 dB

5 CONCLUSION

It was found that dependence of illumination intensity on distance from source L is not well described by simple power model (7) with constant mean attenuation rate α_L, see Figure 2. It is suitable to divide this dependence to two phases, first represents no uniformity in side emission due to accommodation to aperture and critical angle and second with slow decline of mean attenuation rate i.e. LLF2 model.

By using of LLF2 is possible calculated distance of transition L_c between first and second phase. From LLF2 it is simple to calculate real illumination length L_p of side emitting optical fiber.

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FLEX FATIGUE OF PET/PEN FIBERS

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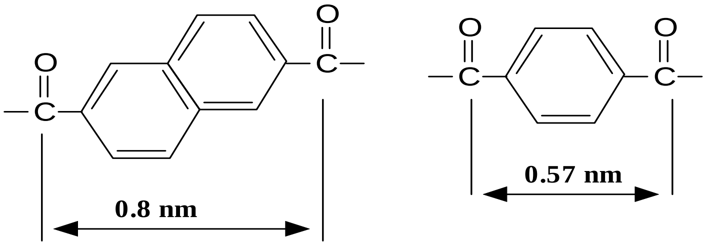
Abstract: *PEN fibers are well known for their high performance properties, resistance and good tensile properties. Their potential markets are packaging, films and fibers. Especially for tire yarns the response to cyclic dynamical deformation is interesting. Blends of PET and PEN have been attracting increasing interest because they combine the superior properties of PEN with the economy of PET. Mixture of these polyesters form due to transesterification during melts processing random copolymers. The glass transition temperature of PET/PEN increases linearly with volume fraction of PEN. It is therefore possible to control properties connected with T_g by including of PEN to PET. The addition of PEN improves gas barrier properties as well. The main aim of this contribution is measurement and characterization of flex fatigue behavior of PET/PEN fibers. These characteristics are obtained at constant pre-straining. The analysis is based on distribution of flex fatigue life (in cycles). The exploratory data analyses tools are used for data treatment and comparison.*
Key words: *Co polyesters, flex fatigue life, Weibull distribution, exploratory data analysis.*

1 INTRODUCTION

The polyethylene 2,6 naphtalate (PEN) is relatively new polyester having rigid naphthalene ring in its backbone on the market. This polyester exhibit higher glass transition T_g (about 123℃), higher crystallization temperature (194℃) and higher melting point (270℃) than PET. The elastic modulus of crystalline regions of PEN in direction parallel with chain axis is 145 GPa. This is about 40% higher than corresponding modulus for PET 108 GPa [5]. PEN fibers are well known for their high performance properties, resistance and good tensile properties. Their potential markets are packaging, films and fibers. Especially for tire yarns the response to cyclic dynamical deformation is interesting [2].
Blends of PET and PEN have been attracting increasing interest because they combine the superior properties of PEN with the economy of PET. Mixture of these polyesters form due to transesterification during melts processing random copolymers. The glass transition temperature of PET/PEN increases linearly with volume fraction of PEN [6]. It is therefore possible to control properties connected with T_g by including of PEN to PET. The addition of PEN improves gas barrier properties as well [1]. On the other hand due to higher stiffness of PEN [3], the low durability in repeated bending can be predicted.
A classical review of fatigue in textile fibers is published e.g. in paper [7]. The imposed loadings are usually tensile, torsional and tension-compression. The behavior of fibers under repetitive bending was investigated by various authors (review is published in work [8]).
The main aim of this contribution is evaluation of flex fatigue of PET/PEN fibers based on the device measuring number of repeated bending cycles till break at constant pre-straining. The analysis is based on distribution of flex fatigue life (in megacycles). The exploratory data analyses tools are used for data treatment and comparison.

2 PET/PEN FIBERS

It is known, that introduction of even low level of 2,6,naphthalene units in place of terephthalate moieties acts to disrupt crystallinity, increase T_g, improve static chain packing, and decrease local segmental mobility in the amorphous phase of copolymers. These results are supported by the geometrical structure of the two units (Figure 1).



A B

Figure 1 Dimensions of 2,6 naphthalene (A) and terephthalate (B) units

The molar volume of PEN (V_{PEN}=182.4 cm^3/mol) is higher than molar volume of PET (V_{PET}=144 cm^3/mol). The amorphous density of PEN (ρ_{aPEN}=1327 kg/m^3) is lower than amorphous density of PET (ρ_{aPET}=1333 kg/m^3). The crystalline density of PEN (ρ_{cPEN}=1407 kg/m^3) is lower than density of PET (ρ_{cPET}=1440 kg/m^3).
The 2,6, naphthalene unit is substantially larger and does not fit into the unit cell of PET. The bulky kinked 2,6 naphtalene units in PEN are much less mobile than the terephthalate units. Amorphous phase free volume and local segmental mobility are reduced due to PEN presence. At the temperatures around 60℃ or higher the motion of rigid naphthalene ring occur. One possible motion is hindered rotations of the naphthalene rings about the backbone. Another possible motion is interlayer slippage of the naphthalene rings. During the deformation of PEN, the naphthalene rings are rapidly aligned parallel to the surface of the fibers and also occurs at highly localized regions. The subsequent slippage can leads to necking behavior during deformation. The naphthalene portions exhibit higher creep compliance. Co polyesters of PET/PEN have a lot of interesting properties influenced by the presence of naphthalene rings. For some applications is interesting to know the degree of endurance in bending.

3 FLEX FATIGUE EVALUATION

For measurement of fibers flex fatigue the special Flexometer device was constructed. Basic result is numbers of repeated bending cycles of fibers till break *FC*. Fiber is fixed in upper movable clamp and guided through slot of diameter 0.2 till 3 mm. Upper clamp should be adjusted to the selected maximum bending angle from 0 till 140° (Figure 2).

