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Effect of UV-weathering on flex fatigue of plastic optical fiber

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REZUMAT – ABSTRACT

Efectul îmbătrânirii UV asupra rezistenței la oboseală prin încovoiere a fibrelor optice din plastic

În cadrul acestei cercetări a fost studiat efectul îmbătrânirii sub acțiunea razelor UV asupra rezistenței îndoire a fibrelor optice din plastic cu emisie laterală (POF). Pentru experimentări au fost folosite două tipuri diferite de POF (denumirile comerciale: Grace & Hypoff) cu trei variante de diametre fiecare. Toate fibrele optice de tip POF au fost fost supuse unui număr de cicluri de îndoire până rupere înainte de îmbătrânire și după supunerea la un proces de îmbătrânire artificială cu raze UV, echivalentul unui an. S-a observat că există o pierdere semnificativă a proprietăților de îndoire, dar flexibilitatea fibrelor optice de plastic este crescută. Fibrele optice de plastic cu diametru mai mic sunt mai afectate de îmbătrânirea artificială sub acțiunea razelor UV decât cele cu diametru mai mare. Pentru estimarea numărului minim de cicluri de îndoire până la rupere a fost folosită distribuția Weibull cu trei parametri.

Cuvinte-cheie: fibre optice de plastic, PMMA, emitere laterală, îmbătrânire artificială UV

Effect of UV-weathering on flex fatigue of plastic optical fiber

In this research, the impact of UV-weathering is evaluated for flex fatigue of side emitting plastic optical fibers (POFs). Two different brand POFs (trade names: Grace & Hypoff) with three different diameters each are used for the experiment. All POFs are tested for the number of bending cycles to break before weathering and after 1 year equivalent of artificial UV-weathering. It was observed that there is a significant loss in terms of bending properties but flexibility of Plastic optical fiber (POF) is increased. Smaller diameter POF's are more impacted by UV-weathering than thicker ones. Three parameter Weibull distribution is used for estimation of minimum numbers of bending cycles to break for POFs.

Keywords: plastic optical fibers, PMMA, side emission, UV-weathering

INTRODUCTION

Optical fibers have a very broad spectrum of use, ranging from transporting light from a source to some device, transmitting optically encoded data or even functioning as a sensor for temperature [1].

Plastic optical fiber (POF) has attracted attention because it is light, soft, inexpensive and easy processing. Applications of POF range from communication [2–3] to decoration [4–5]. POF has also another great use as side emitting optical fibers where it can be used in textile stuff and can be part of the weave or can be bonded at required places for illumination at specific places [1–6].

The environmental factors (mechanical, climatic, chemical, biological and radiometric) certainly have a significant effect on the physical and chemical properties of POF, which obviously affects optical transmission performance of POF leading to the changes in lifetime of POF system [7]. The mechanical behavior of POF has been investigated by few researchers, most of these studies have focused on the light attenuation induced by bends or torsion stresses [8–9].

To clearly know the future of optical fibers we must know how long and well they will behave under different conditions. Sunlight is an important cause of damage to plastics, textiles, paints and other organic materials. Short wavelength ultraviolet light has long been recognized as being responsible for most of this damage [1–6]. So major properties like mechanical properties, light emission ability and bending property have to be tested under accelerated weathering to determine all these properties after weathering and how long optical fibers can perform under normal environment condition. So in this research impact of UV-weathering will be tested for bending properties of POF's.

In this research, three parameter Weibull distribution is used for the estimation of numbers of bending cycles to break for POFs with different diameters.

EXPERIMENTAL PART

POF properties

The side-emitting plastic optical fibers (Grace and Hypoff) with different diameters were tested before and after 1 year equivalent of weathering. The properties of the fibers are shown in the tables 1 and 2.

Flex-fatigue experimental measurement

The strain-stress experiments are proceeded to evaluate basic characterizations with the Instron-4411 tester. The distance between two holders was 200 mm, and the testing speed was 100 mm/min. Each sample was tested for 50 times each, before and after UV-weathering respectively.

The flex fatigue property was carried out with self-made device, as shown in figure 1 and 2. The experiment

Table 1

FIBER DESCRIPTION (GRACE)	
Name	**GRACE**
Diameter (mm)	0.25, 0.5, 0.75, 1
Core composition	PMMA
Cladding composition	Polytetrafluoro ethylene

Table 2

FIBER DESCRIPTION (HYPOFF)	
Name	**HYPOFF**
Diameter (mm)	1, 1.2, 1.5
Core composition	PMMA
Cladding composition	Poly(tetrafluoro ethylene)

measures the bending cycles to break (*FC*) of sample. The fiber is clamped to the upper jaw that is led by a slit, the slit is available for each fiber with the diameter from 0.2 to 3 mm, which defines the area of bending. The upper jaw provides an adjustable pre-swing radius for samples. The pivoting jaw is driven by electric transfer PC14C54 Atas Nachod with the drive-1F SV008iC5 LS Industrial Systems (see figure 2). It is designed to be able to change the swing angle within 0–140º (the angle is read on a scale placed on the protective cover of the engine separating from the carrier of the sample), and a lift height of the upper jaw from the rotation is expressed by the distance from the edge of the lower jaw (such as uncontrolled free section of the sample) within 8–27 mm. The samples can be attached with suitable pre-tension. Measurements can be performed manually after disconnection of transmission system, which is suitable for very brittle materials. The tests are performed after setting minimum and maximum swing radius. The drive motor is set to 100, which corresponds to the swing speed of 116 swings/minute. The length of bend points, the distance between the edge of the upper jaw and the edge of the lower jaw, is 8 mm. Each sample was tested for 50 times before and after UV-weathering.

UV-weathering of POF

It has been stated that, the UV radiation is one of the most important factors determining the polymers lifetime [10–11]. Degradation due to UV radiation is called photo degradation. Chemical reactions (e.g. chain scissions, cross linking, and oxidation) influence the physical properties and thus the material's lifetime [12].

Whatever the application, there is often a natural concern regarding the durability of polymeric materials partially because of their relative newness but also because of the useful lifetime of these materials, knowing the rate of photo degradation is useful in predicting the maintenance and replacement of polymer materials [10].

Besides natural weathering, several test methods have been developed. Accelerated or artificial weathering method we can predict the behavior of products in shorter time. In this work ATLAS weathering machine (UV-2000) is used for accelerated weathering. 15 hours of Atlas UV machine weathering equals to 1 month of natural UV weathering. We treated our samples for 7 days to obtain 1 year of natural weathering. The conditions in the machine are 60 °C and 65% humidity.

Weibull distribution

Weibull distribution with three parameters was used to estimate the distribution of the numbers of bending cycles to break [13]. The function of this distribution is as follow:

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

where *A* is lowest number of repeated bending cycles till break, which is shift parameter, *B* is scale parameter and *C* is shape parameter.

The suitable selection of moments [14] was chose and three nonlinear equations were created to

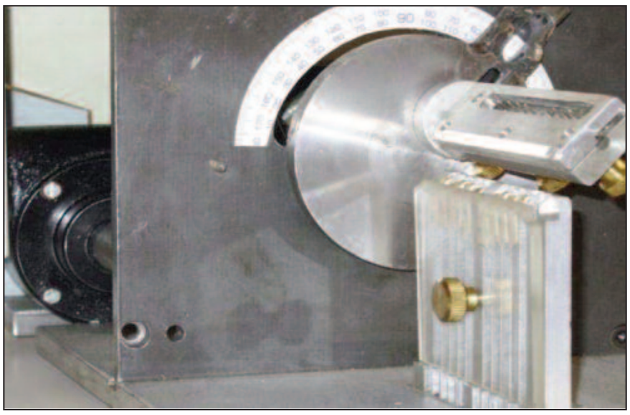

Fig. 1. The prototype device to measure resistance to bending

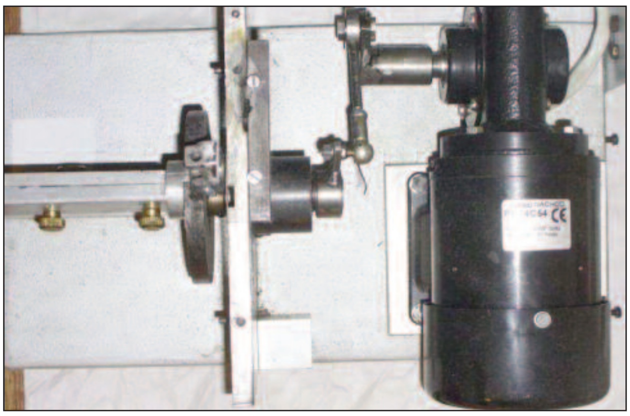

Fig. 2. The prototype instrument to measure resistance to bending-top view (left clamping jaw with protective gear is separated from the plate in the middle of transmission and right motor)

calculate the three Weibull parameters. Cran [15] used this technique for estimation of the three parameters of Weibull distribution. Parameters *A*, *B*, *C* can be estimated from following equations:

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

$$A = \frac{m_1 \cdot m_4 - m_2^2}{m_1 + m_4 - 2m_2} \quad (3)$$

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

where $\Gamma(x)$ is Gamma function. In these equations, m_1 is special, so-called Weibull sample moments can be defined as:

$$m_1 = \sum_{i=0}^{N-1} (1 - i/N)^r \left[FC_{(i+1)} - FC_{(i)}\right] \quad (5)$$

where $FC_{(0)} = 0$ when $i = 0$.

Corrected Weibull 3 Q-Q plot was obtain with the linear fitting function $y = a \cdot x + b$. Here $y = \ln[-\ln(1-p_i)]$, $x = \ln(FC_{(i)} - A)$, $a = C$ and $b = -\ln(B)C$.

The mean fiber strength $E(FC)$ and corresponding standard deviation $SD(FC)$ are computed from equations

$$E(FC) = A + B\,\Gamma\left(1 + \frac{1}{C}\right) \quad (6)$$

$$SD(FC) = E(FC)\left(\frac{\Gamma\left(1 + \frac{2}{C}\right)}{\Gamma^2\left(1 + \frac{1}{C}\right)} - 1\right)^{\frac{1}{2}} \quad (7)$$

where $\Gamma(.)$ is gamma function.

The relationship between flexibility and modulus and diameter is given as follows:

$$F_1 = \frac{64}{E \pi d^4} \quad (8)$$

where *d* is fiber diameter, *E* is initial modulus and F_1 is flexibility.

RESULTS AND DISCUSSIONS

Comparatively plastic optical fibers after weathering tend to break easily, figure 3 shows the bending cycles to break comparison for GRACE fibers with different diameter tested before and after UV-weathering. After weathering the POF breaks 40% easier than the POF before weathering. It is seen that the diameter has a significant influence on bending cycles until break. The numbers of bending cycles to break for POF is decreasing with the increase of diameter. And also there is a decrease of number of cycles to break after UV-weathering. The Weibull Probability plot for Grace 0.25 mm fiber before and after weathering is also shown in figure 4 and figure 5.

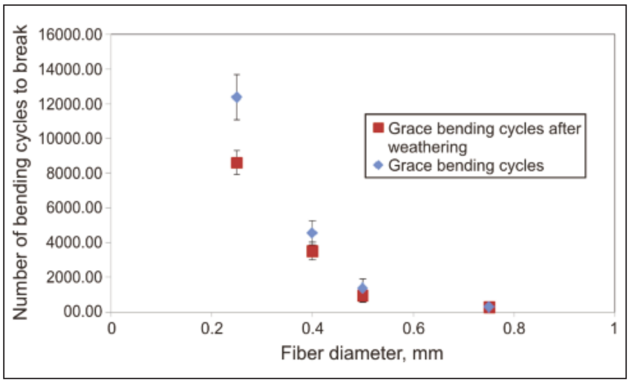

Fig. 3. Bending cycles to break GRACE

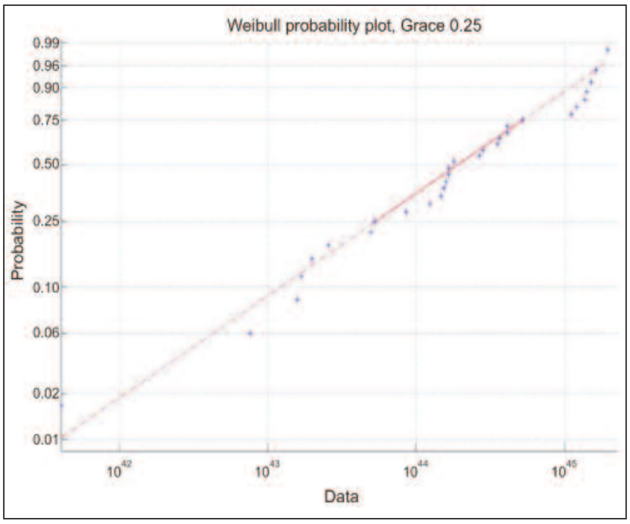

Fig. 4. Weibull Probability Plot (GRACE 0.25)

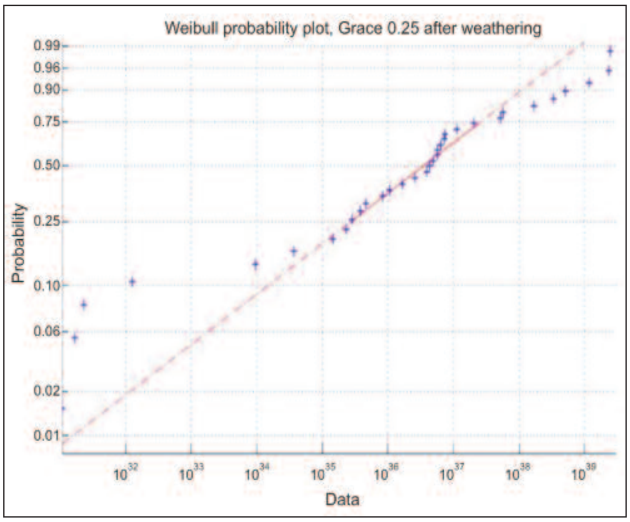

Fig. 5. Weibull Probability Plot
(GRACE 0.25 after weathering)

Figure 6 shows the bending cycles to break comparison for HYPOFF fibers with different diameter tested before and after UV-weathering. POF tend to break on average 30% easier after UV-weathering. Weibull Probability plot for 0.3 mm HYPOFF fiber before and after weathering are also shown in figures 7 and 8.

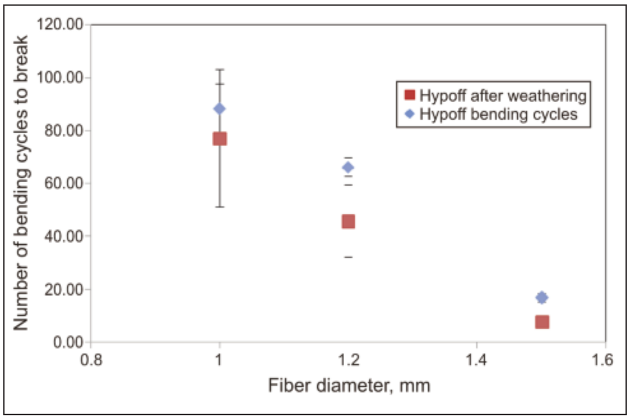

Fig. 6. Bending cycles to break HYPOFF

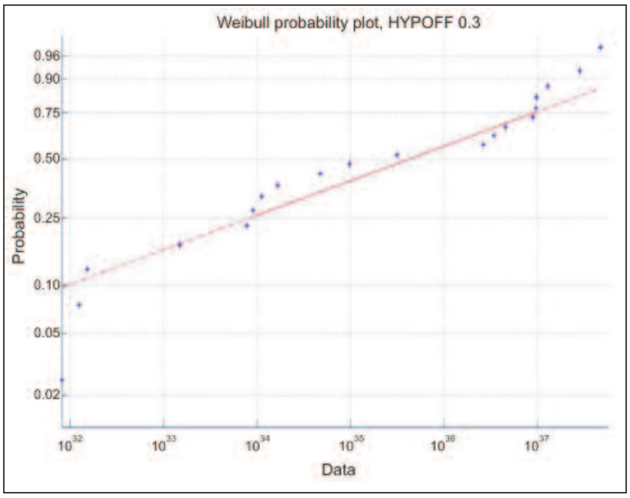

Fig. 7. Weibull Probability Plot (HYPOFF 0.3)

As explained in the previous part, from equations 2–4, parameters A, B and C of Weibull distribution were calculated as shown in table 3. Parameters of Weibull distribution is shown for Grace and Hypoff POF with different diameter and before and after weathering. Parameter B shows the scale parameter, parameter C is the shape parameter and parameter A shows the minimum cycles of bending to break and

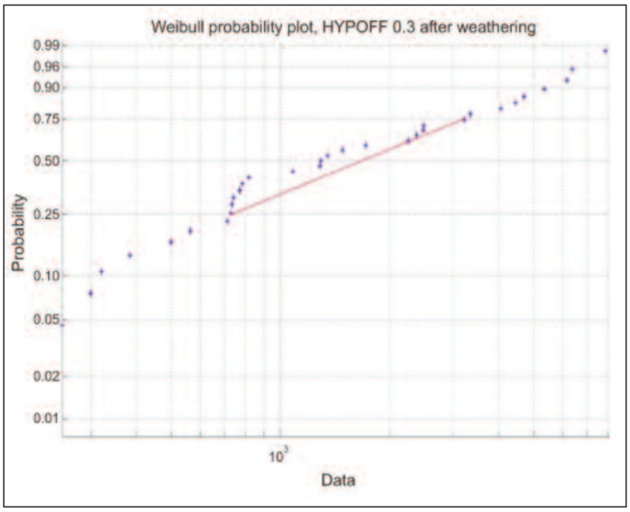

Fig. 8. Weibull Probability Plot (HYPOFF 0.3 after weathering)

there is a decrease of minimum bending of cycles to break after UV-weathering.

Flexibility is calculated from equation (8), from initial modulus and diameter of fiber, POFs with different diameters before and after UV weathering are shown in figure 9 and figure 10. It is seen that there is a

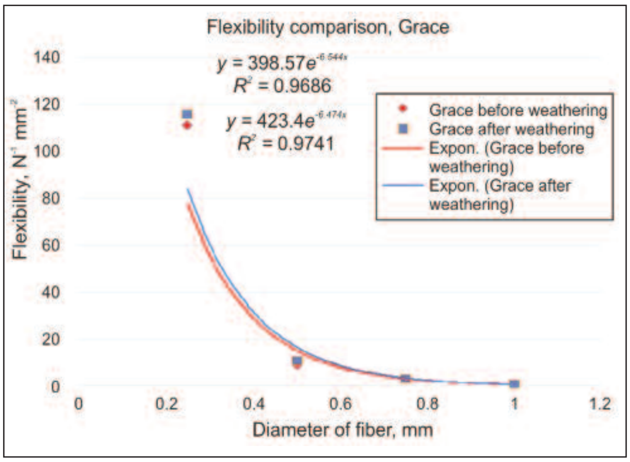

Fig. 9. Flexibility comparison of GRACE optical fibers

Table 3

THREE PARAMETERS OF WEIBULL DISTRIBUTION							
	Diameter [mm]	**Before weathering**			**After weathering**		
		Weibull shift A[Cycles]	**Weibull Scale B[Cycles]**	**Weibull Shape C**	**Weibull shift A[Cycles]**	**Weibull Scale B[Cycles]**	**Weibull Shape C**
GRACE	0.25	834	14938	3.488	576	8050	2.59
	0.5	72.5	936.2	0.6445	44.04	753	0.72
	0.75	71.8	82.6	0.43	34.83	128.18	0.511
	1	45.3	39.3	2.07	20.3	28.2	0.92
HYPOFF	1	30.42	65.04	1.79	15.5	55.34	0.82
	1.2	19.1	51.71	4.09	18.91	20.76	0.68
	1.5	6.11	11.89	1.99	1.95	6.2	1.27

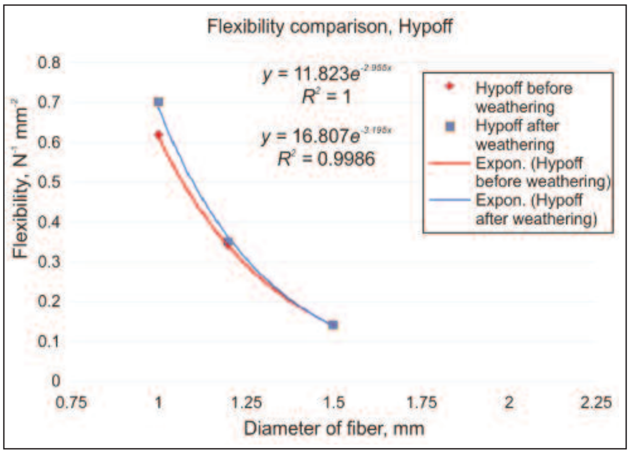

Fig. 10. Flexibility comparison of HYPOFF optical fibers

decrease of flexibility with the increase of fiber diameter and flexibility increases after UV-weathering.