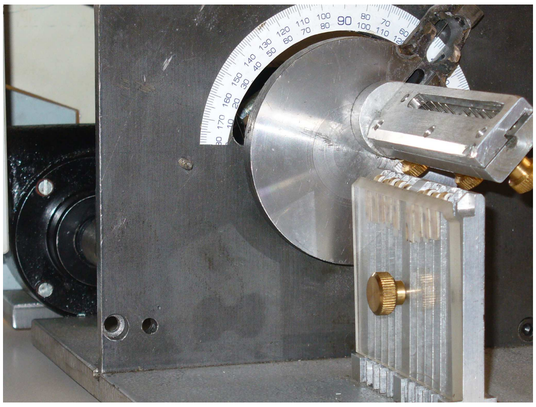


Figure 2 Device for flex fatigue measurements

On the free end of fiber (adjustable in range 8-27 mm) the defined load is mounted. Upper clamp is driven by electrical drive with adjustable frequency of bending per minute. For analysis of *FC* data it is necessary to know their distribution. The computationally assisted exploratory data analysis methods including techniques used here are described in the book [3]. The estimation of proper distribution of *FC* can be realized by using of so-called quantile-quantile (Q-Q) plot. Classical Q-Q plot is based on comparison of empirical quantile function $Q(P_i)$? $FC_{(i)}$ with chosen theoretical quantile function $QT(P_i)$. The probability estimator $P_i=i/(n+1)$ and so-called order statistics $FC_{(1)} < FC_{(2)} < \dots < FC_{(N)}$ (which are the sample values arranged in the increasing order) are used. It was found that for flex fatigue of polymeric fibers three parameter Weibull distribution is useful [6]. Distribution function of this distribution has simple form:

$$F(FC) = 1 - exp\left[-\left(\frac{FC - A}{B}\right)^{C}\right] \quad (1)$$

Here A is lowest number of repeated bending cycles till break, B is scale parameter and C is shape parameter. For quick and rough parameter estimates of three parameter Weibull models the moment based method can be used. The main idea of this method is very simple. Based on the selected 3 sample moments and corresponding theoretical moments for number of repeated bending cycles till break the 3 nonlinear equations can be created. Their complexity is based on the suitable selection of moments [9].

Cran [10] used this technique for estimation of the parameters in three parameter Weibull distribution. Shape parameter C can be estimated from relation:

$$C = \frac{ln(2)}{ln(m_1 - m_2) - ln(m_2 - m_4)} \qquad (2)$$

For estimation of the lower limiting strength A is valid:

$$A = \frac{m_1 . m_4 - m_2}{m_1 + m_4 - 2m_2} \qquad (3)$$

and estimate of scale parameter B is in the form:

$$B = \frac{m_1 - A}{\Gamma(1 + 1/C)} \qquad (4)$$

where $\Gamma(x)$ is Gamma function. In these relations m_r are special, so-called Weibull sample moments defined as:

$$m_r = \sum_{i=0}^{N-1} (1 - i/N)^r \left[x_{(i+1)} - x_{(i)} \right] \qquad (5)$$

For $i=0$ is formally $FC_{(0)}=0$. This very simple technique can be used for the rough estimation of A in three parameter Weibull models.

4 EXPERIMENTAL PART

The fibrous samples having various content of PEN were prepared under comparable conditions. Basic characteristics of these samples are given in the Table 1.

It is clear than the shrinkage is increasing function of PEN content. Shrinkage is generally associated with the relaxation of the oriented amorphous chains and the removal of residual stresses formed during processing of fibers. Stress induced crystallization can reduce the shrinkage as well. Because are both shrinkage temperatures above the start of naphthalene rings motion the shrinkage processes are facilitated.

The flex fatigue life was characterized by the flex cycles to fiber failure FC [cycles]. Measurement was realized on the Flexometer device described above. Fiber was pre-tensioned by weight 2 grams. The numbers of cycles required for fibers to fail FC were registered. The experiments were realized in standard conditions. For each co polyester the n=10 measurements were realized.

Table 1 Basic characteristic of PET/PEN samples

Sample	PEN content [%]	Intrinsic viscosity	Boiled water shrinkage [%]	Dry air-180°C shrinkage [%]
A	0	0.625	0.4	2.7
B	5	0.560	1.4	4.7
C	10	0.586	1.2	7.0
D	15	0.582	2.2	8.4
E	20	0.610	2.2	14.5

5 DATA ANALYSIS

Exploratory data analysis (EDA) techniques allow isolating certain basic statistical features and patterns of data. For analysis of FC data we need to know the suitable data distribution. Simpler task is to characterize data by proper display enabling the estimation of central tendency and spread simultaneously with outlying points and extremes. The computationally assisted exploratory data analysis methods including techniques used here are described in the book [4].

The simple box plot was selected for graphical visualization of data and evaluation of dirty data. This plot is shown for all samples on the Figure 3.

The black squares are median values of *FC* (robust estimators of location) and the white squares width is corresponding to data variance (interquartile distance). Because samples are ordered according to increase of PEN content it is clear that rigid naphthalene rings have negative influence on the flex fatigue life *FC*.

The second task i.e. estimation of proper distribution of FC can be solved in EDA by using of so-called quantile-quantile (*Q-Q*) plot. Classical *Q-Q* plot is based on comparison of empirical quantile function $Q(P_i) \approx x_{(i)}$ with chosen theoretical quantile function $Q_T(P_i)$. For theoretical distribution functions of type $F_T((x-T)/S)$ is attractive to use standardized quantile function $Q_{TS}(P_i)$, [9]. When empirical and theoretical distributions are in coincidence, the relationship:

$$x_{(i)} = T + SQ_{TS}(P_i) \qquad (6)$$

is valid. Here usually *T* is the location parameter and *S* is the parameter of scale and probability estimator $P_i=i/(n+1)$. The so-called order statistics:

$$x(1) < x(2) < \ldots < x(N) \qquad (7)$$

which are the sample values (assumed to be distinct) arranged the in increasing order are used. The *Q-Q* graphs can be constructed for two and with some small difficulties for three term distributions. It is widely accepted that the fatigue data can be described by the Weibull distribution. On the Figure 4 is created *Q-Q* graph for this distribution (the threshold 25020 was selected from Eq. (3).