CONCLUSIONS

This research concludes that:

- After weathering the POF breaks 30–40% easier than the POF before weathering.
- It is seen that the diameter has a significant influence on bending cycles to break. The numbers of bending cycles to break for POF is decreased with the increase of diameter.
- Flexibility of POF decreases with the increase of fiber diameter.
- There is minor increase in flexibility of POF after UV weathering.

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Comparative study about the effect of cleaning processes on the transmission performance of textile based conductive lines

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REZUMAT – ABSTRACT

Studiu comparativ cu privire la efectele proceselor de curățare asupra performanței transmisiei materialelor textile pe bază de linii conductoare

În concordanță cu evoluțiile tehnologice, sistemele electronice pot fi plasate cu ușurință pe suprafețe textile flexibile. Se estimează că va exista o creștere a gradului de utilizare a textilelor electrice în viitorul apropiat, pe măsură ce producția și cererea de astfel de produse va fi din ce în ce mai mare. Este esențial ca, performanțele în funcționare din timpul utilizării să fie investigate în scopul evaluării utilizării de zi cu zi a textilelor electrice. În acest studiu, sunt evaluate performanțele de transmisie ale firelor conductive, acestea fiind unul dintre materialele esențiale ale textilelor electrice. În cadrul studiului, pentru a observa efectul proceselor de curățare asupra caracteristicilor de electroconductivitate ale elementelor conductive din suportul textil, au fost investigate comparativ ciclurile de spălare repetate cu procesele de curățare chimică convenționale.

Cuvinte-cheie: fire conductive, spălare, curățare chimică, electroconductivitate

Comparative study about the effect of cleaning processes on the transmission performance of textile based conductive lines

In parallel with the technological developments, electronic systems can be placed easily on to textile based flexible fabric surfaces. It can be estimated that, there is an increase of the usability of electrotextiles in the near future with the production expansion and the increasing demand of such products. It's essential that, the in-use performances should be investigated in order to evaluate daily usage of the electrotextiles. In this study, the transmission performances of electrically conductive yarns, as one of the essential materials of electrotextiles, are evaluated. Within the study, in order to observe the effect of cleaning processes on the electroconductivity characteristics of textile based conductive pathways, the repeated washing cycles and conventional dry-cleaning processes are investigated comparatively.

Keywords: Conductive yarns, washing, dry-cleaning, electroconductivity

INTRODUCTION

In recent years, technological developments in the mobile technology and portable devices create an indelible impression in our world. On the other hand, clothing is also another indivisible part of our daily life as it is used almost anywhere and anytime. By the help of advancements in technology, clothing has more functions than just a certain climatic protection and a good look. Because of their close location to the body, they can provide a confident man-machine interaction that is necessary for smart and interactive clothing product design.

As widely known, the majority of fibers are non-conductive by nature. At the early stages of electrotextiles, textile-based conductors for electronics were not designed for the purpose of transmitting energy or data [1]. Early textile-based transmission bands generally use metallic multifilament yarns covered with regular threads as signal transmission lines [2]. At that time, the application fields of textiles with different levels of electrical conductivity were mainly required limited applications such as anti-bacterial purposes, static control and electromagnetic interference (EMI) shielding [3, 4, 5]. But with the developments on material science and technology, the textile based materials with sufficient electrically conductive properties provide extensive application fields thanks to the improvements regarding conductance, processability, reliability and signal transmission capability.

The conductive materials in the form of textile based structures are the indispensable components of smart/interactive wearable electrotextiles. In recent years, several methods such as fiber/wire manufacturing from metal plates, sliver or wires, fiber production by spinning and extrusion, coating fibers, yarns and fabrics with metals, metal oxides, metal salts, conductive carbon or conductive polymers have been developed for producing electrically conductive textile materials [6]. Electrically conductive hybrid yarns with user-friendly functions offer not only a wide range of active application possibilities with electronic components such as sensors and actuators, but also passive functionalities such as static dissipation, EM (electromagnetic) protection etc. [7].

Textiles used for clothing should be flexible and elastic in order to provide a comfort feeling [8]. Also tactile properties such as stretch, recovery, drape, shear and handle are the essential parameters for textiles and especially for clothing. For this reason, the electrically conductive materials should be also fine and fabrics should have a low weight per unit area [9].

Textile transmission lines can be placed onto textile surfaces in various ways. Firstly, laying down the conductive lines in the form of wires or yarns during the production of woven, knitted or nonwoven structures is one of the essential method. Also patterning, spraying or any other deposition of the conductive substrate onto textile based structures are also used for many purposes. Finally assembling the electroconductive pathways by using sewing or embroidery methods have also extensive usage for forming electrical circuits on to smart garments and related products [10].

Great effort is being made to replace conventional transmission lines by ones containing a conductive path often made of textile structures placed directly on a flat textile product at the production stage [11]. In order to get a wearable system to comply with the requirements on robustness and ergonomics, the conductive textile should exhibit adequate performances about durability, washability and flexibility. Therefore, textile based conductive transmission lines for networking, require an analysis of the mechanical and electrical characteristics of such materials and how they react to environmental stresses [10]. Several researchers have investigated the physical properties of fabric-based circuits for their mechanical and endurance characteristics and evaluated the effects of mechanical properties such as flexing, bending or abrasion on electrical characteristics of these circuits [12, 13, 14]. The mechanical behavior of metallic stretchable interconnections embedded in an elastic matrix for different and complex mechanical loadings are investigated by Gonzalez et al [15]. They evaluated both experimental and modelling results of stretchable interconnections for electronic circuits. Cho et al also examined the applicability of the textile based strips [16]. They tested the electrical durability of a Cu/Ni electro-less plated fabric reinforced by PU (polyurethane) sealing. Both linear and contact electrical resistance characteristics of the conductive fabrics play an major role in various applications such as body warming, health status monitoring, physical therapy etc. So, it is critical to explore the effects on the characteristics of conductive fabrics, under various conditions [17].

Karaguzel et al investigated the degradation in conductivity when washing screen-printed textile transmission lines [18]. Also Kayacan et al investigated the effects of various physical and chemical processes such as dying, washing and pilling on the electrical performances of knitted conductive yarns [19]. Schwarz et al measured the electrical resistance values of conductive yarns during straining, after cyclic straining, and after washing in order to analyze the stability and the reliability of the yarns [20]. Beside the wet processes, climatic conditions such as humidity can affect the performance of electrically conductive textile based materials. Hertleer et al and Scarpello et al investigate the influence of relative humidity on the performance of textiles in the form of wearable antenna structure [21, 22].

Conductive threads used for making fabric-based circuits need to have certain characteristics depending on the process employed for making the fabric circuits. In order to evaluate the technical competence of the textile lines, certain characteristics should be investigated. Characterization of electronic textile circuits obviously involves evaluation of their electrical behavior [23, 24]. In the case of textile lines supplying power to electronic circuits, which are devoted to leading a constant current, one of the parameters characterizing the line is electrical resistance [10].

As every textile-based materials, smart and interactive textiles, containing electronic infrastructures, are prone to get dirty as a result of daily activities (due to dust, sweat etc.) and they need to be washed [25]. Additionally, there are various studies about the effects of cleaning processes on the electrical conductivity properties of textile-based transmission lines in the literature [2, 26, 27, 28, 29]. However, almost no studies have been subjected to the comparison of wet cleaning cycles to dry-cleaning processes.

In this study, the evaluation of the conductivity properties of the textile based conductive transmission lines are evaluated by the help of measurement of the electrical resistance values when they are subjected to environmental stresses in form of washing and dry cleaning cycles. The results are evaluated comparatively.

EXPERIMENTAL WORK

Materials and method

In this study, electrical resistance variations, being one of the main parameter of the transmission, are examined in order to investigate the transmission performance of the electrically conductive textile lines. Five different electrically conductive yarns have been determined as the materials of the study. Two of them are made of stainless steel fibers while the others are 99% pure silver plated PA 6.6. General specifications of the materials are shown in table 1.

Table 1

PHYSICAL PROPERTIES OF THE CONDUCTIVE YARNS

Sample code	Composition	Yarn count [tex]	Average electrical resistance [Ω/m]
SS1	Stainless steel filament	505	14
SS2	Stainless steel filament	110	71
SP1	Silver plated PA 6.6 filament	116	50
SP2	Silver plated PA 6.6 filament	30	400
SP3	Silver plated PA 6.6 filament	27	500

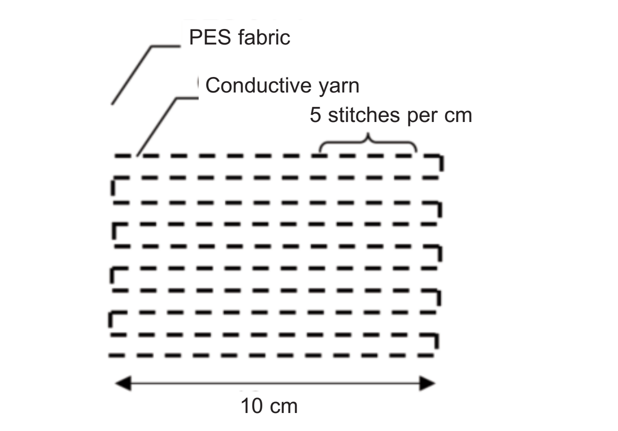

Fig. 1. General composition of the transmission lines

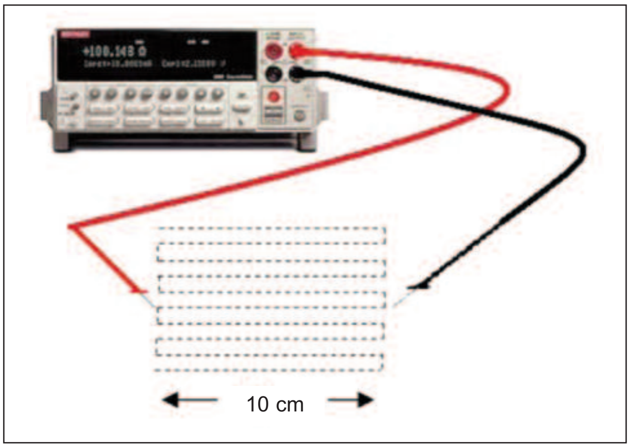

Fig. 2. Electrical resistivity measurement set-up

As seen on table 1, the sample yarns reflect a variety with various electrical resistance values, yarn count and material composition. The conductive yarns are processed by using sewing techniques in order to laying them on the fabric surface to form conductive pathways. Approximately 1 m long conductive yarn is sewn for each sample with 5 stitches per cm. All samples have been sewn on 100% PES raw fabric with a plain weave structure. The general overview for sample composition is shown in figure 1.

10 washing cycles have been carried out by using a home laundry machine with a detergent without optical brightener at 30 °C according to International Standard EN ISO 6330 [30]. In addition to the samples, the machine was filled with cotton fabrics to reach its standard load of 2 kg.

On the other hand, 10 repetitive dry-cleaning processes have been performed by using commercial dry-cleaning system according to International Standard EN ISO 3175 [31] in order to observe the effects of non-wet cleaning procedures on the electrical resistance characteristics of the textile based transmission lines.

After each cycle for both washing and dry-cleaning procedure, the electrical resistance values were measured by using 2-probe method with a broad purpose source-meter Keithley 2400 produced by Keithley Instruments with a range of 0.0001 Ω to 211 MΩ and a basic measure accuracy of 0.012% with 5½-digit resolution.

Measurements were carried out in an unconditioned room to correspond to the yarn's end application conditions. Appropriate grasp-type probes for conductive yarns have been used. The probes have been placed into both ends of conductive lines with a distance of 10 cm throughout the transmission lines as seen on figure 2. By this way, 10 measurements have been taken into account for the each transmission line on fabric surfaces respectively. Mean value of the measurements has been determined. The unit of the results has been presented as Ω /10 cm. ANOVA statistical analysis has been performed to support the interpretation of the results.

RESULTS

The conductive yarns with initial electrical resistance values per 10 cm that shown in table 1, have been sewn onto the fabric surface. 100% PES raw fabric with a plain weave structure having no electrical conductivity characteristic have been formed as a carrying platform for textile based transmission lines.

2 sets of samples have been prepared for washing and dry-cleaning processes. Also 1 set has been remained for control procedure. Repetitive washing and dry-cleaning procedures have been applied to each set of samples.

The electrical resistance values of the samples have been measured to define the effects of repetitive washing cycles. As stated before, approx. 1-m conductive yarn has been assembled on the fabric surface. Before and after each washing cycle, electrical resistance values of each 10 cm-long conductive line has been processed along the 1 m-long pathway. Conclusively, mean value of 10 measurements have been determined for each conductive yarn type. The electrical resistance value changes throughout 10-washing cycle can be seen in figure 3. Also the initial electrical resistance values of unprocessed conductive yarns and the results of final measurements are shown in table 2.

The repetitive washing cycles provide more or less impact on the electrical resistance values of all samples. Having stainless steel composition, the electrical

Table 2

COMPARISON OF ELECTRICAL RESISTANCE VALUES IN TERMS OF WHOLE DRY-CLEANING PROCESS FLOW

Sample code	Initial values of unprocessed raw material [Ω/10 cm]	Final values after 10 washing cycle [Ω/10 cm]
SS1	1.4	3.75
SS2	7.1	9.46
SP1	5	13.32
SP2	40	104.2
SP3	50	57.52

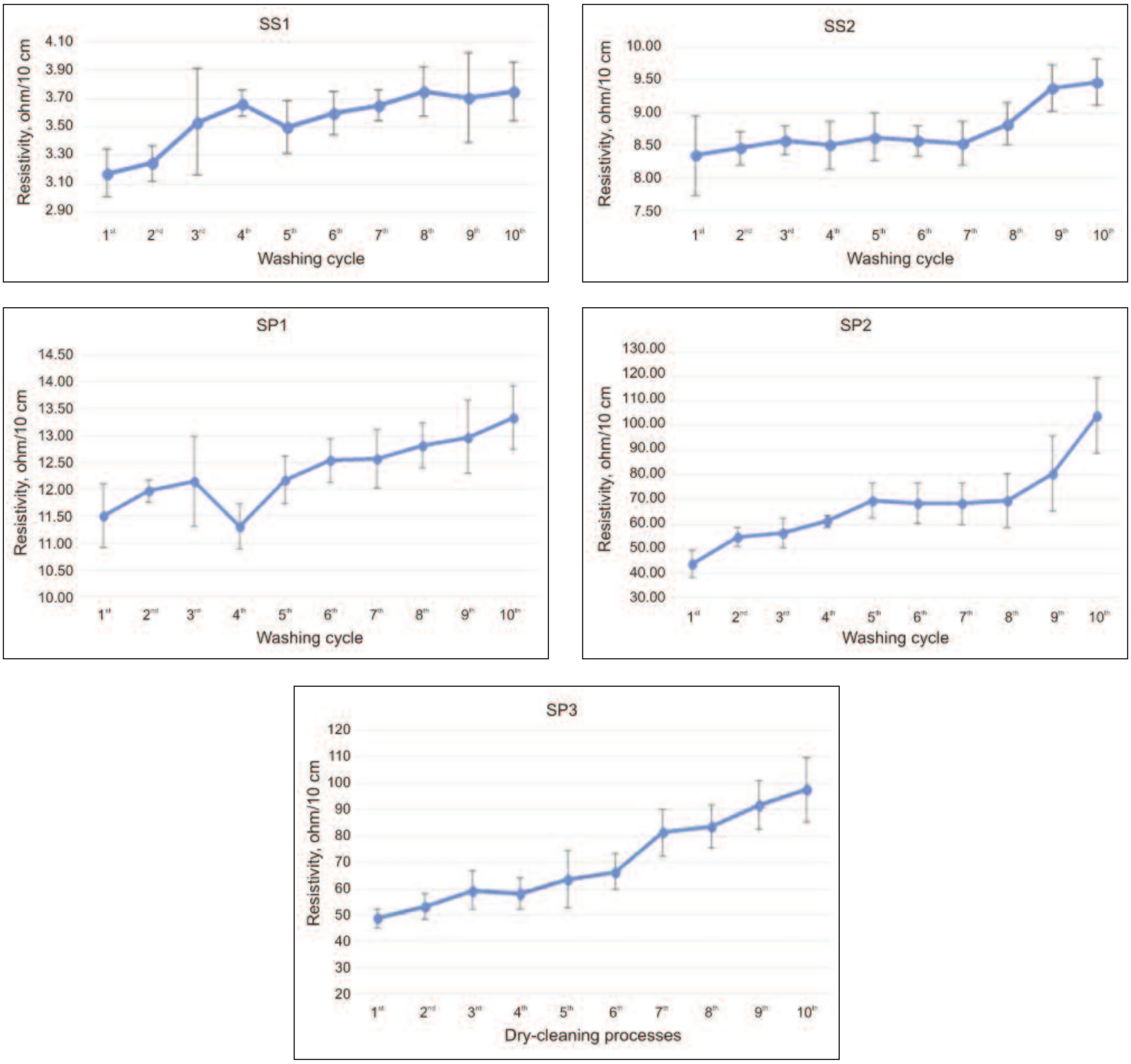

Fig. 3. Mean electrical resistance values of the conductive yarns after each washing cycle

resistance value of SS1 yarns has been increased more than 2.5 times, while SS2 provided an increase about 35% after 10-washing cycle. It can be said that, for the stainless steel samples, the coarser the yarn, the greater performance loss in terms of electroconductivity. On the other hand, among the silver containing samples, SP1 and SP2 showed a poor performance in comparison with SP3. The electrical resistance values of SP1 and SP2 have increased approximately 2.5 times while SP3 reached about 15% more than its initial value.

If the general flow of repetitive washing processes is examined, SS1, SS2 and SP1 yarns have a fluctuation in terms of electrical resistance values as seen on figure 3. But SP2 and SP3 have shown a continuous increasing tendency during almost whole processes and they reached their final level. According to the results, it can be concluded that, the coarser the yarn, the greater the increase for the silver plated samples as seen on table 2.

On the other hand, measurements throughout 10 dry-cleaning are shown in figure 4 and the initial / final values of this process flow can be seen in table 3.

As well as washing cycles, all samples have been also affected by the repetitive dry-cleaning cycles in

Table 3

COMPARISON OF ELECTRICAL RESISTANCE VALUES IN TERMS OF WHOLE DRY-CLEANING PROCESS FLOW

Sample code	Initial values of unprocessed raw material [Ω/10 cm]	Final values after 10 dry-cleaning cycle [Ω/10 cm]
SS1	1.4	3.19
SS2	7.1	8.01
SP1	5	15.4
SP2	40	195.6
SP3	50	97.52

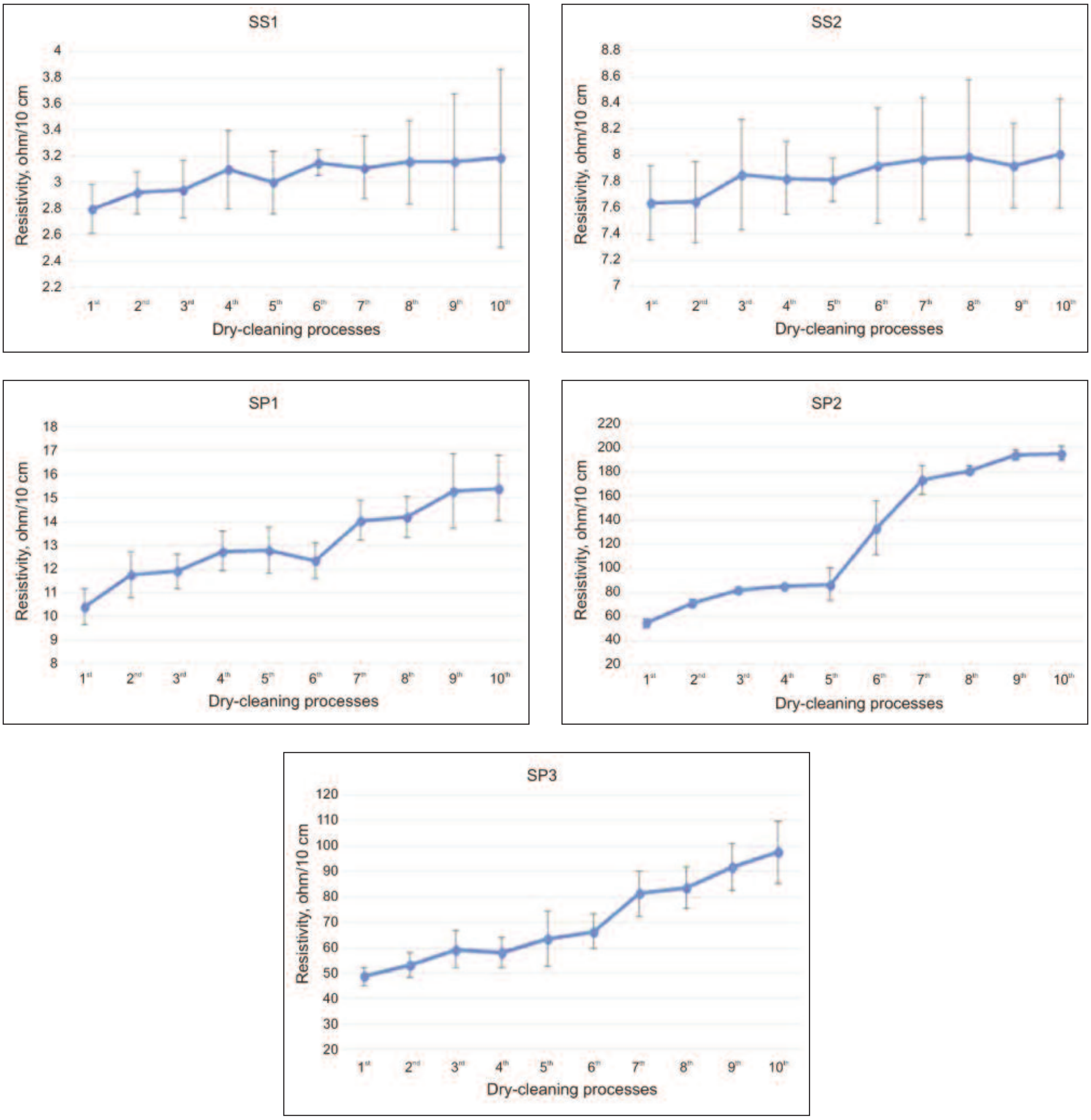

Fig. 4. Mean electrical resistance values of the conductive yarns after each dry-cleaning cycle

negative ways. SS1, SS2 and SP1 yarns follow a fluctuating course during the process flow as observed in washing-cycles. On the other hand, SP2 and SP3 perform a continuous increasing tendency.
As for stainless steel samples, SS2 performs better than SS1. SS2 provides approximately 15% increase, while the resistivity values of SS1 show an increase more than 2 times during dry-cleaning processes.
Among the silver plated samples, SP2 is the one that are affected by dry-cleaning the most. There is approximately 5-time increase considering its initial value. SP3 provides approximately 2 times increase while SP1 performs an increase of about approximately 3 times.
If different cleaning process flows are compared in terms of electrical resistance values of the samples, the overview can be summarized as in figure 5.

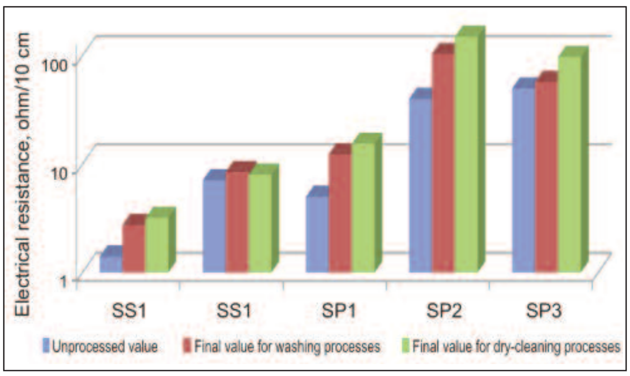

Fig. 5. Comparative results for all conductive yarns

The ANOVA Test also has been performed to support the interpretation of the results in order to determine

Table 4

ANOVA RESULTS OF REPETITIVE WASHING CYCLES						
Source	**Dependent variable**	**Sum of squares**	**df**	**Mean Square**	**F**	**Sig.**
Washing cycles	SS1	2.684	9	.298	3.429	.002
	SS2	6.305	9	.701	2.307	.025
	SP1	27.418	9	3.046	5.483	.000
	SP2	15507.228	9	1723.025	13.213	.000
	SP3	3236.377	9	359.597	18.631	.000

Table 5

ANOVA RESULTS OF REPETITIVE DRY-CLEANING PROCESSES						
Source	**Dependent variable**	**Sum of squares**	**df**	**Mean Square**	**F**	**Sig.**
Dry-cleaning	SS1	1.316	9	.146	.777	.638
	SS2	.982	9	.109	.432	.913
	SP1	129.730	9	14.414	8,853	.000
	SP2	165024.320	9	18336.036	80.487	.000
	SP3	13697.321	9	1521.925	12,265	.000

the effect of cleaning procedures on the electrical resistance values of the textile based transmission lines. Tables 4 and 5 indicate the results of the both process flow.

According to ANOVA test results, the effect of repetitive washing cycles for all types of the samples was found significant at $\alpha = 0.05$ level.

On the other hand, effect of repetitive dry-cleaning procedures, for the yarns with stainless steel composition, was not found statistically significant at $\alpha = 0,05$ level. SS1 and SS2 provide the significant levels as 0.638 and 0.913 respectively. As seen on the results of ANOVA analysis, having 100% stainless steel fiber composition, SS1 and SS2 yarns haven't been affected by dry-cleaning procedures as silver plated ones. The surface of stainless steel materials are also plated by using chromium (III) oxide (Cr_2O_3) layer, to protect the material from oxidation. Even though the layer is impervious to water, it might get damaged due to mechanical actions during repetitive washing processes. This case might be affected their resistivity levels. But it can be concluded that dry-cleaning procedures did not affect to yarn construction. So the increase in resistivity was not found statistically significant for dry cleaning processes.

According to the results of the repetitive washing cycles, the second 5-cycle caused more increase than the first 5-cycle. It can be concluded that the material composition and the general material characterization of the samples reflects more durability against first 5-washing cycle. On the other hand, dry-cleaning procedures provide less effect on stainless steel samples especially for finer samples due to non-wet characterization of the process. As seen on figure 5, dry-cleaning procedures have greater impact on resistivity values especially for silver plated finer conductive yarns. Even though dry-cleaning can be defined as a non-wet process, the increase in electrical resistance can be explained through the damage of silver layer that plated on the fibers/yarn surface, whereby electrical current flow is obstructed. It means that active substances used during commercial dry-cleaning process can affect the conductive layer more than washing cycles.

CONCLUSIONS

Consequently, the results and findings of the study show that, textile based conductive transmission lines that are incorporated onto fabric surfaces have various behaviors in terms of electrical resistance changes against environmental stresses in form of washing and dry cleaning cycles. These behaviors can occurr according to conductive yarn composition and the applied processes.

Protection and aesthetics are the two common dimensions or attributes typically associated with textiles as clothing. However, with the rapidly changing needs of today's consumers, a third dimension is emerging – that of "intelligence" – that is being integrated into fabrics to produce interactive textiles. Researchers working in the area of electrotextiles realize that there are numerous challenging issues as achieving reliable interconnect formation, improving signal integrity, maintaining textile characteristics, providing efficient means of power generation/harvesting [32, 33].

Also, the cleaning procedures, whether washing or dry-cleaning, are one of the indispensable parts of textiles due to their characterization as prone to be dirty in daily usage. If electrotextiles are desired as a part of daily life in the future, it's essential that, the in-use performances should be investigated in order to evaluate their characteristics after cleaning process. The performance tests under different conditions for various conductive textile based pathways should be examined and evaluated.

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Simulation of electromagnetic shielding test results based on differential evaluation algorithm

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SÜMEYYE ÜSTÜNTAĞ
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REZUMAT – ABSTRACT

Simularea rezultatelor testelor de ecranare electromagnetică pe baza algoritmului de evaluare diferențial

Ca răspuns la îngrijorările legate de creșterea ratei radiațiilor electromagnetice, un număr mare de cercetători se concentrează pe dezvoltarea de textile sau materiale compozite cu fibre textile, cu rol de ecranare. În literatură există două tehnici cunoscute de măsurare a eficacității de ecranare a materialelor textile, și anume metoda de transmisie coaxială în linie și metoda camerei de ecranare. În cadrul acestui studiu s-a dezvoltat un model neliniar pentru simularea rezultatelor SE ale metodei transmisiei coaxiale în linie cu metoda camerei de ecranare, folosind algoritmul de evoluție diferențială. Concluzia desprinsă este aceea că metoda transmisiei coaxiale în linie poate fi folosită cu ușurință pentru măsurarea eficienței ecranării electromagnetice a materialelor textile compozite, folosindu-se modelul nostru optimizat.

Cuvinte-cheie: eficiența ecranării, metoda camerei de ecranare, metoda de transmisie coaxială în linie, algoritm de evoluție diferențială

Simulation of electromagnetic shielding test results based on differential evaluation algorithm

In response to the concern about growing electromagnetic radiation rate, a great number of researchers focus on developing textile or textile based composites shielding materials. There are two common measurement techniques to determine the shielding effectiveness of textile materials in literature, namely coaxial transmission line method, shielding chamber method. There is no effective method for comparing the shielding effectiveness results measured using the coaxial transmission line method and the shielding chamber method. In this study, we developed a non-linear model to simulate SE results of the coaxial transmission line method according to shielding chamber method by using Differential Evolution Algorithm. It is concluded that the coaxial transmission line method can be used easily in the measurement of electromagnetic shielding effectiveness of composite textile materials by using our optimized model.

Keywords: shielding effectiveness, shielding chamber method, coaxial transmission line method, differential evolution algorithm

In recent years, the use of electrical and electronic devices that generate electromagnetic (EM) fields has grown rapidly with the fast progress in knowledge and technology. Many electrical/electronic devices that are used in our daily life such as computers, mobile phones, microwave oven, modems, printers, radio, television sets and base stations are capable of emitting EM energy. EM fields have both electric and magnetic field components, and they have hazardous effects on the living tissues and electronic systems. Unwanted reception of EM waves may create an interference phenomenon that has adverse effect called electromagnetic interference (EMI) problem, on the performance of electrical/electronic equipment [1]. The hazardous effect of EM waves on human health can also be considered as an EMI problem since the human body is actually an electrical system with a huge nervous system [2]. Because of the detected negative effects of electromagnetic waves, it has become a necessity to prevent electromagnetic waves from entering into the human body, as well as reducing adverse effects on electronic systems [3–8].

To avoid the problems caused by EM fields, the shielding is required. EM shielding is a process by which a material is able to reduce the transmission of electromagnetic radiation that affects the humans/equipments [9]. Shielding of EM radiation is becoming more critical due to the smaller size and faster operating speeds of electronic components of devices, which make it more difficult to manage the EM pollution they create [7].

When an EM wave is passing through an object, shielding is accomplished mainly by reflection and absorption. As the wave impinges the surface of the object, it forces charges in the object to oscillate at the same frequency of the incident wave. This forced oscillating charge behaves as an antenna and results in reflection. On the other hand, as the charge is forced to vibrate in the medium, energy is lost in the form of heat. This is the decrease of EM radiation due to its absorption [7].

Traditionally, metals and alloys are used for EM shielding; however, these materials are heavy and expensive, and may be subject to thermal expansion and metal oxidation, or corrosion problems associated with their use [10–13]. Lately, applications of electromagnetic shielding with textile materials are used more widely instead of metal screens and other traditional shielding materials. On account of their desirable flexibility and lightweight properties, a large number of researchers pay their attention on developing textile shielding materials [1–18].

The electromagnetic shielding effectiveness (EMSE) is a key parameter which often determines the scope for application of a given material. The shielding effectiveness for metal shields can be determined just by knowing the materials' electrical and magnetic parameters, whereas for the textile structures and composite materials, the shielding effectiveness only can be determined by actually measuring it [19]. Shielding effectiveness (SE) is defined as the ratio of the electromagnetic field intensity measured before and after the shielding material is installed. It can be expressed as:

$$SE\ [dB] = 20 \log (E_1/E_2) \quad (1)$$

$$SE\ [dB] = 20 \log (H_1/H_2) \quad (2)$$

where the values of the electrical component E_1 and the magnetic component H_1 are measured without the shield, whilst the values E_2 and H_2 are measured with the shield. In the far field of any source of electromagnetic radiation, there is a fixed relation between electric and magnetic field, so (1) and (2) are completely equivalent [8]. There are several methods available which allow the shielding effectiveness to be measured such as free space methods, shielding chamber/box methods, coaxial transmission line methods, and dual-TEM cell methods [18–21].

The shielding effectiveness measurement results obtained using currently known methods depend not only on the size of the test sample, the geometry of the test set-up, and the parameters of the source of electromagnetic radiation. At the current state of research and development, it is not always possible to take all of these additional factors into account [19]. Even though, there is a lack of generally accepted standardized methods for measuring SE of conductive textile or textile based composites, there are two common measurement techniques to determine the SE of textile materials in literature; one is the "coaxial transmission line method" and the other is the "shielding chamber method" technique.

The shielding chamber method is generally considered a better test in comparison to coaxial transmission line method [19]. There are numerous adaptations of this method. MIL-STD 285, IEEE-STD-299 and later standards (e.g. IEEE Std 1302-1998) are all based on the shielding chamber method. These standards define the frequencies and electromagnetic field components which are subjected to testing, and state the equipment required & the antenna configurations. In the method, the material being evaluated shields an opening in a correctly shielded enclosure [18]. Comparison measurement of the electrical field intensity E, magnetic field intensity H with the opening open and covered with the shielding material fed into formula (1) or (2) allow the SE to be determined. As compared the coaxial transmission line method, the shielding chamber method can be used to measure at significantly higher frequencies. Also the EMSE of textile fabrics can be evaluated for different polarization of electromagnetic waves with the shielding chamber method. On the other hand, the shielding chamber method has several disadvantages. The test results obtained for the same material tested at different laboratories can vary, even by as much as several dB. This is because the opening type in the shielded wall of the chamber also affects the measurements. Furthermore the shielding chamber method requires excellent proficiency and measurement experience from the test operator.

The coaxial transmission line method specified in ASTM 4935-10 consists of two consecutive transmission measurements between two coaxial adapters with and without sample under test present [22, 23]. The principle of the design of the flanged coaxial line sample holder is based on transmission line theory. For the coaxial transmission line, the principal mode of propagation is the transverse electromagnetic (TEM) wave, meaning that the magnetic (H) and electric (E) field vectors are both perpendicular to the direction of current propagation [8, 23, 24]. The coaxial transmission line method has some advantages in respect of test duration and required labor for preparing the test material. However, it has also serious drawbacks decreasing the limit and confidence of measurement. First, the thickness of the tested materials cannot exceed 1/100 of the wavelength of the EM wave in open space for this method, i.e. the thickness of the material should not exceed 2 mm for a test frequency of 1500 MHz or 3mm for 1000 MHz [18]. In addition it is necessary to ensure a fixed distance between coaxial adapters (in another words constant pressure onto the surface of the sample) during the test. Another important drawback that can cause non-linear effects in frequency-dependent characteristics is inhomogeneities in metal alloy used for producing the coaxial holder. Because of these non-linearities, measurements made by the coaxial transmission line method need some corrections if compared to the shielding chamber method.

Based on the literature review, it is clear that at the current state of research development there is no effective method for comparing the SE results measured using the coaxial transmission line method and the shielding chamber method. Therefore in this study, we developed a non-linear model to simulate SE results of the coaxial transmission line method to the shielding chamber method. In model development and evaluation, we used test results of both coaxial transmission line and shielding chamber method belonging to seven different fabrics woven from hybrid yarns. We also optimized the parameters of the non-linear model by using Differential Evolution Algorithm.

MATERIALS AND METHODS

In this study, seven different fabrics offering electromagnetic shielding were used as samples. The woven fabric samples were made from hybrid yarns which consist of commercially available metal wire (stainless steel) and polyester (PES) filaments. To

Table 1

SPECIFICATIONS OF FABRIC SAMPLES				
Fabric code	Weave type	Weft density [picks/cm]	Warp density [ends/cm]	Mass per unit area [g/m^2]
S1	Plain 1/1	21	25	106
S2	Plain 1/1	23	25	112
S3	Plain 1/1	25	25	116
S4	Plain 1/1	28	25	120
S5	Panama 2/2	28	25	117
S6	Rib 2/2	28	25	118
S7	Twill 3/1	28	25	118

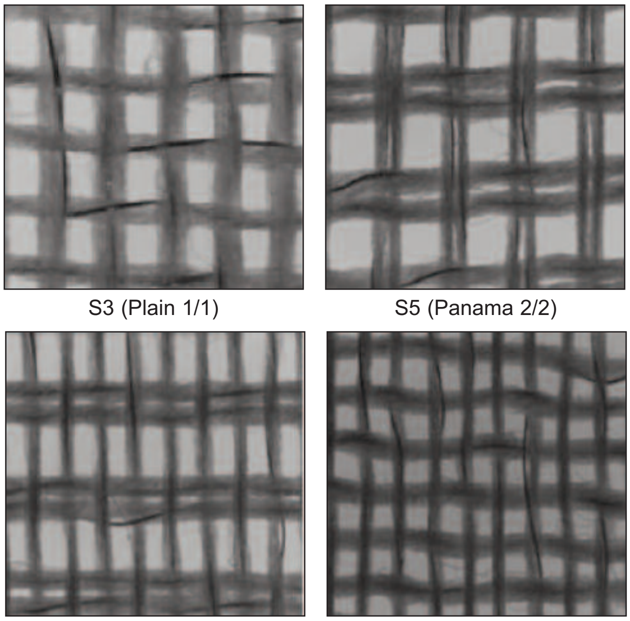

S3 (Plain 1/1) S5 (Panama 2/2)
S6 (Rib 2/2) S7 (Twill 3/1)

Fig. 1. View of different weave types

produce the hybrid yarn, the metal wire was covered with the PES filaments in the S-direction with 300 (Turns per meter-TPM), using a hollow spindle covering machine. 100d/36f PES filament was selected for cover part of hybrid yarns. Stainless steel (SS) wire with diameter 0.035 mm (Nm 131) which has 8.0 kg/dm^3 and 785 Ω/m DC resistance was selected as a core conductive part of hybrid yarn. The hybrid yarns were selected as warp and weft yarns for producing woven fabrics. The specifications of woven fabrics are summarized in table 1. The views of different woven fabric structures are also given in figure 1. Both the coaxial transmission line method and the shielding chamber measurement technique are used for the SE measurements.

SE measurements via coaxial transmission line method

Coaxial transmission line equipment is used according to ASTM D 4935 for the SE measurements of fabric samples in the frequency range of 30 MHz – 1.5 GHz. As seen in figure 2, the measurement setup consists of two coaxial adapters and a network analyzer for generating and receiving the electromagnetic signals.

The shielding effectiveness is determined by comparing the difference in attenuation of a reference sample to the test sample, taking into account the

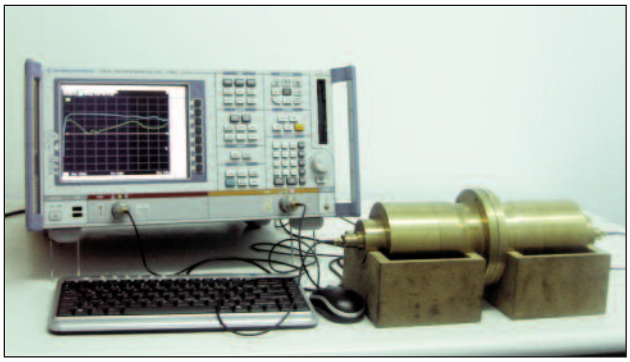
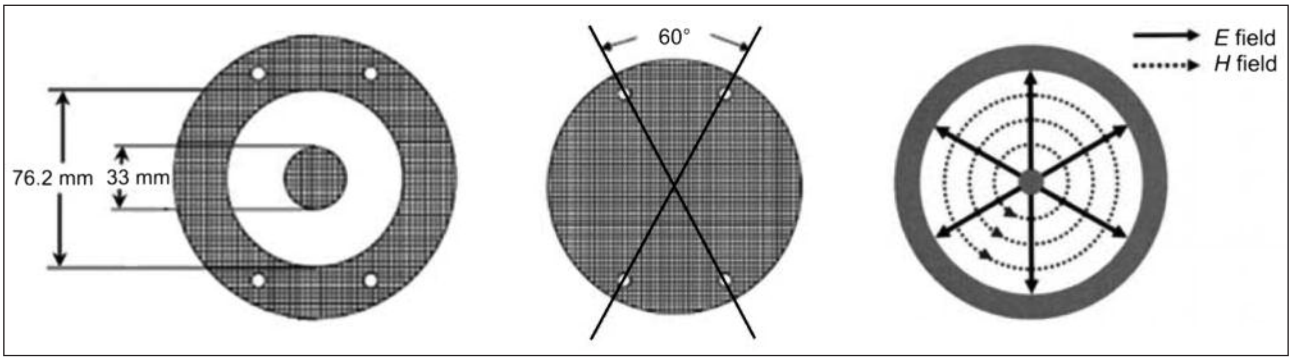


Fig. 2. Test set up of coaxial transmission line method

insertion losses. The reference and the test measurement were performed on the same material. The reference sample was placed between the flanges, covering only the flanges and the inner conductors. A test measurement was performed on a solid disk shape which had a diameter the same as that of the flange (figure 3).



a *b* *c*

Fig. 3. (a) Reference, (b) test sample geometry and (c) electric and magnetic field distribution inside a coaxial line complying with ASTM D 4935-10 [8,13]

The test sample is exposed to electric fields in all directions over the full 360° within the coaxial holder (figure 3c).