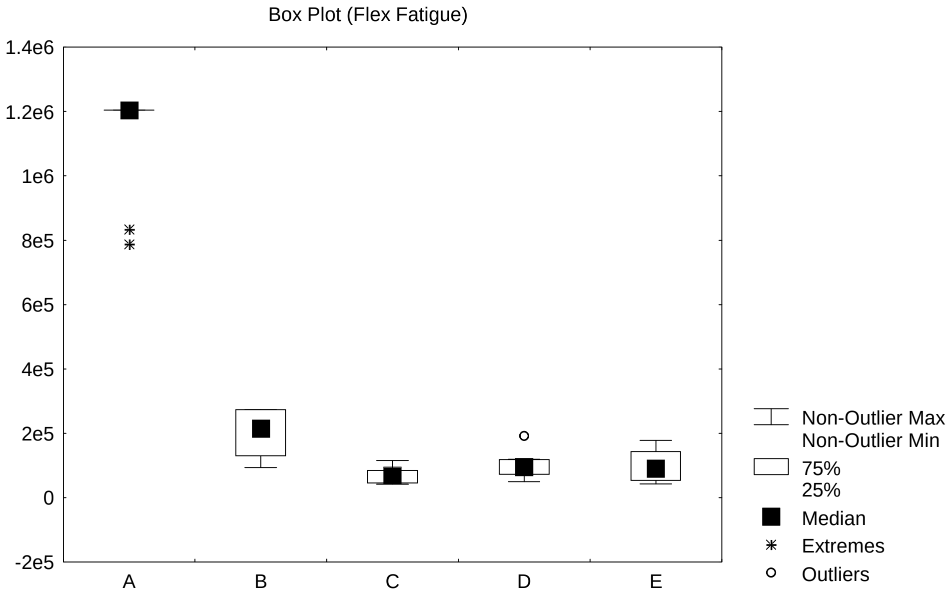


Figure 3 Box plot summarizing FC data for all samples (FC are) on the y-axis

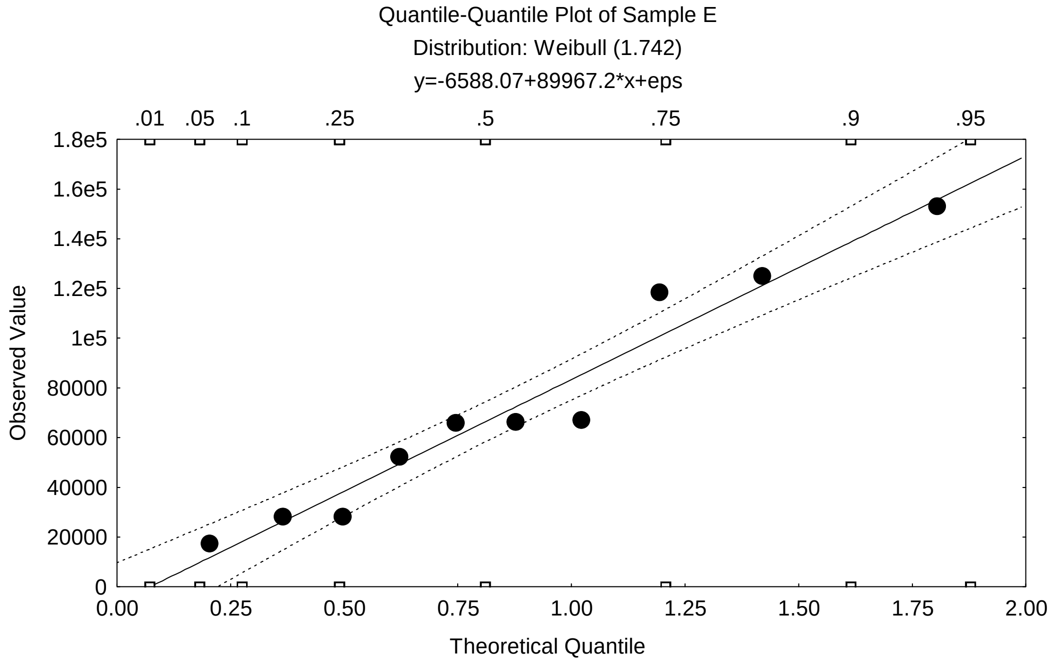


Figure 4 Q-Q plot for Weibull distribution (sample E)

The similar patterns were obtained for all samples. The linearity in this graph supports the usefulness of Weibull distribution for this case. This distribution has simple form (see Eq. (1)). The parameters of this distribution were obtained by Cran procedure and by minimizing of likelihood function [9]. For all samples the shape parameters C was in the range 1.5-2.0 and the scale parameters B in the range 50000-180000 cycles. The threshold parameter T was in the range 25000-35000 cycles.

6 CONCLUSION

The flex fatigue life of PET/PEN copolyesters can be well approximated by the three-parameter Weibull distribution. The PEN content causes decrease of this quantity. The main reason is probably the higher stiffness and more aligned chains in amorphous regions.

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PROBLEM OF DISTANCE AND COMPLEX QUALITY OF FABRICS

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Abstract: The purpose of the paper is to describe the construction of utility value U based criterion suitable for expressing pseudo-distance in the area of computer aided products design. The application of pseudo-distance is demonstrated on the example of characterization of the effect of catalysts on the quality of crease resistant finished fabrics under laboratory conditions. The target fabric was selected according to the requirements to minimize the influence of finishing on the mechanical properties loss and surface abrasion on the one hand and improving the recovery angles on the other hand. The program COMPLEX written in MATLAB is briefly mentioned.
Key Words: distance calculation, complex quality evaluation, utility value, program COMPLEX.

1 INTRODUCTION

One of main task in the realization of computer aided products design is creation of criteria for selection of optimal solution. This criterion can be simply created based on the complex quality indices. The degree of quality (complex criterion) is often expressed as utility value *U* [1]. Evidently, general quality of products is characterized by many of various utility properties R_i *(i=1,…m)*. These are such properties that make it possible for the product to fulfil its function. Utility value $U \in <0, 1>$ aggregates then in some certain way partial quality properties [2].
The purpose of the paper is to describe the construction of this type criterion suitable for computer aided products design. The application of *U* and corresponding pseudo-distance is demonstrated on the example of characterization of the effect of catalysts on the quality of crease resistant finished fabrics under laboratory conditions. The target fabric was selected according to the requirements to minimize the influence of finishing on the loss of mechanical properties and surface abrasion on the one hand and improve the recovery angles on the other hand. The application of so called Bootstrap, for calculation of basic statistical characteristics, is mentioned. The program COMPLEX written in MATLAB will be briefly mentioned

2 DISTANCE FUNCTION

For computer aided design purposes is essential to calculate the distance between target (required) product and various variants evaluated experimentally, calculated virtually or selected from database system. Let the target product is characterized by set of G_i values for *m* utility properties and *j* - th variant product is characterized by the set of R_{ij} properties for the same utility properties. Let the each property has importance characterized by some weighting factors β_i, standardized to have sum equal to one. The distance d_j between target fabric and *j-h* variant fabric is in majority cases calculated from selected metric. General Minkowski distance (metric) is given by relation [6]:

$$d_{Mj} = \sqrt[p]{\sum_{i=1}^{m} (G_i - R_{ij})^p} \qquad (1)$$

where for *p*=1 it is Hamming distance and for *p*=2 it is Euclidean metric. The consequence of increasing *p* is increasingly to exaggerate the more dissimilar units relative to the similar ones.