SE measurements via shielding chamber method

SE of the fabric samples was also tested based on the shielding chamber measurement technique. The test set up was prepared according to IEEE Standard 299-1997 [25] and IEEE Standard 1302-1998 [26] and a schematic diagram of the test set up is given in figure 4.

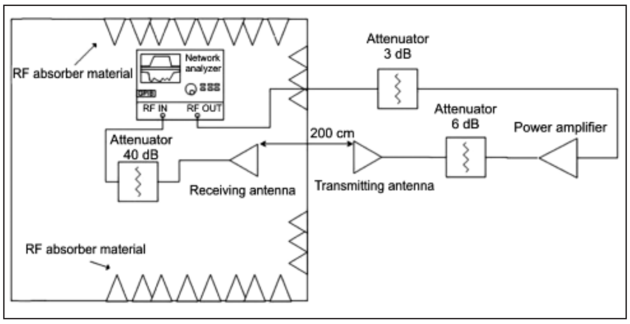
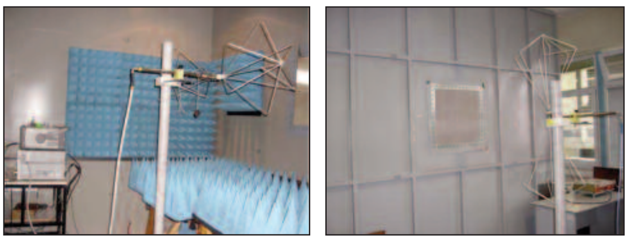


Fig. 4. Schematic diagram of shielding chamber method test setup

The measurement device was placed inside the tested enclosure (figure 5a), whilst the signal source was located outside. Electromagnetic signals were generated and transmitted through an antenna outside the chamber (figure 5b). The test area, in the shape of a square (0.6 x 0.6 m^2), was obtained by creating an opening in the wall of the shielding chamber. The measurements were carried out while the transmitting antenna is placed outside of the shielded chamber and the receiving antenna was within the shielded chamber. Signals were measured by a spectrum analyser with the antenna inside the chamber. Radio frequency absorbing materials have been used on the walls inside the shielding chamber in order to diminish the reflection which may occur at the walls of the chamber. SE tests were carried out in the frequency range of 0.030 GHz to 1.5 GHz. For different frequency ranges, different antennas, such as biconical (30 MHz – 300 MHz), log-periodic (300 MHz – 1 GHz) and horn (1 GHz – 1.5 GHz) were used. The distance between the receiving and transmitting antennas were 200 cm.



a *b*

Fig. 5. Photographs of the prepared test set up: Shielding Chamber inside (a), outside (b)

Measurements were performed by using both horizontal (figure 5a) and vertical polarization (figure 5b) of antennas.

Differential evolution algorithm based model development

By solving some engineering problems, especially in the systems without transfer function relating the input(s) to the output(s), population based algorithms became popular in recent years [27–30]. Differential Evolution Algorithm (DEA) is one of the most popular, simple and powerful algorithm and it utilizes some strategies such that crossover, mutation and selection, like the other population based algorithms. These strategies are carried out in DEA's basic steps as can be seen in figure 6. The algorithm starts a randomly generated initial population whose size is represented by NP (population size). The initial population contains possible candidate solutions of the problem. If the solutions are satisfactory, the algorithm ends; otherwise the individuals in the population are mutated in the mutation step. In the mutation operation, a mutation scheme is used in which a vector is generated called as mutant vector. After the crossover and evaluation steps, the new individuals that are new possible candidate solutions of the problem are selected in the selection stage and re-evaluated in the algorithm. Detailed information about DEAs and their applications to electromagnetics can be found in the literature [30].

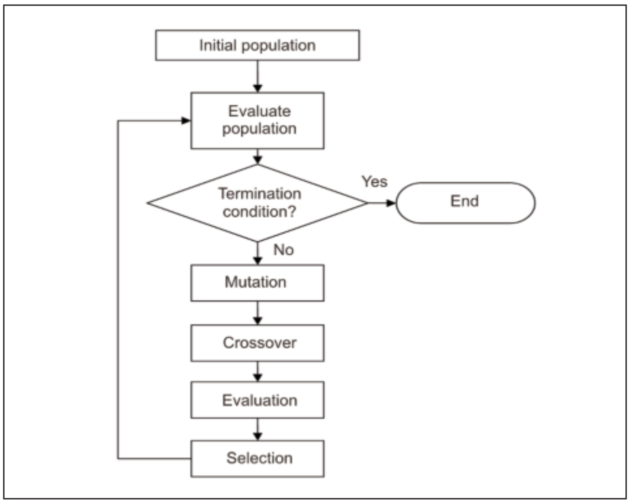


Fig. 6. Simple optimization process of Differential Evolution Algorithm

Applying the DEA into a specific problem, a model whose parameters will be optimized is selected. Generally, the structure and the number of the parameters of the model are based on experience. In our work, we chose a simple model having five parameters (P_1 to P_5) to be optimized by DEA,

$$SE = P_1 \times f + P_2 \times \exp(P_3 \times f) + P_4 \times SE_{in} + P_5 \quad (3)$$

where SE is resulting electromagnetic shielding effectiveness in dB, *f* is frequency in GHz, and SE (in dB) is the raw measurement results obtained by

Table 2

CONTROL PARAMETERS OF DIFFERENTIAL EVOLUTION ALGORITHM	
Control Parameter	Value
Population size (NP)	100
Crossover rate (CR)	0.8
Scaling factor (F)	0.8
Generation size	1000
Crossover type	Binomial
Mutation vector	$v_i^{(G+1)} = x_{best}^{(G)} + F(X_K^{(G)} - x_L^{(G)})$

coaxial line holder method. The model was used to simulate the results of coaxial line holder method to the results of the shielding chamber method for the both horizontal and vertical polarization states of SE measurements. Since the shielding chamber measurements are carried out two different polarization states (i.e. horizontal and vertical), the model needs two optimized sets of the parameters. We used only one exponential term in our simple and effective model in order to control the non-linear behavior of the SE values. Control parameters of DEA are given in table 2. In the mutation vector given in the table, x_K and x_L represents different individuals in the population, x_{best} is the best individual in the population, G is generation, v is the mutation vector, and F is the scaling factor.

By using our proposed model in case of the control parameters given in table 1, we implemented the optimization procedure given in figure 6. In our study, we observed that the control parameters given in table 2 have a limited impact onto the model results if the model is defined properly and the control parameters are not trivial. If NP is selected very large, for example, solutions generated by DEA may not converge to the results expected. In other hand, if it is selected in a narrow range, the number of the individuals to be mutated may be inadequate and the results may not reach to the global minimum. For all the optimization purposes, we used only one dataset belonging to the fabric coded as S4 in ref. [14].

RESULTS AND DISCUSSIONS

Model development is the most important step in differential evolution algorithm. Because the algorithm can't converge a minimum value unless a proper model that that meets the need of all non-linearities isn't defined. As a result, we selected the model given in equation (3) and then started the algorithm. After several times running of the optimization process, the optimized model parameters for the two types of the polarization states are given in table 3. It is important to note that each optimization process takes less than 10 seconds for a standard personal computer. Also note that, we used average DEA outputs belonging to several runs, but for simplicity we rounded the values for calculation purposes.

Resulting equations obtained by optimized models for both horizontal and vertical polarization states are given in equations (4) and (5), respectively.

Horizontal,

$$SE = -8.70 \times f - 50.10 \times \exp(-22.44 \times f) - - 0.29 \times SE_{in} + 67.31 \quad (4)$$

Vertical,

$$SE = -11.14 \times f - 41.24 \times \exp(-20.28 \times f) - - 0.12 \times SE_{in} + 64.98 \quad (5)$$

Simulation results of the coaxial line holder method according to the anechoic chamber method are given in figures 7 to 13. In graphs, dotted (· · · ·) and solid line (——) traces represent raw measurement results of the coaxial line holder method and the results of the anechoic chamber method, respectively. Our main effort in this work is to develop an optimized model that makes useful the coaxial line holder method in measurement of electromagnetic shielding effectiveness, especially for composite textile materials. The results of our proposed model are represented by dash-dotted (– · – ·) traces in following graphs.

As can be seen from the comparisons given in the figures 7–13, our optimized model successfully simulated the raw results to that of anechoic chamber method, although we used the measurement results of only S4 coded fabric as simulation data. In other words, we used the dataset of the S4 fabric as training data and the others were test data. In order to test

Table 3

OPTIMIZED MODEL PARAMETERS WITH BEST ESTIMATES AND ROUNDED VALUES				
Optimized parameter	**Horizontal polarization**		**Vertical polarization**	
	Rounded	**Best estimate**	**Rounded**	**Best estimate**
P_1	–8.70	–8.70404	–11.14	–11.14397
P_2	–50.10	–50.10097	–41.24	–41.24209
P_3	–22.44	–22.43594	–20.28	–20.27622
P_4	–0.29	–0.28682	–0.12	–0.11936
P_5	67.31	67.31209	64.98	64.98298

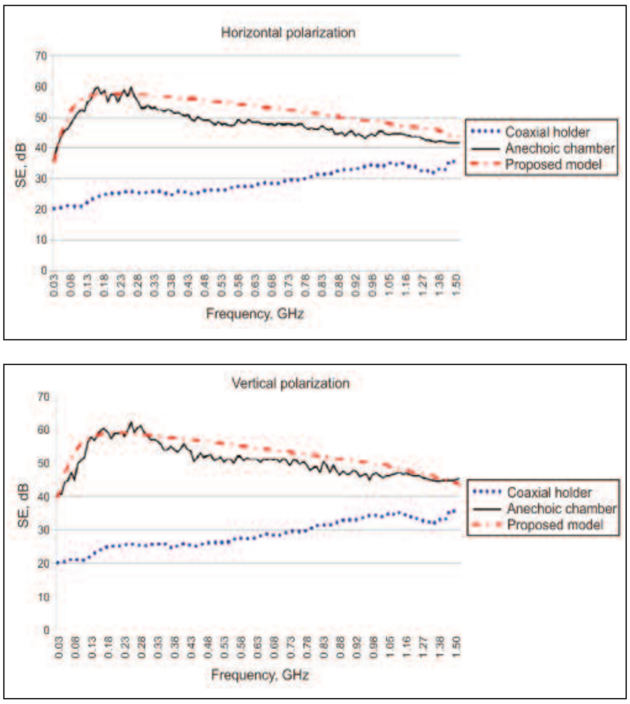


Fig. 7. Simulation results between the coaxial line holder and anechoic chamber method for S1 coded fabric

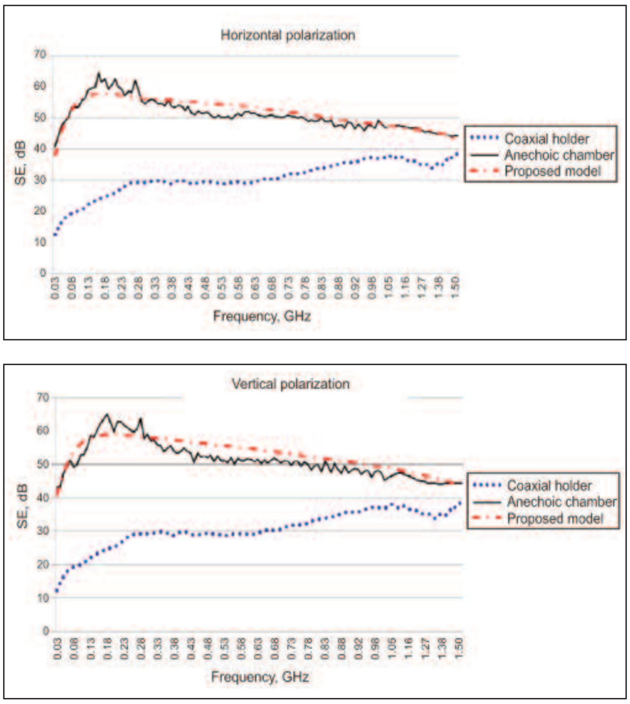


Fig. 9. Simulation results between the coaxial line holder and anechoic chamber method for S3 coded fabric

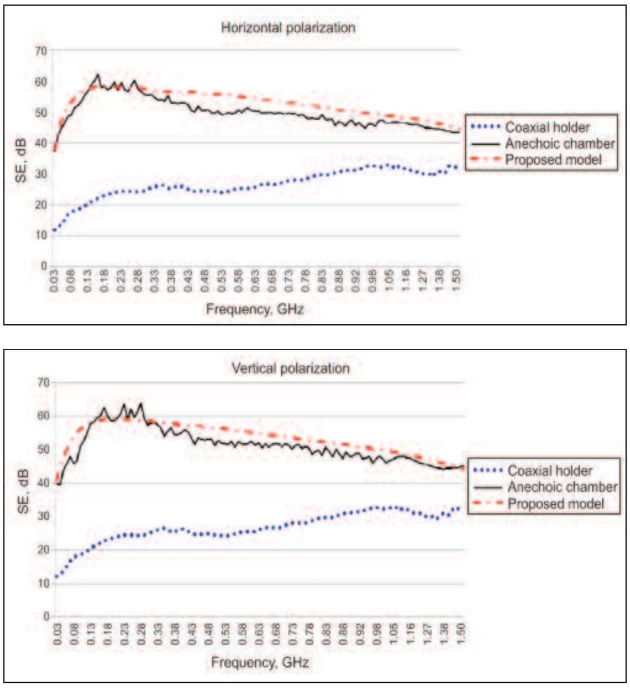


Fig. 8. Simulation results between the coaxial line holder and anechoic chamber method for S2 coded fabric

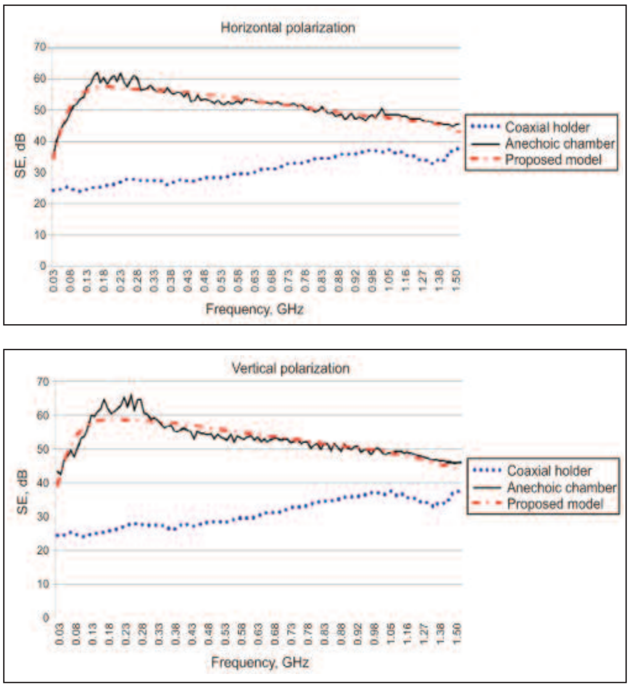


Fig. 10. Simulation results between the coaxial line holder and anechoic chamber method for S4 coded fabric

our model performance we calculated the average percentage errors of each fabric for both horizontal and vertical polarizations. Because of the fact that measured and calculated results consist of a large number of data (more than 3400), we give only average percentage errors in table 4.

Since our main aim is to develop only one model for all fabric types and for both horizontal and vertical polarizations presented in this work, there may some small and insignificant deviations between our proposed

Table 4

Fabric code	Average percentage errors	
	Horizontal	Vertical
S1	8.67	5.57
S2	6.25	5.23
S3	3.36	4.93
S4	2.17	2.99
S5	4.62	7.36
S6	4.18	7.49
S7	3.04	2.91

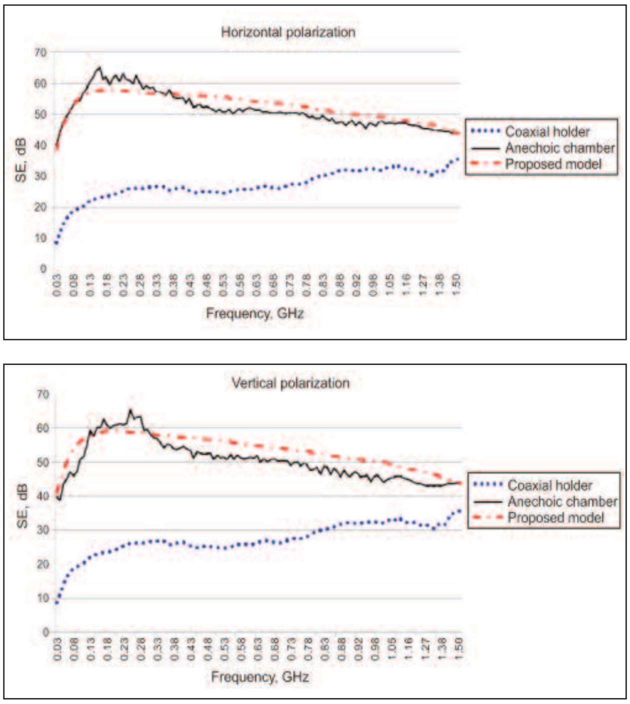


Fig. 11. Simulation results between the coaxial line holder and anechoic chamber method for S5 coded fabric

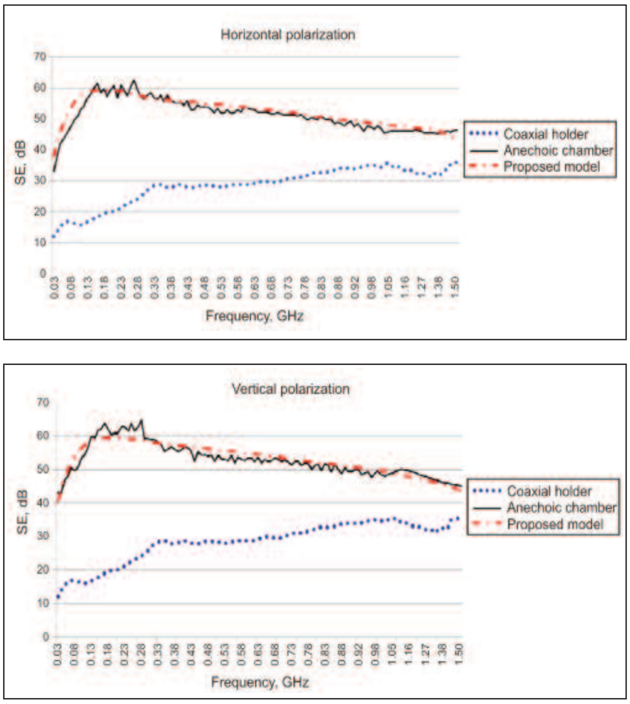


Fig. 13. Simulation results between the coaxial line holder and anechoic chamber method for S7 coded fabric

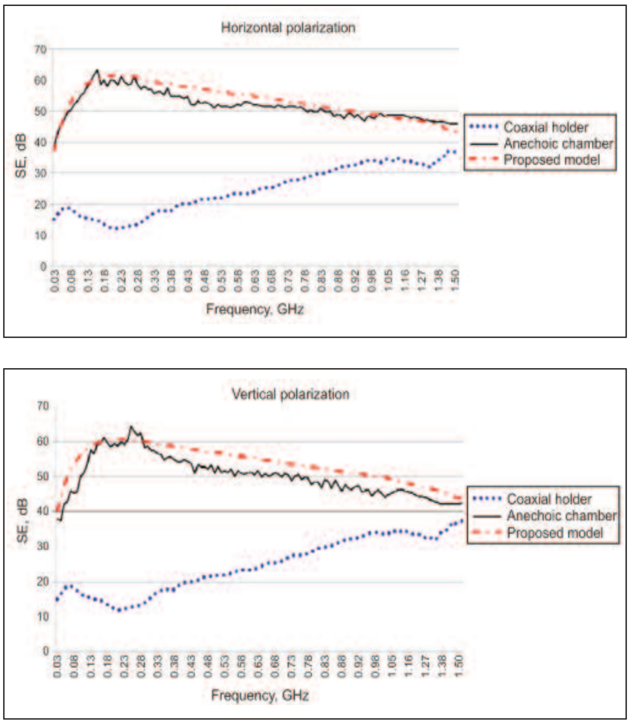


Fig. 12. Simulation results between the coaxial line holder and anechoic chamber method for S6 coded fabric

model results and anechoic chamber's results, especially below 0.3 GHz. This problem can be solved by using more complicated and consequently more parameters to be optimized. Fortunately, the errors given in table 4 are less than 10%; we think that we have a simple but efficient model.

CONCLUSIONS

In this study, we developed a non-linear model to simulate SE results of the coaxial transmission line method according to that of shielding chamber method and then we optimized the parameters of the model by using Differential Evolution Algorithm. In model development and optimization, we used only one dataset (test results of both coaxial transmission line and shielding chamber method) belonging to one type of the fabric samples and resulting optimized model successfully simulated the results of the other fabrics. Also, the model proposed in this work can be used for specially woven and knitted fabrics after small modifications in the model and its parameters. We concluded that the coaxial transmission line method can be used easily in the measurement of electromagnetic shielding effectiveness of composite textile materials by using our optimized model.

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A membrane coated composite mesh for repairing pelvic floor defects using electrospinning method

YAO LU YAN-CHUN CHEN PEI-HUA ZHANG

REZUMAT – ABSTRACT

Plasă compozită acoperită cu membrană pentru repararea defectelor planşeului pelvin, obţinută prin electrofilare

Metoda implantării unei plase este o metodă eficientă pentru repararea planşeului pelvin la femei (PFD). Materialele pregătite în cadrul acestui studiu au fost materiale compozite constând din material neresorbabil şi material resorbabil. Fiecare plasă compozită a fost alcătuită dintr-un strat de membrană din nanofibră PLA/PLC depus prin electrofilare și un strat din plasă tricotată din PP. Caracteristicile și structura diferitelor tipuri de plase PP au fost investigate cu ajutorul microscopiei de scanare electronică (SEM), calorimetriei cu scanare diferențială(DSC), difracției cu raze X (XRD), unghiului de contact al apei și prin evaluarea lipirii. Rezultatele au demonstrat că metoda electrofilării este una practică și eficientă pentru producerea unei plase compozite cu membrană laminată. Diametrul fibrei și mărimea porilor membranei diferă foarte mult față de membrana formată pe folie de aluminiu, dar hidrofilia întregului compozit depinde în special de stratul membranar. Evaluările XRD și DCS au demonstrat un grad înalt de cristalinitate și punct de topire crescut al compoziției plasei compozite. Adausul de cauciuc-fluor a fost foarte eficient pentru lipirea celor două straturi, așa cum a fost demonstrat de către testele de aderență și de imaginile SEM ale secțiunii transversale ale plasei compozite.

Cuvinte-cheie: plasă compozită membranată, repararea planşeului pelvin, electrofilare, PLA/PLC

A membrane coated composite mesh for repairing pelvic floor defects using electrospinning method

Mesh implanted method is an effective way to repair female pelvic floor functional disorder (PFD). The paper prepared composite meshes consisted of nonabsorbable material and absorbable material. Each sample was made with a PLA/PCL nanofiber membrane layer by adopting electrospinning method, and a layer of knitted PP mesh. The properties and structure of composite meshes with different-structure PP mesh layer were investigated by scanning electron microscopy (SEM), differential scanning calorimetry (DSC), X-ray diffraction (XRD), water contact angle, and bonding evaluation. The results show that it is an effective and practical way to produce membrane coated composite mesh using electrospinning method. The fiber-diameter and pore-size of membrane layer differs a lot from that collected directly on aluminum foil, but hydrophilicity performance of the whole composite mesh depend mainly on the membrane layer. The XRD and DSC evaluation demonstrated the high degree of crystallinity and melting point of the composition in the composite mesh. The addition of fluororubber was proved effectively bonding two layers together by testing bonding power and taking SEM photos of mesh's cross section.

Keywords: coated composite mesh, pelvic floor repairing, electrospinning, PLA/PCL

INTRODUCTION

Female pelvic floor functional disorder (PFD) is accompanied by pelvic floor structure defects caused by various reasons, mainly performing as pelvic organ prolapse (POP), stress urinary incontinence (SUI), chronic pelvic pain and so on. Through mesh being fixed in the skin, subcutaneous, pelvic fascia and ligament, the pelvic viscera can be supported and return to normal anatomical position [1]. Therefor it is an effective way to repair weak pelvic floor tissue by implanting mesh into human body. The repairing mesh can be classified into nonabsorbable mesh, absorbable mesh and composite mesh according to its materials' characteristics. The composite mesh is combined with absorbable materials that can be degraded and absorbed by human body for a period of time like polylactic acid (PLA) polymer, collagen and nonabsorbable materials which cannot be degraded and absorbed like polypropylene (PP), polyester.

Electrospinning can prepare superfine fibers with diameters from 5 nm to 1 μm owning high specific surface area and porosity [2] and have good applications in biological engineering. PLA and polycaprolactone (PCL) are both biomedical materials approved by the USA Food and Drug Administration (FDA) for their non-toxic and good biological compatibility. PLA has high strength but low elongation and weak fighting strength. Adding PCL to PLA is beneficial to improve material's strength, flexibility and cell-attached force [3–5]. Boland [6] prepared PLA/PCL nanofiber membranes with different diameters and morphology to expand its application in biological engineering. Yang et al. [7] found that smooth muscle cells grew superior on PLA/PCL blending stent to that on single component PLA stent.

Mesh used for pelvic floor has similar structure and material with hernia mesh. Prolene® (Ethicon, Somerville, NJ, USA) and Gynemesh® PS (Ethicon, Somerville, NJ, USA) are both implanted materials and have mesh structures knitted by PP filaments. Prolene® is mainly used for herniorrhaphy but Gynemesh® is applied in gynecological area. The diameter of PP filaments and structure of these two products are different, which result in different mechanical performances, such as thickness, porosity, strength, flexibility and so on. Both hernia mesh and pelvic mesh are used as supportive material for fascia defects or used as bridging material, but hernia mesh need to be close-knit owning high mechanical strength, and pelvic mesh need to be thin, soft to improving patients' life quality. Overall, hernia mesh and pelvic floor mesh are similar but owning different performance requirements.

Development of hernia mesh is more mature then that pelvic floor mesh. Moreover, there are fewer composite mesh in the market special used for pelvic floor now, so some products we will mention are used in hernia area. There are several ways to prepare composite mesh. For example, Pelvitex® (C.R. Bard Corp. USA) is composed of PP mesh covered with collagen. Vicryl® and Monocryl® are made with PP monofilaments interlaced with polyglactin 910 and polyglecarpone monofilaments, respectively. Keitaro Tanaka et al. [8] studied a composite mesh with 90% PLA covered on 10% PP knitted mesh, and demonstrated the composite mesh showed lower level of adhesion and shrinkage compared with the other two light-weight mesh and middle-weight PP nonabsorbable mesh. Parviz et al. [9] compared kinds of meshes including conventional PP knitted mesh, two-layer meshes using different materials covered on PP mesh, and demonstrated that an absorbable material covering on a nonabsorbable mesh would prevent adhesion and biomaterial-related intestinal fistula formation. The paper prepared and studied composite meshes composed with a layer of conventional reinforcement PP mesh and a layer of PLA/PCL electrospinning membrane. To compare composite meshes with different structures, two composite meshes having the same PLA/PCL membrane layer but different PP mesh layer were prepared. Scanning electron microscopy (SEM), differential scanning calorimetry (DSC), X-ray diffraction (XRD), water contact angle, bonding power evaluation techniques were used to investigate the structure, morphology and properties of these PLA/PCL nanofiber membrane coated composite meshes.

MATERIALS AND METHOD

Materials

PP monofilaments used to knit PP mesh were developed by State Key Laboratory for Modification of Chemical Fibres and Polymer Materials, Donghua University. The PP monofilament's diameter is 0.1 mm, linear density is 7.2 tex. The breaking strength and breaking elongation of PP monofilaments are 58.31 CN/dtex and 20.15 %, respectively. Poly(D,L-lactic acid) and PCL polymers which were used to prepare electrospinning membranes were purchased from Yisheng New Materials co., LTD (Shengzhen, China). The molecular weight of PLA is 10^5 and PCL's molecular weight is 8×10^4. Methylene dichloride (DCM) and N, N-dimethyl formamide (DMF) were obtained from Damao Chemical Reagent Factory (Tianjing, China) as solvents for PLA and PCL polymers. Fluororubber bought from National Medicine Group Shanghai Chemical Reagent Co., LTD (Shanghai, China) was applied as binder between PP knitted mesh layer and electrospinning membrane layer. All of the chemicals were analytical reagent grade and were used with no further purification.

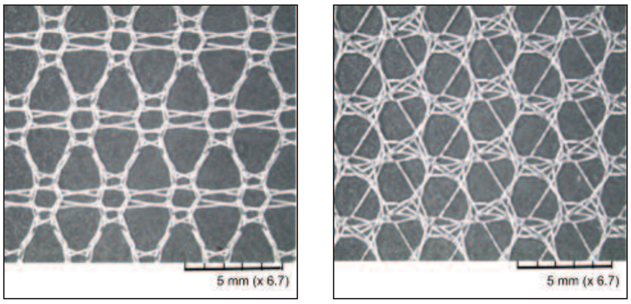
Preparation of PP meshes

The PP meshes were formed by process of warping, knitting and heat-setting. Warping process used 6 cylinder blocks with size of 7×7 inches and 60 filaments for each cylinder block. Knitting process used PP monofilaments to form two kinds meshes namely Structure A and Structure B. Structure A is a diamond-pore mesh knitted in 20E Raschel machine with 3 Guide Bars (fig. 1a), while structure B is hexagon-pore mesh knitted in 16E Raschel machine with 3 Guide Bars (fig. 1b). Heat setting process was intent to make meshes flat which was slightly curly after knitted by knitting machine. The heating temperature for two meshes are both 130 °C, and heating time was 15 min for Structure A mesh and 10 min for

Table 1

WEAVING PARAMETERS OF TWO PP MESHES

Sample	Code of inserted yarn	Arrangement of threading	Amount of warp let-off [mm/rack]
Structure A	GB1: 1-0 / 0-1 //	Full set threading	2150±50
	GB2: 0-0 / 2-2 / 1-1 / 3-3 / 0-0 /3-3 / 1-1 / 2-2 / 0-0 / 3-3 //	One in one out	1420±50
	GB3: 3-3 / 1-1 / 2-2 / 0-0 / 3-3 / 0-0 / 2-2 / 1-1 / 3-3 / 0-0 //	One in one out	1970±50
Structure B	GB1: 2-3 / 2-1 / 2-3 / 1-0 / 1-2 / 1-0 //	One in one out	1760±50
	GB2: 1-1 / 1-0 / 1-0 / 2-2 / 2-3 / 2-3 //	One in one out	1150±50
	GB3: 1-0 / 1-2 / 1-0 / 2-3 / 2-1 / 2-3 //	One in one out	900±50



a *b*

Fig. 1. Microphotographes of two PP meshes: *a* – Structure A; *b* – Structure B

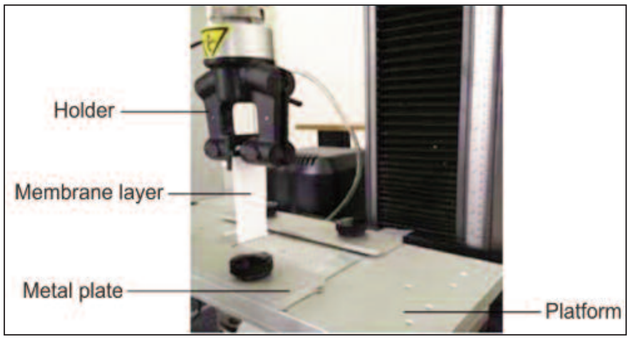


Fig. 2. Schematic diagram of electronic universal-testing machine

Structure B mesh. In our previous study, we dealt with two meshes under different temperature and different time of duration in heat-setting process. The above heating parameters were chosen for owning best mechanical performance after mesh being heated. The difference of length of time (15 min for Structure A mesh, 10 min for Structure B mesh) is due to structure difference of these two meshes. In heat setting process, the mesh can have corresponding porosity by adopting suitable designing density.

Preparation of coated composite meshes using electrospinning method

The above two knitted meshes were used for preparing coated composite meshes. In order to obtain coated meshes, the PLA/PCL membranes were adhered to the conventional knitted PP mesh. The PLA/PCL nanofiber membranes were gained by electrospinning process which was carried out using 8% w/v PLA/PCL solution at blending ratio of 7/3. The solvents used to dissolve PLA and PCL polymers were DCM:DMF at ratio of 4:1. For electrospinning process, the solution was transferred to a 5-ml syringe pump. The flow rate of polymer solution was 0.6 ml/h, the applied voltage was 12 KV, the receiving distance was 15 cm. The resulting fibers were collected on PP meshes which have been blushed with 8% w/v fluororubber solution using acetone as solvent. The fluororubber was used to bind nanofiber membrane layer and PP mesh layer together, and to form a stable two-layer composite mesh.

To differ from the PP knitted meshes we mentioned in section 2.2, the coated composite meshes were named as Structure 1 and Structure 2 according to the PP mesh used as reinforced layer. That means Structure 1 mesh is PLA/PCL membrane coating on Structure A PP knitted mesh, and the same for Structure 2 mesh.

Characterization of structure and performance

(1) Morphological studies

Surface structure of coated composite mesh was characterized by HITACHI S - 3000 scanning electron microscope (HITACHI Co,. Ltd., Japan). Fiber average diameter of the membrane layer was calculated using 100 individual diameters to each sample by using Photoshop CS3 software. Pore-size of membrane surface was analyzed by American contador automatic membrane pore measuring instrument.

(2) DSC

The thermal analysis of composite mesh was obtained by DSC. Dry samples (5 mg) were heated from 20 °C to 200 °C at a scanning rate of 10 °C /min using Phrisl differential scanning calorimetry (USA) under nitrogen atmosphere.

(3) XRD

Crystallization property was obtained by XRD measurements which were recorded using a Shimadzu XRD-6000 diffractometer (Germany). XRD measurements of prepared samples were operated at 40 KV and 200 mA. A Cu-Kα radiation source was used to scan samples in a 2θ range from 0° to 60° with a scan rate of 0.06 °/s. The d-spacing was determined from Bragg's law [$n\lambda = 2d\sin\theta$], where θ is the diffraction angle, λ is the wave-length [λ = 1.54056 Å for a Cu target]. The degree of crystallinity was determined by implementing the area integration method from XRD intensity data over the range of 2θ from 0° to 60°.

(4) Contact angle measurements

Contact angles of water on the surface of composite meshes were measured by a OCA15EC Contact Angle Meter (Beijing North Defei Co,. Ltd., Beijing). The experiment was operated at room temperature using a yellow-light source, with water volume around 4 μl. Static contact angle was test on each sample's 5 different positions. The final average contact angle was calculated by these 5 data.

(5) Bonding test

Bonding test was measured by electronic universal-testingles were cut into 60 mm × 25 mm rectangle shape. The testing process began with holder clamping PLA/PCL layer which was partly detached from composite mesh at 90° angle, and the whole sample was placed on testing machine platform with metal plate fixing (figure 2). The holder rose at speed of 150 mm/min and machine calculated loads acting in composite meshes automatically until membrane layer was completely removed from PP mesh.

RESULTS AND DISCUSSION

Structure and performance of PP meshes

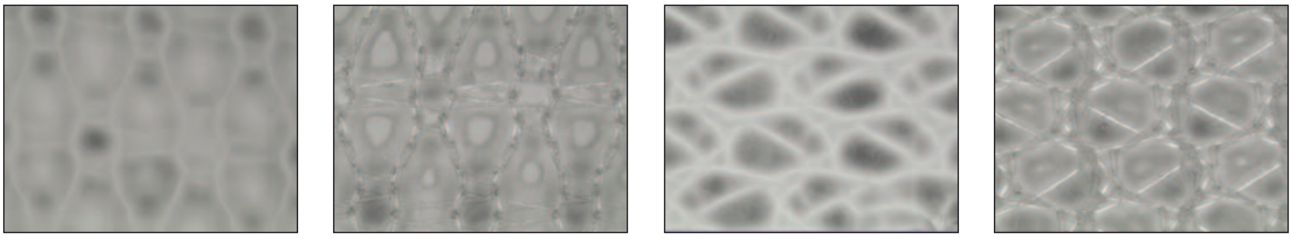
Some structure and performance parameters of PP meshes including porosity, pore-size, thickness, weight per square meter are listed in table 2. Both meshes have high porosity and large pore-size which are good for reducing complications and recurrence rate according to Pushkar [10] and Junge [11]. The complications refer to illness induced by mesh-implantation which are mainly infection, mesh erosion, adhesion, shrinkage for pelvic floor repairing mesh. These complications damage patients' health and may result in high recurrence rate. Structure A and Structure B mesh are similar in thickness, weight and porosity, the most difference between them are mesh-structure and pore-shape.

Structure and pore-size of PLA/PCL coating membranes

Figure 3 presents microphotographs of two composite meshes using different structure PP meshes. Figure 4 shows fiber diameter distribution and average fiber diameter of PLA/PCL membranes coated on two structure meshes and aluminum foil directly. Figure 5 presents SEM photos of the above membranes (×8K). An obvious gap of fiber-size can be seen among the three samples. Fibers collected on Structure 1 mesh have the biggest average diameter. Nanofibers on Structure 2 mesh and aluminum foil show similar size and morphology which are finer and more uniform than that on Structure 1 mesh.

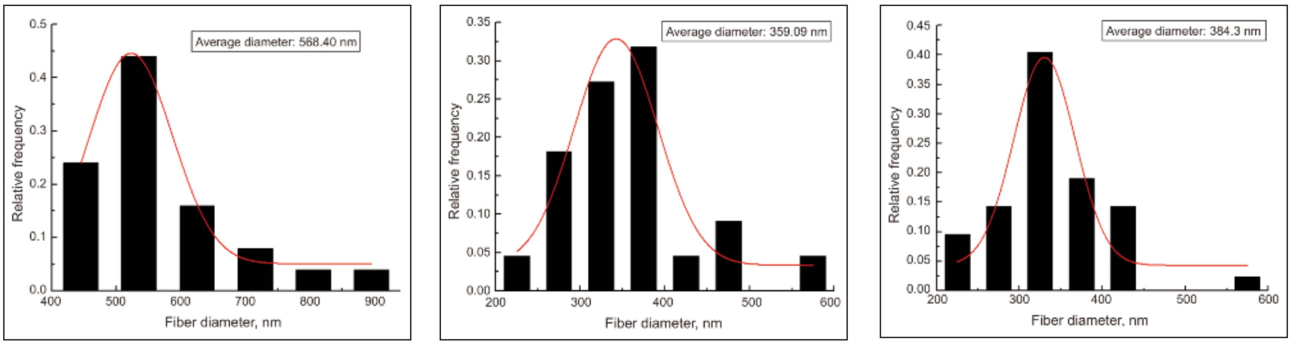
Figure 6 presents pore-size distribution of PLA/PCL membranes on two structure meshes and aluminum foil. The average pore-size of coating layer on two PP meshes is similar, both around 6.5 μm.