Unfortunately, these distances are not invariant to changes in scale and the results can change appreciably by simply changing the units of measurement.
The *Mahalanobis distance* is in fact a generalization of the idea of standardization. The squared Euclidian distance based on standardized variables is the sum of the squared differences, each divided by the appropriate variance. When the variables are correlated, a distance can be defined to take this correlation into account.
The *Mahalanobis distance* (metric) can be thought of as an appropriate statistical distance for use in properties space similarly as the Euclidean distance but where there exist different variances and covariance between properties expressed by covariance matrix [6]:

$$d_{MAj} = \sqrt{(G - R_j)^T C^{-1} (G - R_j)} \qquad (2)$$

where C is covariance matrix for properties, G is vector of properties for target product and R_j is vector of properties for j th variant product.
For case of two properties (G_1, G_2) and (R_1, R_2) suppose that the variances for each property are s_1^2 and s_2^2, respectively, and that the correlation between both properties is r. The squared Euclidian distance based on the original values is:

$$d_E^2 = (G_1 - R_1)^2 + (G_2 - R_2)^2 \qquad (3)$$

The same quantity based on standardized properties is squared (*standardized Euclidian distance*):

$$d_{SE}^2 = \frac{(G_1 - R_1)^2}{s_1^2} + \frac{(G_2 - R_2)^2}{s_2^2} \qquad (4)$$

If r = 0, then the last quantity is also the Mahalanobis distance.
If $r \neq 0$, the Mahalanobis distance is:

$$d_{MA}^2 = \frac{1}{1 - r^2}\left[d_{SE}^2 + \frac{2r(G_1 - R_1).(G_2 - R_2)}{s_1 s_2} \right] \qquad (5)$$

The differences between Euclidian and Mahalanobis distances are shown in the Figure 1.

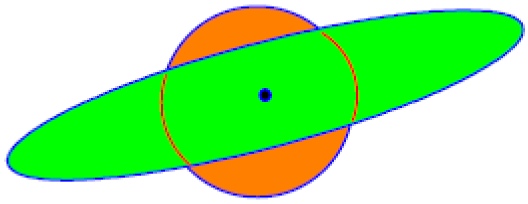

Figure 1 Differences between Euclidian (circle) and Mahalanobis (ellipse) distances

In the red circles are all distances shorter or equal to selected value (equal to circle radius). The corresponding Mahalanobis distances are lying in the green ellipse.
The main shortcoming of all these distances is assumption of symmetry i.e. distance from target value is the same if properties are increased or decreased. For the case of calculation distance for computer aided product design it is in fact distance characterizing loss of quality. It means that target product has prescribed quality and aim is to construct variant product with similar “or better” quality. Higher distance then should correspond to smaller quality only.

3 COMPLEX QUALITY CHARACTERIZATION

The products quality is generally characterized by several properties expressing their ability to fulfil functions it was designed for. The degree of quality (complex criterion) is often expressed as utility value $U \in <0, 1>$ (see e.g. [1, 4]). General quality of products is characterized by various utility properties x_i (i=1,...m). These are such properties that make it possible for the product to fulfil its function. For complex evaluation, the R (n x m) matrix is available containing for individual $V_1, ...V_n$ variants (R matrix rows) the values of selected $R_1, ...R_m$ characteristics (R matrix columns) The R_{ij} element of the matrix thus expresses the value of the j - th characteristic of x for the i - th variant of V_i.

A special technique for U calculation is the so called "base variant method". When applying the method of base variant for expressing of products quality, the following problems have to be solved:

- Selection of x_i characteristics corresponding to utility properties,
- Determination of preferential functions $u_{ij}=u(R_{ij})$ expressing "partial quality" for chosen utility property
- Assessment of the importance w_i of individual utility properties
- Proper aggregation, i.e. determination of the U function.

For j - th variant is here omitted symbol j and e.g. u_i is used The weighted geometrical average U is calculated by the relation:

$$U = exp(\sum_{i=1}^{m} w_i \, ln(u_i)) \qquad (6)$$

The U value can be used alone as complex quality criterion for each variant and target product as well. In this case the U values for some variants can be better than for target product.

The pseudo-distance is calculated from relation:

$$d_p = K.(1 - U) \qquad (7)$$

where K is constant with meaning of maximum possible distance when quality is equal to zero. The simplest is to choose K=1, and pseudo-distance is then usually in the interval <*0, 1*> or K=10 and pseudo-distance is then usually in the interval <*0, 10*>. In the case of pseudo-distance computation the target properties are usually used instead of properties for an absolutely satisfactory product.

Partial utility function u_i is in fact psychophysical variable expressing the sensation of quality induced by (measured) characteristic of utility property. The computation of preferential functions is dependent on the measurement scale and property type.

Ordinal characteristics - in this type of scale, classification has been introduced, but differences are not quantified. Grades are awarded by the comparison with etalons.

Cardinal characteristics - are usually expressed in physical units. There are two types of cardinal characteristics.

One-side bounded characteristics are those where above the H_j value the utility is maximal and does not change any more (strength, modulus, abrasion resistance, etc.). After standardization the partial utility function is computed e.g. by using Harrington preference function. The same approach is used for cases when below the H_j value the utility is maximal (shrinking, abrasion degree, etc.).

Two-sides bounded characteristics are those where on both sides from "the optimum" partial utility decreases (e.g. porosity, air permeability).

The nonlinear transformation to preference functions for cardinal utility values is given in the work [1]. For expressing of pseudo-distance it is sufficient to replace standardization and nonlinear transformation to the partial utility function by the piecewise linear transformation. For one side bounded properties quality is monotone increasing or decreasing function of quality characteristic x and therefore the piecewise linear transformation has form shown on the Figure 2.

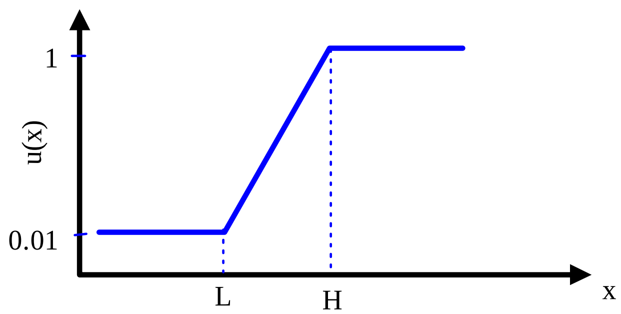

Figure 2 Transformation for one side bounded utility properties (L is lower limit and H is upper limit)

For two side bounded properties quality is monotone decreasing function of property value x on both sides from optimal (constant) region and therefore has the piecewise linear transformation form shown on the Figure 3.

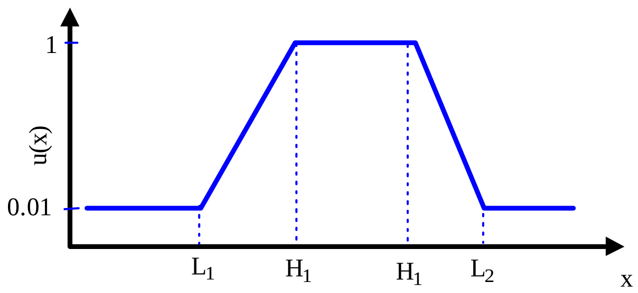

Figure 3 Transformation for two side bounded utility properties (L_1, L_2 are lower limits and H_1, H_2 are upper limits)

4 BOOTSTRAP SIMULATION

The core of Bootstrap is generations of artificial samples from proper distribution [5]. For the case of products quality it is useful to use one of two basic techniques.