However, membrane on aluminum foil shows a smaller pore diameter of 1.93 μm. This is due to the macroporous structure of PP meshes that makes it difficult for nanofibers to closely deposit. But we think the relative large pore-size structure may be better for tissue growth.



a *b* *c* *d*

Fig. 3. Microphotographes of two coated composite meshes: *a* – front side of Structure 1 mesh; *b* – back side of Structure 1 mesh; *c* – front side of Structure 2 mesh; *d* – back side of Structure 2 mesh



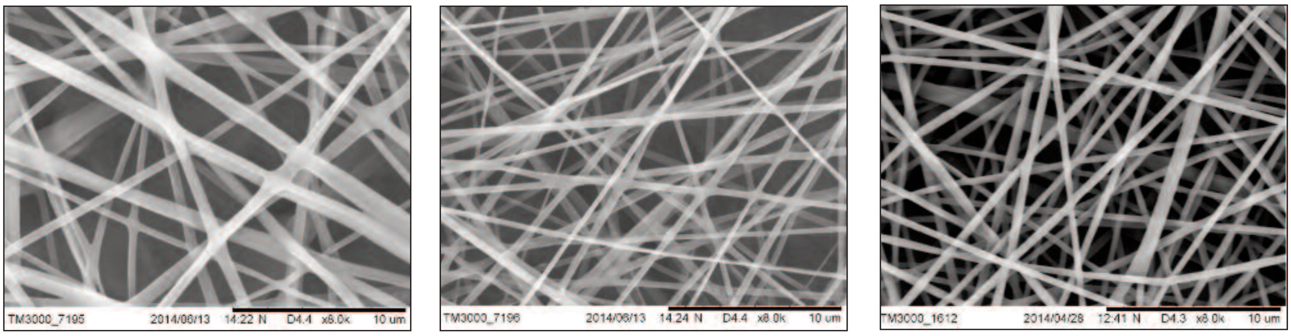
a *b* *c*

Fig. 4. Fiber-diameter distribution of PLA/PCL coating membranes (*a* – covered on Structure 1 PP mesh; *b* – covered on Structure 2 PP mesh; *c* – covered on the aluminum foil)

Table 2

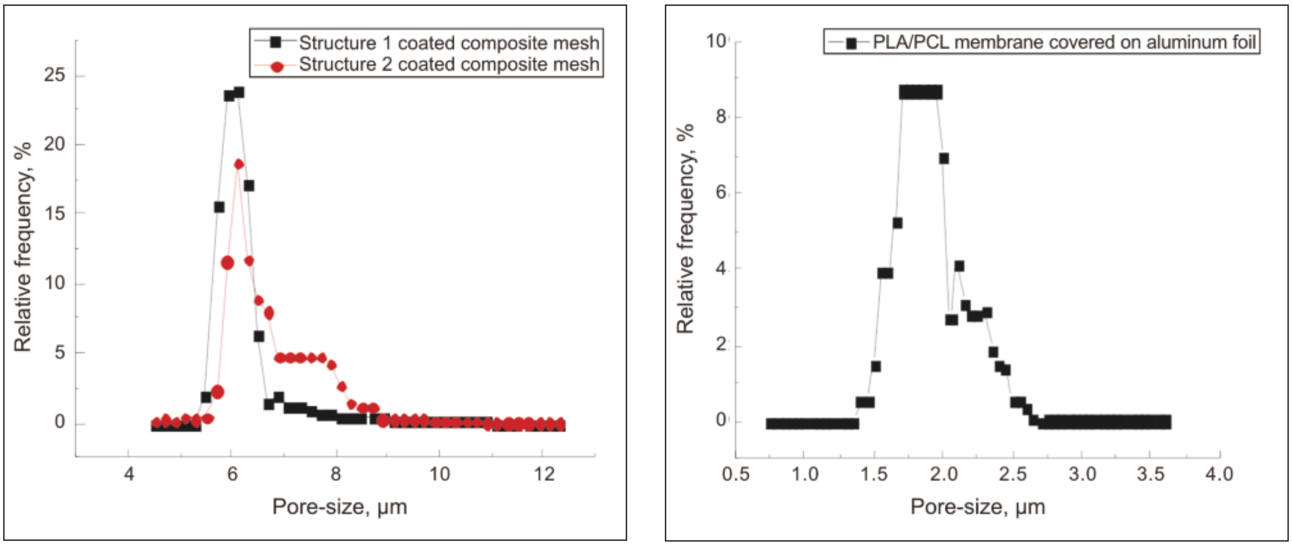
Parameters of two knitted PP meshes

Sample	Porosity / %	Pore-size / mm L_1	Pore-size / mm W_1	Thickness / mm	Weight per square meter / (g·m^2)
Structure A	68.53	2.70	3.10	0.412	41.19
Structure B	63.40	2.65	3.45	0.387	35.97



a *b* *c*

Fig. 5. Scanning electron micrographs of PLA/PCL coating membranes (*a* – covered on Structure 1 PP mesh; *b* – covered on Structure 2 PP mesh; *c* – collected on the aluminum foil)



a *b*

Fig. 6. Pore-size distribution of coating membranes
a – covered on two structure PP meshes; *b* – covered on aluminum foil

Thickness and weight per square meter of membrane coated composite mesh

The composite mesh was prepared by bonding two layers together which may lead to change of thickness and weight compared to PP knitted mesh. The above performances are very important to pelvic repairing mesh implanted into human body. According to Sergent [12], patients' dissatisfaction and district of their life quality after surgery are always connected to implanted mesh's weight. Figures 7 and 8 present weight per square meter and thickness of two kinds meshes, respectively. The PP knitted mesh commented in graphs were those used in composite mesh. From these figures, we can see that there was only small difference in thickness and weight per area after coating membrane layer. However, the composite mesh was fully protected by PLA/PCL membrane on one side. That means the electrospinning means of making coated composite mesh can prepare a two-layer product which will not have significant increase on both thickness and weight, but have big change on its appearance.

Contact angle measurement

Contact angle between the coating layer and water drops was measured to determine the hydrophilic character of coated composite meshes. It is known that the lower the contact angle is, the higher the hydrophilic performance of the sample surface. Table 3 shows contact angle of coating layer on composite meshes and PLA/PCL membrane on aluminum foil. The three samples were all hydrophobic material with no significant difference on contact angle. This means

Table 3

Contact angle of coated composite mesh

Sample	Contact angle (°)	CV%
Structure 1 coated composite mesh	125.6	2.45
Structure 2 coated composite mesh	131.9	4.17
PLA/PCL membranes covered on the aluminum foil	125	3.66

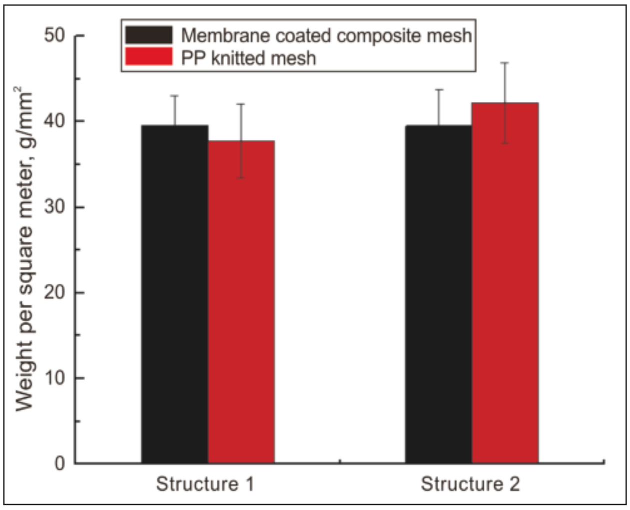


Fig. 7. Weight per square meter of coated composite and PP mesh

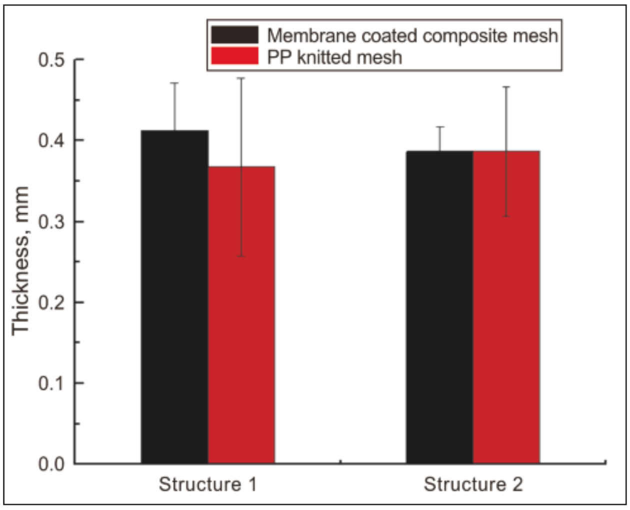


Fig. 8. Thickness of mesh coated composite mesh and PP mesh

coated composite meshes' hydrophilic performance depended mainly on the coating material's nature.

Crystallinity and thermal performance

The XRD and DSC were carried out to determine crystallinity and thermal performance of coated composite mesh. Figures 9 and 10 present XRD pattern and DSC curve of coated composite mesh, respectively. The degree of crystallinity was 63.85%. The sample possessed 3 reflection peaks (965, 483, 499) and a small peak (63). The peaks were detected at 2θ = 14.22°, 17.14°, 18.60° and 22.6°, respectively. Their corresponding d-spacing values were determined as 0.62, 0.52, 0.48 and 0.35 nm [fig. 9]. The three sharp crystal peaks in coated mesh with strong absorption intensity lead to the high degree of crystallinity.

It can be seen from figure 10 that the sample existed 3 melting peaks. The peak values in DSC curve were 56.37 °C, 152.85 °C and 166.03 °C corresponding to the melting points of composition materials in coated mesh, respectively. It reveals that PP, PLA, PCL were all shown stably and well-distributed in the composite membrane, method of electrospinning did not reflected materials' properties.

Bonding test

The electrospinning PLA/PCL membrane cannot fit well to the PP knitted mesh without any bonding measures. The paper used 8% w/v fluororubber dissolved in acetone as adhesive. Figure 11 presents photos of composite mesh with and without blushing adhesive between membrane layer and knitted mesh layer. It can be seen that membrane layer integrated to the mesh layer evenly and closely with the application of fluororubber (fig. 11b), while the edge of PLA/PCL membranes easily separated from mesh layer without fluororubber treatment (fig. 11a).

Bonding performance between PLA/PCL membrane layer and PP mesh layer was evaluated by calculating bonding load until two layers was detached and taking SEM photos of two layers' cross section. Figure 12 presents bonding power between two layers of the composite mesh. The x-coordinate of the

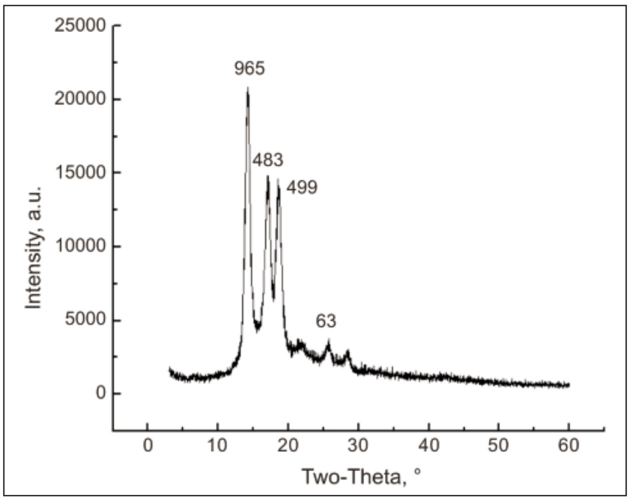


Fig. 9. XRD pattern of coated composite mesh

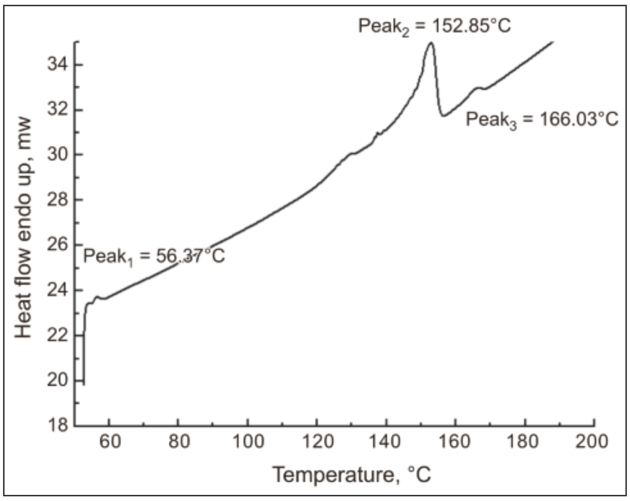
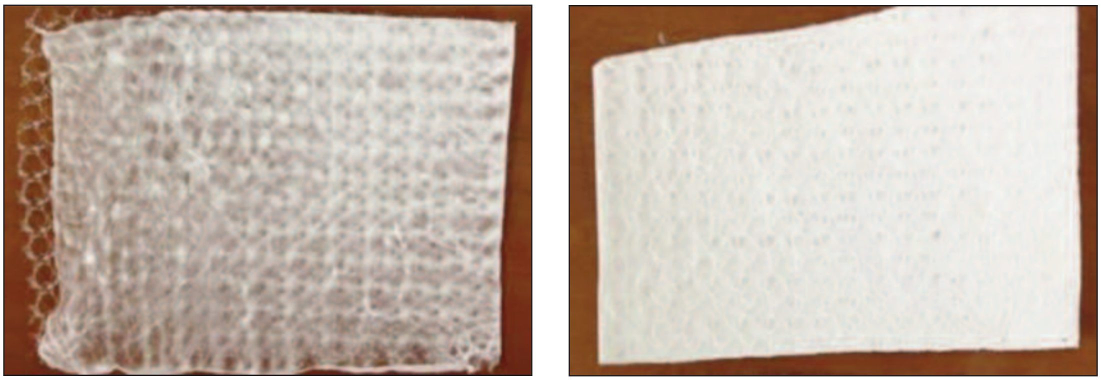


Fig. 10. DSC curve of coated composite mesh



a *b*

Fig. 11. Composite mesh under different treatments: *a* – PLA/PCL spay-coated on PP mesh directly; *b* – PLA/PCL spay-coated on PP mesh with brushing fluororubber on PP mesh

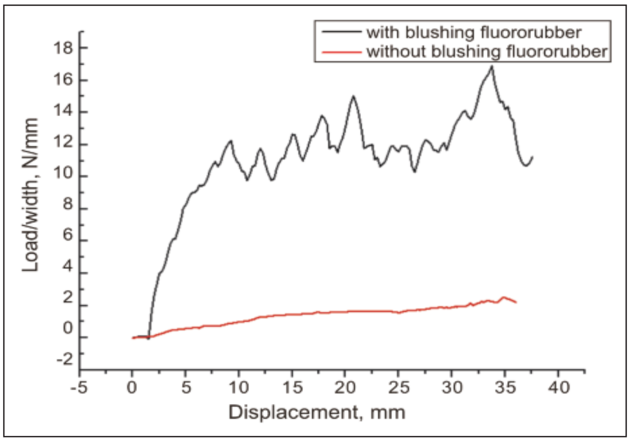


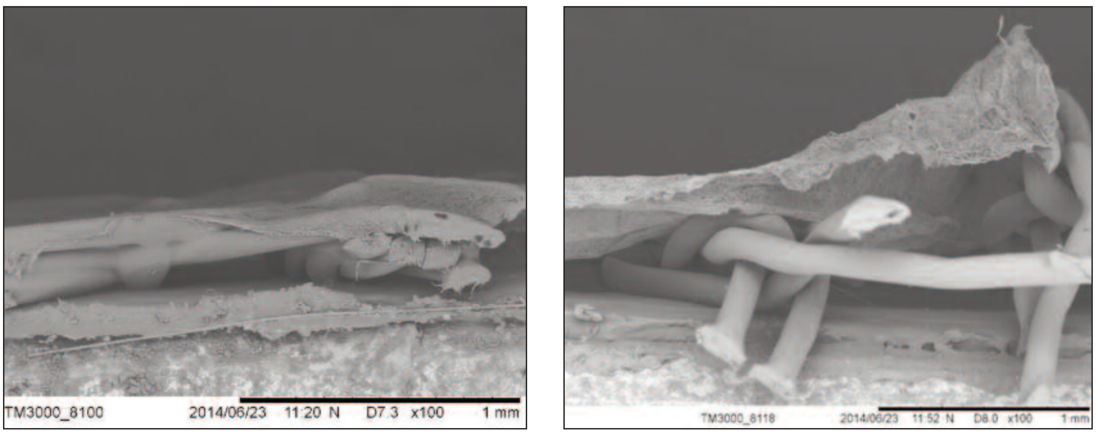
Fig. 12. Bonding power between PLA/PCL membranes layer and PP mesh layer

graph refers to the displacement of holder which clamped the membrane layer and dragged it apart from the PP mesh layer. The y-coordinate of the graph refers to strength value that holder need to draw membrane layer apart per sample width. From figure 12, we can see that bonding power between two layers which have used fluororubber as adhesive was around 15 N/mm while the power between layers without adding fluororubber was less than 2 N/mm. The adhesion phenomenon between two layers was weak and unstable without the help of fluororubber.

Figure 13 presents SEM photos of coated composite meshes' cross section with and without using fluororubber. It is clear that electrospinning membrane glued closely and flatly to mesh layer for sample using fluororubber as adhesive, while membrane layer appeared loosely for sample without adding fluororubber. Therefore, the application of fluororubber is an effective bonding measure for forming two-layer coated composite mesh.

CONCLUSIONS

The paper adopted PP monofilaments to prepare two PP meshes namely Stucture A and Structure B. The coated composite mesh was prepared based on these two PP meshes. The composite mesh consists of a PLA/PCL electrospinning membrane layer bonding with PP knitted mesh using 8% w/v fluororubber as binding agent. The two composite meshes named Structure 1, Structure 2 adopted Structure A and Structure B PP mesh as reinforcement layer. The paper studied two composite meshes composed of conventional reinforced PP mesh layers and



a *b*

Fig. 13. Scanning electron micrographs of coated composite meshes' cross section: *a* – adding fluororubber; *b* – without adding fluororubber

electrospinning PLA/PCL membrane layer, which aimed to compare these composite meshes with various test.

To study the structure and performance of these tow-layer composite meshes, several experimental techniques were carried out including SEM, DSC, XRD, water contact angle, and bonding evaluation between two layers. The fiber-diameter of PLA/PCL membrane collected on aluminum foil differed a lot from that on Structure A PP mesh, but similar with which on Structure B mesh. The pore-size of membrane coated on PP meshes are both larger than that collected on aluminum foil. The membrane prepared by electrospinning method fully coating one side of the PP mesh did not cause significant increase on both thickness and weight. By comparing water contact angle of two coated composite meshes with PLA/PCL nanofiber membrane, the results show that the hydrophilic performance depends mainly on the coating material's nature. From XRD evaluation, the three sharp peaks with strong absorption intensity existed in diffraction pattern lead to the high degree of crystallinity. The melting peaks in DSC curve corresponded to the melting point of three materials in composite mesh (PLA, PCL, PP) which means these materials were all shown stable and the electrospinning method we used to prepare the composite meshes will not affect material's nature. Bonding test was aimed to evaluate the adhesion phenomenon between membrane layer and knitted mesh layer. The results demonstrate the addition of fluororubber effective bonded two layers together, especially compared with the sample without adopting fluororubber. By studying structure and performance of the coated composite mesh, we provided a practical and effective product for repairing pelvic floor defects. The product was shown stable consisted of two layers, the convention layer worked mainly as support effect and smooth porous membrane layer may better promote tissue growth.

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Mathematical correlation between section lines in 3D shapes and fashioning lines in 3D knitted fabrics

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REZUMAT – ABSTRACT

Corelații matematice între liniile de secțiune ale corpurilor 3D și liniile de conturare din tricoturile cu geometrie tridimensională

Tricoturile 3D prezintă un potențial deosebit pentru aplicații tehnice complexe, cunoscând în ultimele decenii o dezvoltare semnificativă. Prima etapă în proiectarea tricoturilor conturate spațial este reprezentată de trecerea de la planul de secțiune al corpului 3D la planul tricotului. Din punct de vedere matematic, liniile de secțiune ale oricărui corp 3D sunt continue, astfel putând fi definite cu precizie. Tricoturile însă sunt alcătuite din ochiuri cu anumite dimensiuni, care trebuie avute în vedere atunci când se definește modelul matematic al segmentelor din liniile de conturare drepte sau curbe. Lucrarea prezintă o metodă de definire a incrementului vertical, respectiv orizontal ale liniilor de conturare, bazată pe aproximarea erorilor dintre liniile de secțiune continue și liniile segmentate din planul tricotului.

Cuvinte-cheie: model matematic, linii de secțiune, linii de conturare, aproximarea erorilor

Mathematical correlation between section lines in 3D shapes and fashioning lines in 3D knitted fabrics

3D shaped knitted fabrics present a very good potential for complex technical applications and have known a significant development in the last two decades. In order to design a 3D-shaped knitted fabric, the first step to be followed is represented by the transition from the 2D solid evolutes of the geometric shape to the fabric plan. Mathematically, the section lines for each type of 3D shapes are continuous and they can be accurately defined. However, knitted fabrics are made of stitches of certain dimensions that must be taken into consideration when defining the mathematical models of the straight or curved fashioning line segments. The paper presents a method to define the vertical and horizontal increment of a fashioning line, based on the error approximation between the continuous section lines and the segmented lines in the fabric plan.