First method is based on the three parameter Weibull distribution and can be used if the primary measurements are at disposal. Distribution function of three parameter Weibull distribution this distribution has simple form for property $FC = x_j$

$$F(FC) = 1 - exp\left[-\left(\frac{FC - A}{B}\right)^C\right] \tag{8}$$

Here *A* is lowest value of property, *B* is scale parameter and *C* is shape parameter. For quick and rough parameter estimates of three parameter Weibull models the moment based method can be used. The main idea of this method is very simple. Based on the selected 3 sample moments and corresponding theoretical moments for the 3 nonlinear equations can be created. Their complexity is based on the suitable selection of moments.

The Weibull type moments can be used for estimation of the parameters in three parameter Weibull distribution [5]. Shape parameter *C* can be estimated from relation:

$$C = \frac{ln(2)}{ln(m_1 - m_2) - ln(m_2 - m_4)} \tag{9}$$

For estimation of the lower limiting strength *A* is valid:

$$A = \frac{m_1.m_4 - m_2^2}{m_1 + m_4 - 2m_2} \tag{10}$$

and estimate of scale parameter *B* is in the form:

$$B = \frac{m_1 - A}{\Gamma(1 + 1/C)} \tag{11}$$

where $\Gamma(x)$ is Gamma function. In these relations m_r are special, so-called Weibull sample moments defined as:

$$m_r = \sum_{i=0}^{N-1} (1 - i/N)^r \left[FC_{(i+1)} - FC_{(i)}\right] \tag{12}$$

For $i=0$ is formally $FC_{(0)}=0$. The so-called order statistics $FC_{(1)}<FC_{(2)}<...<FC_{(N)}$ (which are the sample values arranged in the increasing order) are here used. This very simple technique can be used for the estimation of parameters in three parameter Weibull models.

Second method is based on the normal distribution and it is useful if the only mean values x_{Mj} of all utility properties are given. Here it is necessary to have external information about variability of measurements i.e. standard deviations s_j. Usually it is simplest to estimate coefficient of variation of individual utility properties.

The normal distribution $N(x_{Mj}, s_j)$ is then used for generation of the Bootstrap samples. For generation of simulated samples random numbers $N(0,1)$ generated by random number generator are used. These values are transformed to the individual variables x_j by using of relation:

$$x_j = x_{Mj}.(1 + CV_j / 100) \tag{13}$$

where CV_j are variation coefficients of individual utility properties. As robust characteristics of total mean from all simulated samples $E(U)$ the median value is used and as interval covering 95% of Bootstrap sample means the 2.5 and 97.5% all sample quantiles are calculated.

The whole procedure of the statistical characteristics of pseudo-distance d_P estimation is divided to the following parts:

a. Generation of $x^{(k)}_j$ *(j=1,.....m)* values having normal distribution with mean values x_{mj} and variances s^2_j. The pseudorandom number generator built in MATLAB is used.
b. Calculation of the pseudo-distances $d_P^{(k)}$ using the relation (4).
c. The steps I and II are repeated for *k=1,.....n* (usually *n=1200* is chosen).
d. Construction of a histogram from the values $d_P^{(k)}$ *(k=1,.....n)* and computation of the estimators of $E(d_P)$, $D(d_P)$.

This technique (in details see. [6]) has been applied in program COMPLEX written in MATLAB.

5 EXPERIMENTAL

The main aim is to show the procedure of pseudo-distance calculation on the simple and clear example. The effect of catalysts on the quality of crease resistant finishing was investigated under laboratory conditions. The target fabric was selected according to the requirements to minimize the influence of finishing on the loss of mechanical properties and surface abrasion on the one hand and improve the recovery angles on the other hand. This fabric is in fact ideal one because the (at least small) drop of mechanical properties due to this type of finishing is obvious.

The V_0 variant is an *untreated* fabric, the V_1 is a fabric with crease resistant finish treated with the *Catalyst AC* (Monsanto) and the V_3 is a fabric with resistant finish treated with the *Catalyst CR* (Cassela). The values of target fabric are denoted as D_i in the Table 2.

Table 1 contains selected R_i characteristics (utility properties). All the measurements were done by means of standard testing procedures.

Mean values R_{Mj} of x_j utility properties and values corresponding to just unsatisfactory S_j and satisfactory D_j (target fabric) base variants are given in Table 2. The relative errors of measurements were in all cases of below 5%. For Bootstrap simulation the conditions of the same relative precision of measurements 5% were then selected.

Table 1 Selected utility properties

Code	Utility property	Dimension
R_1	Tensile Strength	N/5cm
R_2	Elongation	%
R_3	Tearing Strength	mN
R_4	Shrinking	%
R_5	Dry Recovery Angle	degree
R_6	Wet Recovery Angle	degree
R_7	Surface Abrasion	%

Table 2 Values of individual utility properties

	R_1	R_2	R_3	R_4	R_5	R_6	R_7
V_0	372	9.7	16700	3.1	62	67	0.03
V_1	316	8.7	8520	2.1	114	120	2.77
V_2	336	9.4	9480	2.7	119	125	1.78
S_i	250	7	8000	3	110	110	5
D_i	372	10	16700	1	135	145	0.03
w_i	0.1	0.1	0.1	0.1	0.2	0.3	0.1

6 RESULTS AND DISCUSSION

By using of the above described program COMPLEX in MATLAB the mean $E(d_P)$, variance $D(d_P)$, and limits of 95% confidence interval of population pseudo-distance were computed. Results are summarized in Table 3 (weights w_j are given in the Table 2 and limit value K=10 was chosen).

Table 3 Statistical Characteristics of pseudo-distances

Type	Mean $E(d_P)$	lower limit 95% CI	upper limit 95% CI	Euclidean distance
V_0	9.83	9.83	9.83	106.87
V_1	7.83	7.70	7.9	8180.3
V_2	6.44	6.38	6.50	7220.1

The histograms of simulated pseudo-distance from Bootstrap samples for variants V_1 and V_2 are presented in Figure 4. The slight deviations from normality and higher spreads are clearly visible.