Keywords: mathematical model, section lines, fashioning lines, error approximation

INTRODUCTION

A 3D shaped knitted fabric is produced using the spatial fashioning technique. These kind of fabrics are characterised by a 3D geometry that is based on a 3D solid with regular or irregular shape. Until now, the researchers focused more on the shape modelling than on the modelling of the section and fashioning lines [1]. To ensure a proper definition of the 3D knitted fabrics, both section lines of the 3D body and the fashioning lines of the 3D shaped knitted fabric must be defined [2, 3, 4]. Fashioning lines have usually two components: one with a decreasing direction and one with increasing direction. The final 3D shape is obtained through the union of these lines according to their specific parameters (line increment and stitch dimension). Taking into account the particularities of the knitted fabrics, the fashioning lines are formed by varying the number of stitches knitted in each row.

Section lines, given by the 2D develop of the 3D solid are represented by continuous lines: straight (with constant increment) or curved (with variable increment). A fashioning line, given by the 2D develop of the fabric plan is segmented, being compounded by multiple line segments [1], as illustrated in figure 1.

Because the fashioning lines are not continuous lines, as it is the case with the section lines, they are quantified using the line increment Δ*r* and Δ*a*, representing the number of rows, respectively needles by which the line varies at each step. The basic element is the knitted stitch and its dimensions – the stitch pitch and height. The fashioning line can be therefore considered as a polygonal line that follows the stitches in the knitted fabric. Due to the nature of these lines (the section line is continuous while the fashioning line is segmented) the equations that define them will differ.

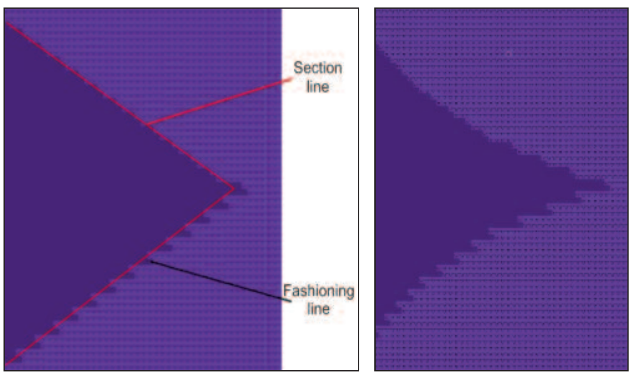

Fig. 1. Aspect of fashioning lines: *a* – straight and *b* – curved

In order to ensure a correct definition of the narrowing and widening steps, which are given by the line increment Δr and Δa, a strictly correlation between section lines in 3D shapes and fashioning lines in 3D knitted fabrics must be made. When this correlation is made, between these lines occur differences that influence the number of stitches that must be produced in a row in order to obtain a certain dimension. To solve this problem the surface of the 3D shape develops bordered by the fashioning line must be determined.

For rectangular knitted panels (when the length and width of the panel are known) the surface and the necessary number of stitches can be easily determined. For knitted fabrics with irregular shape (figure 2) that are defined by a curved fashioning line (as illustrated in figure 1b) a difference or error will occur between fashioning and section lines. Initially this error can be practically approximated but if an exactly shape is required rigorous solutions, represented by the integral calculus and approximation, must be applied. The integral calculus consists in finding the numerical approximation for the surface *S* [5].

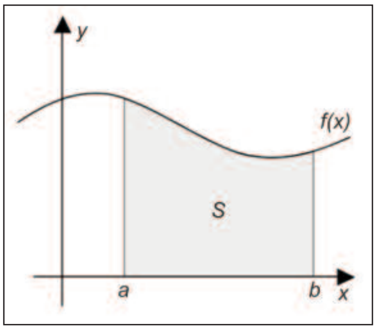

Fig. 2. Numerical integration

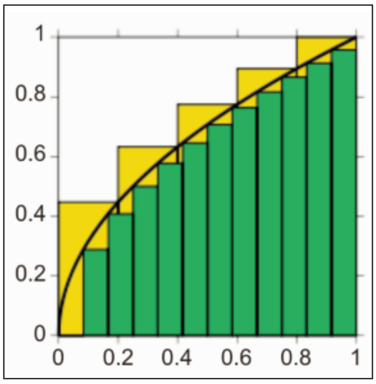

Fig. 3. Error approximation for $y = f(x)$ function with 5 and 12 steps

If the $y = f(x)$ section line curve is consider on [0,1] interval the integral surface of the $f(x)$ function on the given interval is represented by the integral area of f and is noted $\int_0^1 \sqrt{x}\,dx$. The error approximation has been carried out using 5 and 12 steps, as illustrated in figure 3. It can be remarked that if a higher number of approximation steps is used the error between the section and fashioning line is smaller.

ERROR APROXIMATION METHODS

Several techniques for approximating the definite integral can be used [4] to approximate the errors that occur between the fashioning and section lines, so that the surface of the knitted fabric, the number of stitches, the narrowing and widening steps are accurately determined:

- Rectangle rule (also called midpoint rule);
- Trapezoidal rule;
- Simpson's rule.

Rectangle rule

The rectangle method (also called the *midpoint* or *mid-ordinate rule*) computes an approximation to a definite integral, made by finding the area of a collection of rectangles whose heights are determined by the values of the function. The rectangle rule offers three possible solutions, as illustrated in figure 4:

- The left rule uses the left endpoint of each subinterval;
- The right rule uses the right endpoint of each subinterval;
- The midpoint rule uses the midpoint of each subinterval.

For the error approximation of a knitted fabric fashioning line specific geometry the best suitable method is represented by the right rule, which use the endpoint of each interval. For the $y_i = f(x_i)$ function, with $\Delta Dx_i = h_i = \Delta a_i$, the error approximation is given by the following relations:

- Left rule

$$\int_a^b f(x)dx = \Delta a_1 h_1 y_0 + \Delta a_2 y_1 + \ldots + \Delta a_n y_{n-1} + R_n \quad (1)$$

- Right rule

$$\int_a^b f(x)dx = \Delta a_1 y_1 + \Delta a_2 y_2 + \ldots + \Delta a_n y_n + R_n \quad (2)$$

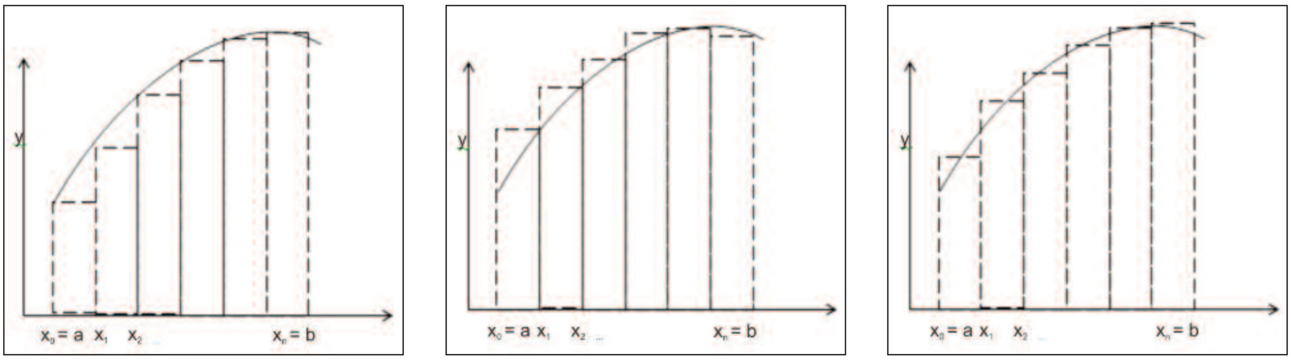
Fig. 4. Error approximation using the rectangle rule

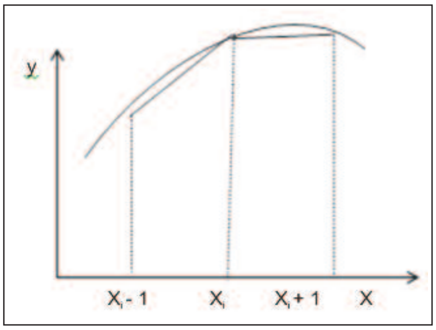

Fig. 5. Error approximation using the trapezoidal rule

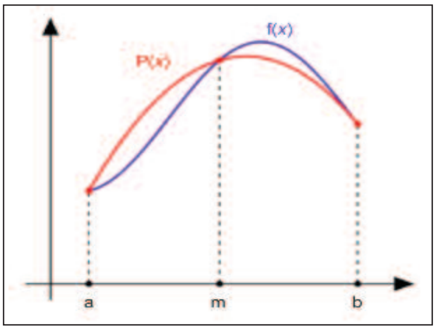

Fig. 6. Error approximation using the Simpson's rule

- Midpoint rule

$$\int_a^b f(x)dx = \sum_{i=1}^{n} \Delta a_i f\left(\frac{\Delta a_{i-1} + \Delta a_i}{2}\right) + R_n \qquad (3)$$

where: Δa is the horizontal increment, h – the horizontal step and R_n – error approximation.

The vertical increment Δr must be defined in order to complete the calculus of the fashioning line. Generally, the vertical increment can be 1, 2 or 3 courses. When the vertical increment is set up the technical limitations of the knitting process should be considered.

Trapezoidal rule

The trapezoidal rule works by approximating the region under the graph of the function $f(x)$ as a trapezoid and calculating its area, as illustrated in figure 5. On $[x_i, x_{i+1}] = [\Delta a_i, \Delta a_{i+1}]$ segment the trapeze is determined by the $(\Delta a_i, 0)$ $(\Delta a_{i+1}, 0)$ extremities of the segment on OX axis and by the $(\Delta a_i, f(\Delta a_i))$ $(\Delta a_{i+1}, f(\Delta a_{i+1}))$ $f(x)$ function values in the extremities. The error approximation is given by the following relations:

$$\int_a^b f(x)dx = \sum_{i=1}^{n} h_i \frac{f(\Delta a_{i-1}) + f(\Delta a_i)}{2} + R_n \qquad (4)$$

$$h = \frac{b-a}{n} = \Delta a, \quad x_i = a + ih, \quad i = 0...n \qquad (5)$$

Where: Δa is the horizontal increment, h – the horizontal step and R_n – error approximation.

Simpson's rule

In contrast to the trapezoidal rule, which uses the linear interpolation method (the approximation is made using straight), the Simpson's rule use quadratic polynomial parabolic interpolation (figure 6). One derivation replaces the integrand $f(x)$ by the quadratic polynomial $P(x)$ which takes the same values as $f(x)$ at the end points a and b and the midpoint $m = (a + b)/2$. Due to this reason the precision of this method is superior to rectangle or trapezoidal rule.

The error approximation is given by the following relations:

$$\int_a^b f(x)dx \approx \frac{\Delta a}{3}\,[f(\Delta a_0) + 4\,f(\Delta a_1) + 2\,f(\Delta a_2) + ... + 2\,f(\Delta a_{n-2}) + 4\,f(\Delta a_{n-1}) + f(\Delta a_n)] + R_n \qquad (6)$$

where: Δa is the horizontal increment and R_n – error approximation.

ERROR APROXIMATION USING SIMPSON'S RULE

When considering the correspondence between section lines and fashioning lines, equivalence between the continuous surface of the 3D body and the discontinuous fabric made of stitches must be made. The most suitable method used to determine the error between the section and fashioning lines is represented by the Simpson's rule.

An application has been developed using different browser – supported programming languages in order to define fashioning lines of a 3D fabric. The interface and computations was carried out in PHP and JavaScript combined with a mark-up language (HTML). The designed application allow the users to determine the errors using the Simpson's method and the line increment Δr and Δa, according to the bordering function.

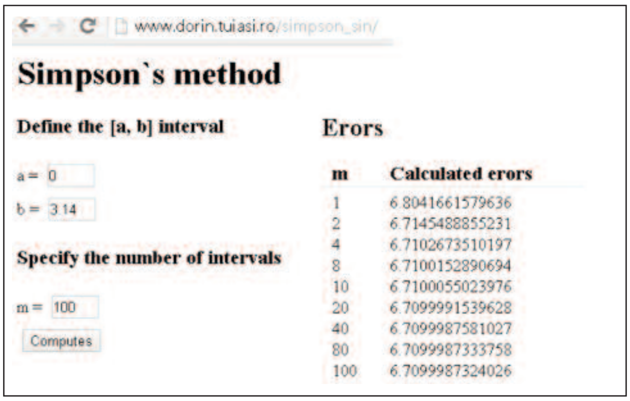

Fig. 7. Error determination for the first example $f(x) = \sin(x) + 1.5$

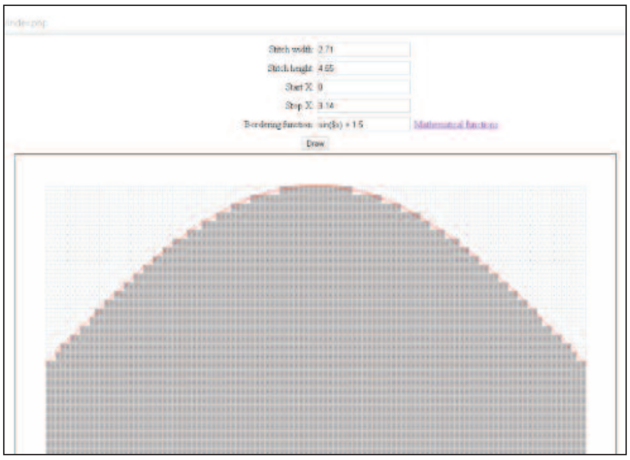

Fig. 8. Narrowing and widening steps for $f(x) = \sin(x) + 1.5$

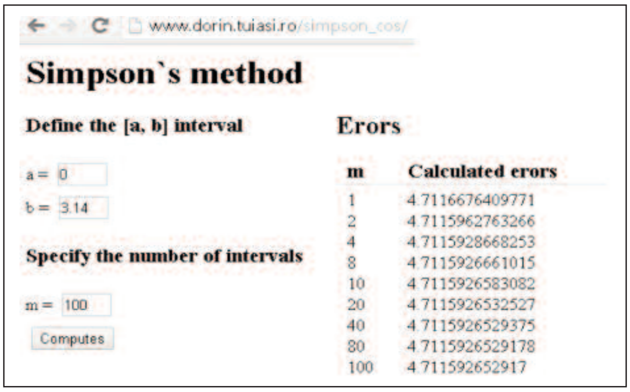

Fig. 9. Error determination for the second example $f(x) = \cos(x) + 1.5$

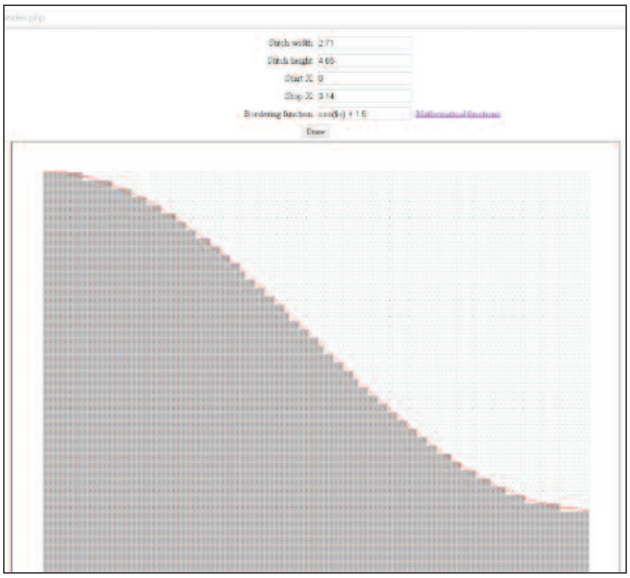

Fig. 10. Narrowing and widening steps for $f(x) = \cos(x) + 1.5$

Two cases have been illustrated for two different functions corresponding to fashioning lines with variable increment: $f(x) = \sin(x) + 1.5$ and $f(x) = \cos(x) + 1.5$. The program calculates the error based on Simpson's rule (figures 7 and 9) and it determines the distribution of stitches along the fashioning lines within the knitted fabric (figures 8 and 10). The stitch distribution is determined based on the stitch dimension (height and width) according to the intended fabric density. In figures 8 and 10, the lighter areas correspond to needles not working in the knitting programme.

CONCLUSIONS

The 3D shaped knitted fabrics that are produced using the spatial fashioning technique have a good potential for technical applications. In order to produce such a fabric it is necessary to ensure the correlation between the 3D shape of the solid and the 2D develop of the knitted fabric. Also the errors that occur between the section and fashioning lines must be determined in order to define the widening and narrowing steps specific for the fashioning technique. The most suitable method that can be used for error determination is represented by Simpson's rule because it allows a smooth approximation between section and fashioning lines.

An application was developed to determine the distribution of stitches along the fashioning lines with variable increment corresponding to the section lines of 3D solids. In both cases that were presented ($f(x) = \sin(x) + 1.5$ and $f(x) = \cos(x) + 1.5$) it must be emphasised that the errors decrease with the increase of the number of intervals considered.

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Study regarding the obtaining of fibrous bases by rotational spinning of the protein hydrolysates from sheep skin wastes

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REZUMAT – ABSTRACT

Studiu privind obţinerea de suporturi fibroase prin filarea rotaţională a hidrolizatelor proteice din deşeuri de piei de ovine

Lucrarea investighează posibilităţile de obţinere prin procedeul filarii rotaţionale a unor suporturi microfibroase din hidrolizate proteice rezultate prin procesarea deşeurilor din piei de oaie tip Chamois provenite de la operaţia de finisare uscată (slefuire-deprafare). Studiul evidenţiază principalele aspecte legate de parametrii de reţetă şi de process pentru filarea rotaţională a unor soluţii de hidrolizate alcaline, corelate cu analiza fizică (microscopia SEM, spectroscopia în IR) în vederea elucidării modificărilor structurale şi morfologice apărute pe microfibrele obţinute, cu potenţiale aplicaţii în diverse domenii.

Cuvinte-cheie: degresare prin ultrasonare, hidroliză electrolitică, piei chamois, filare prin efect rotaţional, analiză spectrală, structuri morfologice

Study regarding the obtaining of fibrous bases by rotational spinning of the protein hydrolysates from sheep skin wastes

This paper investigates the possibilities of producing microfiber substrates from protein hydrolysates resulting from Chamois sheepskin waste processing from dry finishing operations (buffing-dusting) using the process of rotational spinning. The study highlights the main aspects of the recipe and process parameters for rotational spinning of hydrolyzed alkaline solutions, coupled with physical analysis (SEM microscopy, IR spectroscopy) in order to elucidate the structural and morphological changes occurring on microfibers obtained, with potential applications in various fields.

Keywords: degreasing by ultrasound, electrolytic hydrolysis, chamois skin, rotational spinning, spectral analysis, morphologic structures

INTRODUCTION

The leather manufacturing process generates a variety of solid waste (0.7 kg/kg of raw material, described in detail in various materials UNIDO [1, 2, 4]. Waste from sheepskin processing contain: wet blue (WB) split, trimmings, shavings and leather dust (especially from dry finishing operations of buffing/dusting) in significant amounts (151.3 t/min. tons leather) [3, 4]. The data provided by FAO (Food and Agriculture Organization) shows that worldwide processing of 11 million tons of raw skin generates approximately 5 million tons of solid waste [2–4]. During skin processing, waste has a chemical composition comparable with the finished leather, of which the collagen protein component is of particular interest. The transformation of the collagen component into collagen hydrolysates using different methods (alkaline, enzymatic acidic, neutral, alkaline/enzymatic or acidic/enzymatic hydrolysis) as such or functionalized leads to products that can be used to manufacture non-woven fabrics for the textile/leather industry [5], pore-forming agents [6], surfactants, [7–9], biosensors [10], composite materials for the food industry [11–13], construction [14], fertilizers for agriculture [14,15].

Microfibrous (nanofibrous) substrates obtained from natural polymers based on hydrolysates are another category of materials with various applications as: protective coatings, batteries, sensors, tissue engineering, filter materials, medical textiles, intelligent textiles.

The new method for obtaining micro/nanofibres, generically called spinning by centrifugal or rotational effect, allows much higher speeds compared to another common method of spinning, electrospinning [16], recording a significant increase of yield, low power consumption (high voltage is no longer used) and the possibility to work with a wide range of solvents and melt polymers [17].