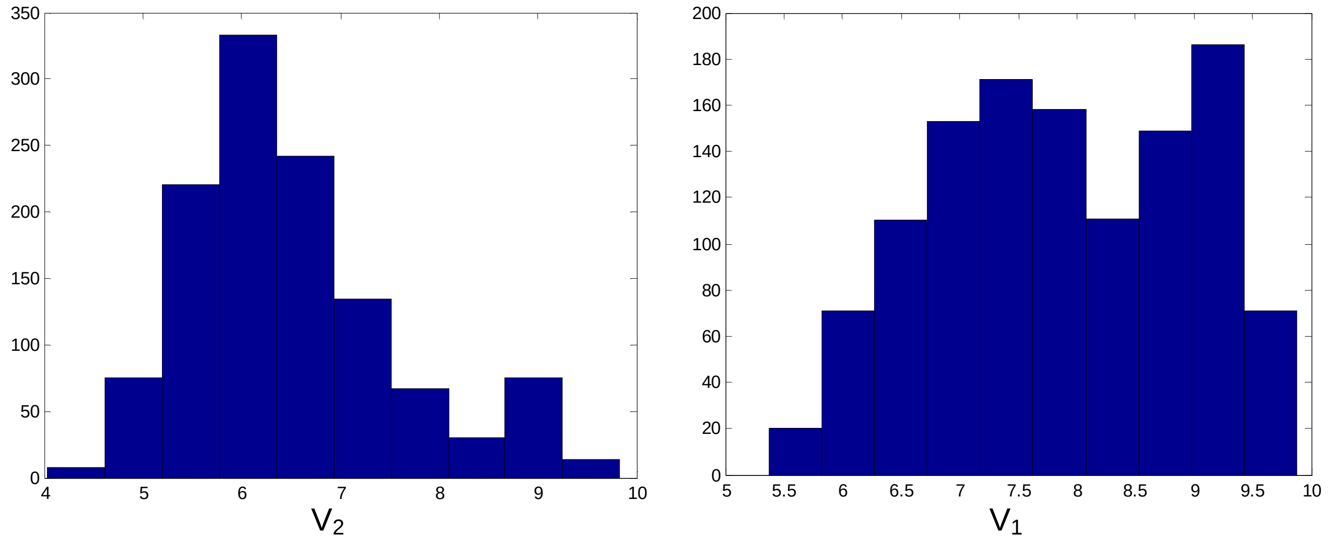

Figure 4 Histogram of simulated pseudo-distance from Bootstrap samples

Apparently, based on $E(d_P)$ the V_2 variant is slightly better that the V_1 one. From statistical point of view the pseudo-distances for V_1 and V_2 variant are significantly different. The pseudo-distances show the relative big difference from target due to relatively high loss of surface abrasion and tearing strengths mainly. The corresponding Euclidean distance (last column in the Table 3) is not useful here because the shortest distance is for untreated variant V_0.

7 CONCLUSIONS

Evidently expressing the pseudo-distance based on complex quality evaluation is of a universal character. There are, of course, many other techniques; some of them (e.g. polar property diagram) do not even carry out any aggregation. The advantage of the pseudo-distance d_P manifests itself especially in the case when quality of a whole series of products is being compared. The pseudo-distance has many advantages in comparison with classical distances. Main improvement is proper functioning for the cases of one side bounded properties (asymmetric partial utility functions) and no problem with different units.

It can be expected that procedures for objective evaluation of distances will keep on developing and they will thus simplify a complex optimization of products design process in respect of their required utility. The application in the computer aided products design will be more precisely oriented to the better quality of products.

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SIMPLE METHOD OF WATER SURFACE SPREADING KINETIC ON HYDROPHOBIC TEXTILES

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Abstract: *The simple method of water surface spreading kinetic on hydrophobic textiles based on the direct image based information about real drop contours is described. The measurements of images contour changes as function of spreading time are used for description of water drop spread kinetics on the surface. The selected knitted fabrics created from hydrophobic fibers with different cross section profiles are evaluated. Calculations are realized by own programs in Matlab software.*

1 INTRODUCTION

The transport of both moisture vapor and liquid away from the body is called moisture management [1]. Moisture management has the following functions:

- Regulation of body temperature - when the human body core temperature exceeds 37℃, sweat is produced.
- Transporting the sweat away from the skin and evaporating it to the atmosphere which reduces body temperature.

Due to absorption of the sweat generated by the body the weight of cloth increases with a negative effect on performance. Moisture management avoids this effect. Synthetic fibers such as polyester are hydrophobic, meaning that their surface has few bonding sites for water molecules. Hence, they tend to remain dry and have good moisture transportation and release. For liquid transport within fabrics, two phenomena must be accounted for - wetting ability and wicking ability [2]. The term 'wetting' is usually used to describe the change from a solid-air interface to a solid-liquid interface. Wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. As capillary forces are caused by wetting, wicking is a result of spontaneous wetting in a capillary system [3]. Many test methods have been developed to measure liquid water absorbency and water vapor transport in fabrics [2]. These methods measure different aspects of moisture management characterristics of fabrics. Moisture Management Tester (MMT) is used to determine the liquid spreading and transfer rates of a fabric [4]. The method of measurement is based on the change of the electrical resistance of the fabric with its water content. Six concentric rings (sensors) of different sizes are then placed on both surfaces of the fabric. The distance between two consecutive rings is 5 mm except the first one which is at 1.5 mm from the centre. They allow us to measure the spreading and the transfer of water along the 2 faces. More specifically they allow to determine the water content at different ring locations (local) and consequently on the overall (global) surface. The considered fabric is held fixed by top and bottom sensors with a certain pressure. After its introduction on the top fabric top surface, the liquid solution will move in the three space directions according to the following steps:

- spreading outward on the top surface of the fabric,
- transferring through the fabric from the top surface to the bottom surface,
- spreading outward on the bottom surface of the fabric.

One of parameters of MMT is characterization of spreading of liquid drop on the upper surface of the fabric from measurements of spreading outward on the top surface.

Main aim of this work is replacement of this approximate measuring system by direct image based information about real drop contours. These measurements are used for description of water drop spread kinetics on the surface of selected knitted fabrics created from hydrophobic fibers with different cross section profiles. Calculations are realized by own programs in Matlab software.

2 SURFACE SPREADING

The spreading of a drop on a solid surface is a problem of considerable interest and difficulty in fluid mechanics, where the basic physical processes are still not completely understood. In this work, we are concerned with the spreading of a non-volatile liquid drop (in the small measured interval 140 sec) on a solid plane substrate with a positive value of the spreading parameter $S=\gamma_{SG}-\gamma_{SL}-\gamma > 0$ (with γ_{SG}, γ_{SL} and γ, respectively, the solid-gas, solid-liquid, and liquid-gas interfacial tensions). Therefore, spontaneous spreading occurs and the coverage of the solid by the liquid can be stopped only by the “small thickness effects” [3]. Consider the simplest case of a small viscous droplet spreading on a surface which it wets completely (Figure 2a). By small we mean that the drop radius is sufficiently small so that gravity is negligible.
Drop spreading kinetic can be expressed by the Tanner model [5] describing the changes of drop radius *R(t)* as function of time t in the form:

$$R(t) = R_1 t^n \text{ or } ln R(t) = ln(R_1) + n.ln(t) \quad (1)$$

where *R(t)* is drop radius in time t, R_1 is drop radius in time *t*=1 sec (spread rate characteristics) and *n* is parameter dependent on forces influencing significantly spreading process (viscosity, capillarity, gravitation, surface tension). Value of *n* is usually in the range of 1/4 till 1/10.
Harth and Shubert model [6] is based on the assumption that the spread kinetics is influenced by capillary, viscosity and gravitation forces only. After some time interval the drop is in the form of liquid film (Figure 2b). Let this film propagates from an infinite, stationary source. The propagation of such a film is known to exhibit the diffusive dynamics, allowing us to write $L^2 \sim Dt$, where *L* is the propagation distance from the source and *D* is the effective diffusivity. Then in the Tanner model is parameter *n* = 0.5.

3 EXPERIMENTAL PART

3.1 Samples

The rib knitted fabrics composed from mixture of staple polyester and Lycra (ratio 94/6%) with the same construction parameters and planar mass 195 [g.m^{-2}] were prepared. Sample “circular” is prepared from yarn 16.5 tex with classical polyester fibers having circular cross section (Figure 1a) and sample “Coolplus” is prepared from yarn 16.5 tex with Coolplus fibers having “four lobal” cross section (Figure 1b).

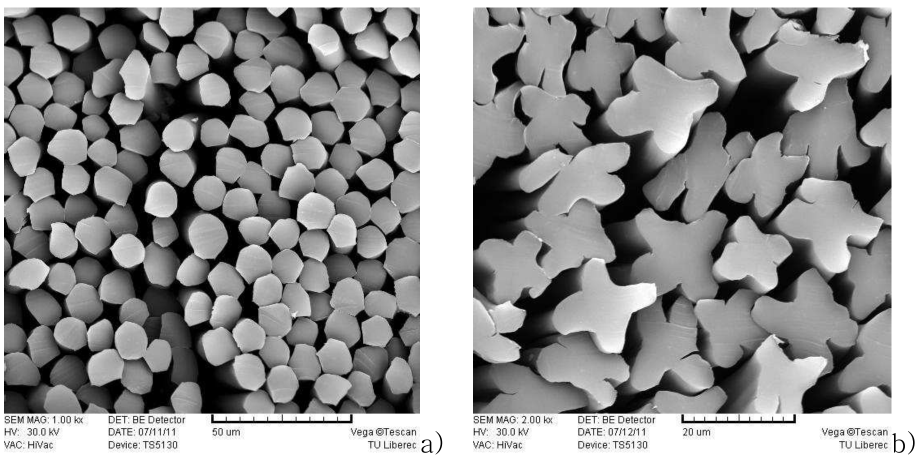


Figure 1 Polyester fibers a) circular cross section, b) Coolplus

Total volume porosity of fabric from circular fiber was 80.25% and of fabric from Coolplus fiber was 82.42%. Before measurements were samples conditioned for 24 hours at temperature 21.1℃ and relative humidity 65.2% in special chamber.

3.2 Measurements of wetting ability

Water wetting ability is indicator of maximum loading capacity of fabric for water by so called water absorptive capacity P [%]. The water absorptive capacity measure the liquid stored within the test piece itself after drainage has occurred horizontally. Samples of fabrics having dry weight M_s were immersed into distilled water bath for 1 min. After removal from water bath were samples hanged in horizontal position for 1 min and then weighted (wet weight M_m). The water absorptive capacity is defined by relation:

$$P\,[\%] = \frac{M_m - M_s}{M_s}.100 \qquad (2)$$

3.3 Measurements of water spreading

Sample 9x9 cm was held fixed in special frame with CCD camera on the top. A drop from 0.2 ml of distilled water was introduced to the top surface of the fabric and changes of drop contours at times t_i were recorded by series of images after 2 sec. intervals till 140 sec. The typical shape of water drop at 2 seconds and 140 seconds are shown in Figure 2. The MATLAB program DROP for identification of real contours (see contour line in Figure 2a) by image treatment was created [8]. The equivalent perimeters P_i and areas S_i were calculated from contours coordinates. The equivalent radius of spread water drop R_{Pi} based on the assumption that real contour is replaced by contour of circular shape with the same perimeter is given by:

$$R_{Pi} = \frac{P_i}{2\pi} \qquad (3)$$

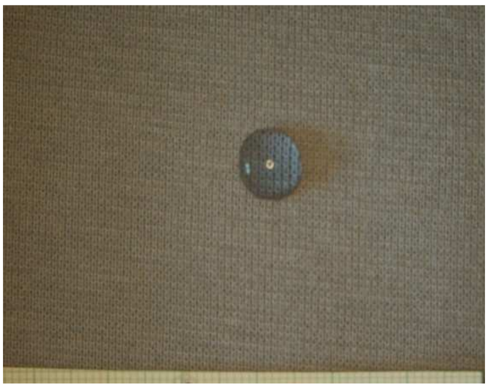
The equivalent radius of spread water drop R_{Si} based on the assumption that real contour is replaced by contour of circular shape with the same area is calculated from relation:

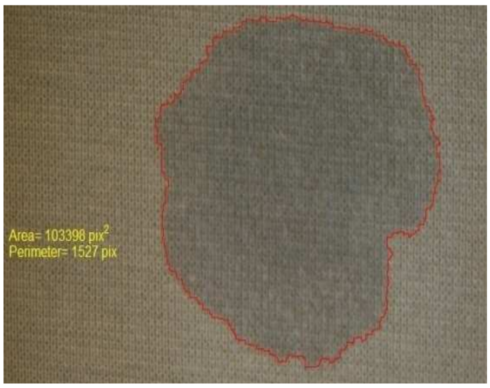
$$R_{Si} = \sqrt{S_i/\pi} \qquad (4)$$

Basic statistical characteristics were calculated from 5 repetitions by robust Horn procedure [7].

4 RESULTS AND DISCUSSION

For sample “circular” the mean value of water absorptive capacity P=29.98% and for sample “Coolplus” the mean value water absorptive capacity P=31.93% were evaluated. These differences are not so high and inter capillary attracted water looks similar for both cross sections. The real image of drop spread at 2 seconds is shown in Figure 2a) and real image of drop and calculated contour for drop spread at 120 seconds is shown in Figure 2b).


a)



b)

Figure 2 Real image of drop spread at 2 seconds (a), real image of drop and calculated contour for drop spread at 120 seconds (b)

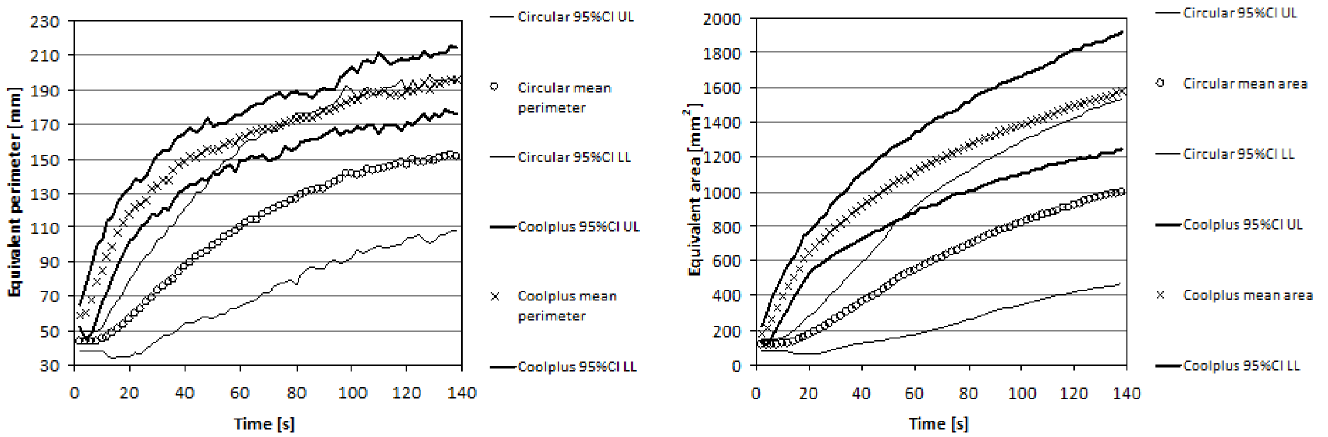
The dependence of mean values and 95%-th confidence interval of “circular” and “Coolplus” samples equivalent perimeters on time is shown in Figure 3a) and corresponding dependence of equivalent areas on time is shown in Figure 3b).

It is visible that the equivalent perimeters and equivalent areas for sample “Coolplus” are significantly higher than for sample “circular”. Therefore the spread potential of profiled fibers is much higher.

The plot of log R_{Pi} as function of log t_i for both samples is shown in Figure 4a) and corresponding plot of log R_{Si} as function of log t_i for both samples is shown in Figure 4b).

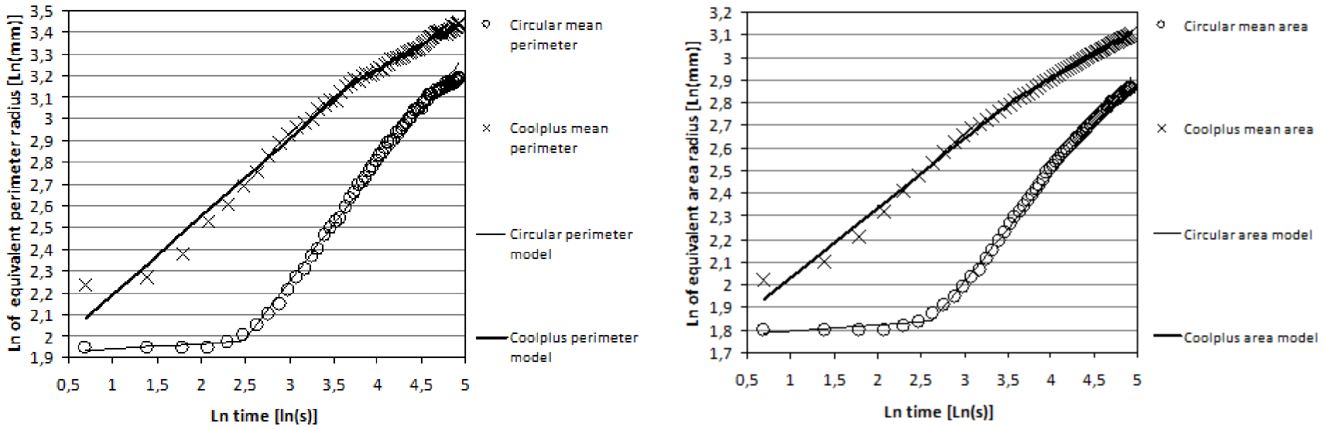
The equivalent radius R_{Si} is much higher than equivalent radius R_{Pi}. For both cases is logarithmic plot composed from two linear parts indicating different mechanism of spreading in initial phase (surplus of water) and second phase (spread of film). These linear parts calculated by linear regression (see. [8]) are superimposed into Figure 4. The parameters n_1, R_1 and n_2, R_2 calculated by linear least squares from log R_{Pi} on log t_i and log R_{Si} on log t data (see Eq. (1)) are summarized and in the Table 1.

It is clearly visible that spread kinetic for sample “Coolplus” is much higher than spread kinetic for sample “circular”. The parameters n are different for each stage and for different fiber cross sections as well.



a) b)

Figure 3 Dependence of equivalent perimeters on time (a), dependence of equivalent areas on time for samples “circular” and “Coolplus” (b)



a) b)

Figure 4 Dependence of log equivalent radius from perimeters on log time (a), dependence of log equivalent radius from areas on log time (b) for samples “circular” and “Coolplus”

Table 1 Parameters of Eq. (1) for different equivalent radius

Parameters	circular shape		Coolplus	
	R_P	R_S	R_P	R_S
n_1	0.024	0.027	0.358	0.306
R_1	1.918	1.766	1.832	1.723
n_2	0.526	0.470	0.225	0.218
R_2	0.670	0.598	2.331	2.037

5 CONCLUSIONS

The proposed method is relatively simple and precise. It is possible to investigate the evolution of real boundary of water drops from their contours. The equivalent radius calculation depends on initial assumption (the same perimeter or the same area). It is possible to calculate the anisotropy of spread from real contours as well. It was found that the shape of fiber cross section has significant influence of kinetic of water spread.

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"TRADITION AND HIGH-TECH DEVELOPMENT – KEYS TO THE TEXTILE MARKET"

24th IFATCC World Congress, June 13-16 2016, PARDUBICE (Czech Republic)

At the end of the nineteenth century the first attempts of textile chemists and colorists to join and work hand in hand in the fast growing textile industry of northeast Bohemia region began. These efforts were crowned with the foundation of the first Continental Textile Chemists and Colorists Society in 1908. In the same area production of dyestuffs has started and several small producers of textile auxiliary agents supported the tremendous development of the textile manufacturing.

The textile chemistry and coloration nowadays are becoming a new dimension – not only as the key to the fashion and comfort but also as a tool of the textile industry sustainability and last but not least as an extension of the new textile materials and fabrics into the new technical applications. Environmentally friendly, cost effective and energy efficient flexible technologies joining the tradition of chemistry with high-technologies, and boosted by new emerging disciplines, such as, to name a few biotech and nanotech, need to be communicated. Due to the significance of modern textile sector the forthcoming congress has obtained patronage of the Prime Minister of the Czech Republic.

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