If in the case of electrospinning, operating conditions necessary for an optimal process requires the use of polar solvents with low evaporation temperature and the fiber forming polymer solutions with low concentrations, spinning by centrifugal effect uses polymer solutions with a wide range of concentrations and vapor low-pressure, and the requirement for strengthening the filaments in the solutions is the balance between the solvent evaporation time and the critical concentration of the solvents for polymers [18]. Also, by centrifugal (rotational) spinning, spinning flow rate through a nozzle is at least 10 times higher than in

the case of electrospinning, eliminating the restrictions on the use of substances having a low dielectric constant [19].
This paper aimed to recover and exploit Chamois skin waste produced during dry finishing operations of buffing/dusting, in order to obtain protein hydrolysates, which were then used for developing microfibrous substrates by rotational spinning process, starting from a number of applications of this method for spinning solutions of natural and synthetic polymers [17, 20], or developing substrates for tissue engineering [21, 22]

EXPERIMENTAL WORK

Materials and Method

To produce microfibrous substrates from protein hydrolysates (obtained by electrolytic hydrolysis according to the methodology described in [23]) from Chamois skin dust waste, the following substances and devices were used: 38% HCl (Merck), 98% glacial acetic acid, NH_4OH, trichlorethylene, ethyl alcohol, acetone, distilled water, digital pH meter, pH indicator paper, chamois skin powder waste, 98% formic acid (Kanto LTD), distilled water, deionized water. For the experiments of degreasing chamois skin powder waste, described in [24], for the preparation, analysis and characterization of protein hydrolysates obtained by electrolytic hydrolysis [23], and of protein hydrolysate spinning solutions, the following were used: Vibrocell Sonic degreasing device with resonator tube, heating oven with thermoregulating chamber, laboratory electrolytic hydrolysis equipment, high rotational speed centrifuge, DIGILAB – SCIMITAR FTS 2000 IR-ATR spectroscope with ZnSe crystal, wavelength range between 750 and 4000 cm^{-1}, with a resolution of 4 cm^{-1}, Origin IR spectra processing software, and Nahita Rotary Viscometer for apparent viscosity measurement.

Experimental

a. Preparation and rheological characterization of spinning solutions

Starting from protein hydrolysate obtained electrolytically, according to our own methodology presented in [25], we moved on to the experimental protocol for obtaining fibrous substrates from protein hydrolysate solutions by preparing three protein hydrolysate spinning solutions having the following concentrations: 25% , 35% and 45% in 98% formic acid, prepared by mixing, dissolving and homogenising hydrolysate powder in formic acid at room temperature for 3 h. The solutions thus prepared were characterized rheologically by measuring the apparent viscosity, η_a, at working temperature 25±0.1°C at 3, 6, 9, 12, 24 h intervals after preparation using a rotational Nahit Rotary Viscometer (Japan) according to ISO 3219/1993 [26]. The values obtained for viscosities thus determined are presented in table 1.

Table 1

VALUES OF APPARENT VISCOSITY OF PROTEIN HYDROLYSATE SOLUTIONS USED FOR THE CENTRIFUGAL SPINNING PROCESS

Sample	Working concentration of spinning solutions from hydrolysates [%]	Apparent Viscosity η_a [Cp]
H25	25 % in FA	930
H35	35 % in FA	1200
H45	45% in FA	870

b. Centrifugal spinning

After preparing the spinning solutions we moved on to the actual spinning on a laboratory equipment whose suggestive diagram is shown in figure 1. The spinning process was presented in detail in previous papers [17–20] and consists in the use of solutions or melt of natural or synthetic polymers which supply a spinning head provided with multiple nozzles which rotates with a speed ranging from 3,000 to 20,000 rpm, depending on the rheological characteristics of the fiber forming polymer. Recipe parameters such as: the nature of the polymer, the nature of the solvent, concentration and the viscosity of the solution, to which processing parameters are added (working speed, the spinning nozzle geometry, number of nozzles, diameter of the spinning head, working temperature), are among the control factors of the morphological structures of fibrous substrates obtained.

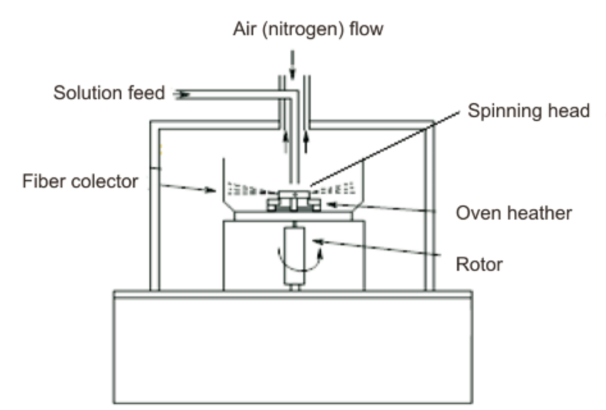


Fig. 1. Diagram of the centrifugal spinning equipment

The solvent evaporation temperature combined with the distance of deposition by centrifugal effect in relation to the substrate on which nanofibres are deposited is another factor that can help monitor the size and uniformity of fibrous substrates.
Random or parallel orientation of the fibers from solutions and/or melt on the substrates is also dependent on the spinning head geometry as well as on the flow rate of the fluid (air, nitrogen, etc.) and on the solvent evaporation rate. Steps of forming fibrous layers are: initiation of polymer solution flow, flow elongation, evaporation of the solvent, the deposition on the

substrate. In order to carry out the spinning process from solutions prepared according to the methodology previously described [20], we used a centrifugal spinning equipment of our own design to obtain microfibrous substrates and to analyze the morphologic and structural appearance of structures deposited on the substrates. In table 2 are given the working conditions and spinning parameters used during laboratory experiments.

The general appearance of microfibres deposited onto the working surface is presented in figure 2.

Table 2

TECHNOLOGICAL PARAMETERS OF CENTRIFUGAL SPINNING				
Sample	**Working concentration [%]**	**Temp. [°C]**	**Spinning nozzle diameter [μm]**	**Rotational speed of the spinning head [rpm]**
H25	25	25	300	2800
H35	35	25	300	3000
H45	45	25	300	3200

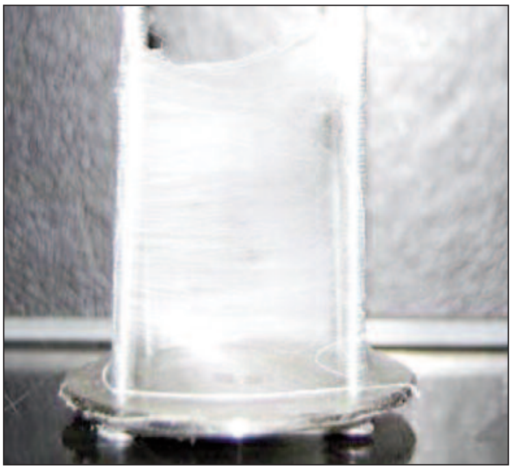


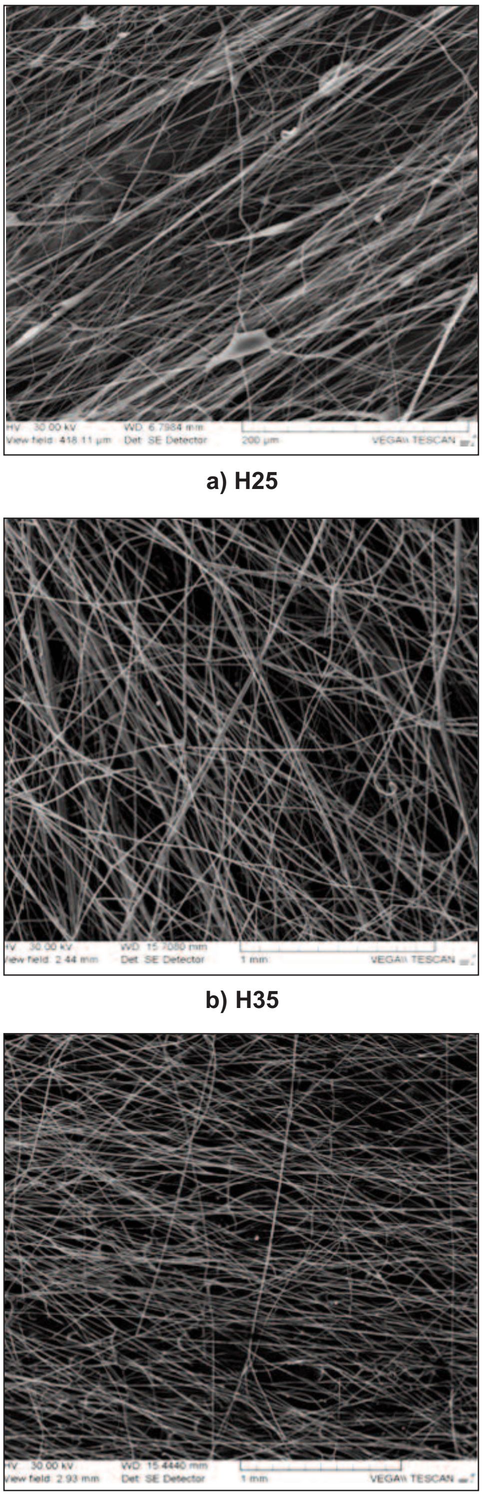
Fig. 2. General appearance of the substrate covered with microfibres from protein

Morphological characterization of microfibrous substrates

The morphologic appearance of microfibrous structures obtained after spinning by centrifugal effect was analyzed by scanning electron microscopy using a VEGA TESCAN (Czech Republic) electron microscope equipped with Atlas software for image analysis.

As seen from the images shown in figures 2–4, the resulting microfibers have a continuous and uniform appearance with a random deposition on the contact surface. The density of deposition on the substrate increases with increasing concentration of hydrolysis product due to increased evaporation rate of solvent in the presence of evaporation fluid flow (air, and nitrogen respectively).

At the same time, the degree of stretching and orientation of amino acid residues in the protein hydrolysates in the centrifugal spinning area increase with increasing concentration of solvent, leading, at the same time, to the reduction of the number of fibers deposited on the substrate. The formation of hydrogen bonds and intermolecular links and formation of associated molecules in hydrolysate solutions increase with increasing concentration of hydrolysate, allowing structural stabilization of solutions resulting in an increase in fiber deposit density as hydrolysate concentration increases (figure 3, a-c).

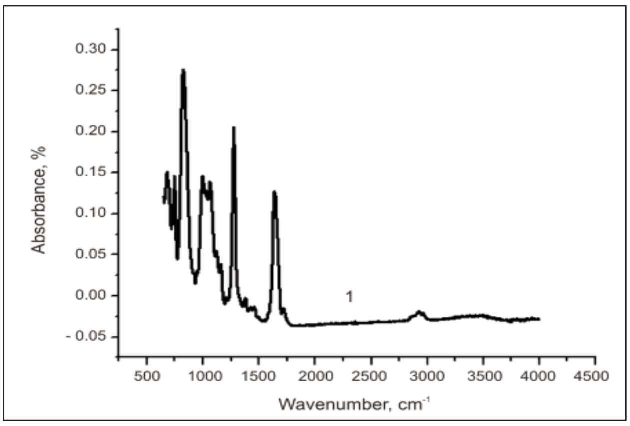


a) H25

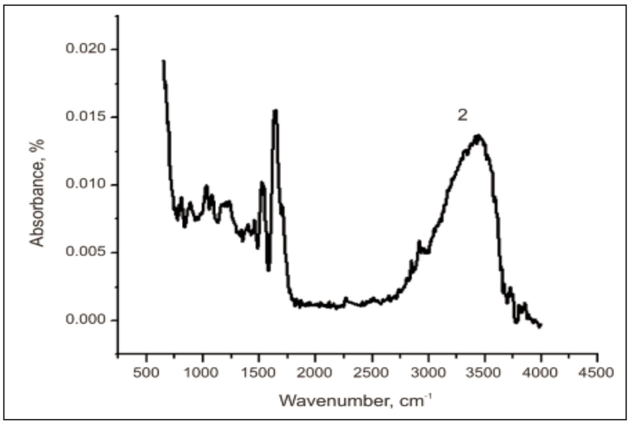
b) H35

c) H45

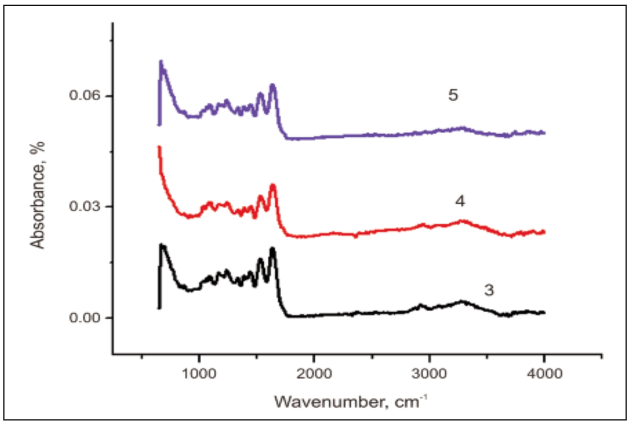
Fig. 3. SEM images of microfibers from protein hydrolysates



a



b



c

Fig. 4. Characteristic IR spectral bands: 1 – Initial sample; 2 – Hydrolysed sample; 3 – microfibre with 25% AF; 4 – microfibre with 35% AF; 5 – microfibre with 45% AF.

In terms of characteristic spectral bands in the IR domain (figure 3), it is noted that the initial sample of waste from dry finishing operations (buffing-dusting), the characteristic peak of amide A (corresponding to NH groups at 3300 cm^{-1}) disappears due to the process of destruction caused by previous processing operations (preliminary tanning and wet finishing). It should be noted that after electrolytic hydrolysis performed in the presence of NH_4OH [24], the peak shifts to 3660 cm^{-1}, indicating a tendency of hydrogen bonds to reform and reposition.

Characteristic peaks and their intensity in the amide I (1630 cm^{-1}), amide II (1500–1660 cm^{-1}), and amide III (1130–1300 cm^{-1}) regions, as well as bands corresponding to the triple-helical areas between 1130–1300 cm^{-1} appear much diminished in intensity and shifted to lower wavelengths for hydrolysate solutions (figure 3b) when compared with the initial sample of Chamois skin powder (fig. 3), and hydrolysate powder (3b), due to the interaction of solvent-hydrolysate, breaking of hydrogen bonds, and reforming hydrogen bonds and new Wan der Waals bonds in other areas (inter- and/or intramolecular). The repositioning of these characteristic peaks in microfibrous samples may also be due to the action of formic acid, as well as to the stretching process due to centrifugal forces during rotational spinning.

CONCLUSIONS

The experiments have led to the obtaining of a spinning solutions prepared using protein hydrolysates from Chamois skin powder, with optimal rheological characteristics for centrifugal spinning, finally resulting micro fibrous structures with continuous and uniform aspect, having a deposition density directly proportional to the concentration of used hydrolysate.

The modification of the spectral bands (IR) characteristic of the microfibers in hydrolysates suggests breaking of hydrogen bonds, the formation of new hydrogen bonds and Wan der Waals bonds due to the stretching effect under the action of the centrifugal forces in the spinning area. Changing the solvent concentration in the spinning solution can lead to repositioning and reformation of inter and intramolecular bonds (formation of molecular associates).

The complexity of recipe components and technological factors involved in the spinning process requires further experiments to optimize working conditions.

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Calculation method for the determination of the unit costs of fabrics woven in semi-automatic looms in small-sized enterprises

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REZUMAT – ABSTRACT

Metodă de calcul pentru determinarea costurilor unitare ale țesăturilor produse în întreprinderile mici-mijlocii cu războaie de țesut semi-automate

Modul elementar de maximizare a profitului în țesătoriile de mici dimensiuni, care îşi desfășoară activitatea într-un mediu extrem de competitiv din industria textilă, este de a reduce costurile, cu condiția menținerii stabile a calității producției. Cu toate acestea, asemenea majorității întreprinderilor de mici dimensiuni din industrie, care au o structură de producție de tip atelier pe bază de comandă, procesele de calculație a costurilor sunt în mod curent efectuate pe baza experiențelor profesionale, fără o metodă specifică. Aceasta complică controlul costurilor și maximizarea profitului în țesătoriile de mici dimensiuni.

În cadrul acestui studiu, obiectivul a fost de acela de a conștientiza referitor la semnificația calculării corespunzătoare a costurilor în țesătoriile de mici dimensiuni și de a propune o metodă de calcul de bază pentru calcularea costurilor unitare. În plus, metoda de calcul a costurilor, care a fost elaborată având în vedere cerințele întreprinderilor din regiune, a fost aplicată în calcularea costurilor unitare pentru articolele "fular" și "eșarfă", acestea fiind cele mai frecvente produse țesute în intreprinderile de mici dimensiuni din regiune.

Cuvinte-cheie: țesere, războaie de țesut semi-automate, calcularea costurilor unitare, metodă de calculare a costurilor, întreprinderi mici

Calculation method for the determination of the unit costs of fabrics woven in semi-automatic looms in small-sized enterprises

The most basic way of maximizing the profit in small-sized weaving enterprises, which manufacture in a highly competitive environment in textile industry, is to reduce the costs provided that the product manufacturing quality is kept stable. However, as most of the small-sized enterprises in the industry have a workshop-type manufacturing structure on a per order basis, the cost calculation processes are usually conducted based on professional experiences without a specific method. This complicates the cost control and profit maximization in small-sized weaving enterprises.

Within this study, the objective was to raise awareness on the significance of proper cost calculation in small-sized weaving enterprises and to propose a basic calculation method for the calculation of unit costs. In addition, the cost calculation method, which was developed considering the requirements of the enterprises within the region, was applied in calculation of the unit costs of “peshtemal” and “scarf” items, which are the most popular woven products in the small-sized weaving enterprises in the region.

Keywords: weaving, semi-automatic looms, unit cost calculation, cost calculation method, small-sized enterprises

INTRODUCTION

The enterprises that manufacture goods and services, which the society needs, by combining various production factors are the building blocks of national economies. The said enterprises’ being able to make a profit and so to contribute to the economy is made possible by manufacturing products in required quantities with minimum cost. In the industries where free competition is dominant, although the selling prices of manufactured goods are determined by the enterprises, they arise at the point where supply and demand cross under the market conditions. Therefore, the most important activity that needs to be performed so that enterprises can make profit in a preferred rate is to calculate the costs in the most correct way and to build an efficient cost control system. Thus, it will be possible to have minimum manufacturing costs by continuously checking them [1].

Weaving industry, which is one of the most important sub-branches of textile industry, is a manufacturing industry where there is a high level of competition in the world market today. The fact that the unit prices of fabrics, which are especially woven in the countries such as China, India and Brazil where the labor and energy costs are relatively low, are low and that the output is high complicates the competitiveness of other countries in this industry.

Enterprises need methods for an efficient calculation of their manufacturing costs and for a consistent cost control in order that they can compete and can be permanent in weaving industry [2, 3]. Medium-sized and big enterprises in the industry usually have the cost calculation programs and the trained personnel to use the methods for efficiently calculating the manufacturing costs within their existing organizational structures.

However, as most of the small-sized enterprises in the industry have a workshop-type manufacturing structure on a per order basis, the cost calculation processes are usually conducted based on professional experiences without a specific method. The possibility of making a mistake is quite high in cost calculations which are conducted without any specific method. In this industry where there is a high level of competition, such cost calculation mistakes may cause small-sized enterprises to encounter financial difficulties in a short time.

Various studies related to the subject are summarized as follows.

Rendall et al. (1999) conducted a survey study in order to research the cost management in textile companies and evaluated the results. The results proved that companies usually used traditional cost management systems and could not benefit from the advantages of modern cost management systems. However, apart from this, it was suggested that companies endeavored to improve themselves with practical experiences [4].

In their study, Koç and Kaplan (2006) made a theoretical approach in order to determine the cost of the yarns which are manufactured with specific properties in yarn enterprises. Following this, they made a cost calculation for 30/1 combed cotton weaving yarn by using the equations obtained from this theoretical approach, and compared the obtained values under the light of literature [1].

In another study, Kaplan and Koç (2006) defined equations for the calculation of the cost of a typical woven fabric and conducted an application study in a weaving enterprise. They made a cost calculation for a woven fabric with specific properties and the data obtained from the calculation were compared to the data obtained from the literature. At the end of the study, it was stated that the suggested equations were usable in the cost calculation of a woven fabric [5].

Ünal and Koç (2010) studied the manufacturing parameters, performance specifications and cost analysis of woven towel fabrics. Moreover, they endeavored to develop a software program which would optimize the costs of towel fabrics and to optimize the cost elements so as to minimize the unit cost [6].

In their study, Koç and Çinçik (2010) examined the energy types and amount used during the manufacturing of woven fabrics. As an application study, they also analyzed the energy consumption in a weaving enterprise. They aimed to develop a theoretical model in order to determine the energy consumption in the enterprise [7].

In their study, Değirmenci and Çelik (2013) elaborated the factors which affect the unit cost in a knitting enterprise and developed a software which calculates the unit cost of double-knit fabrics. At the end of the study, they compared the theoretical calculations and the results obtained from the software, and it was observed that the results obtained from the software were successful. By means of the software, the cost calculations in enterprises will be able to reach a definite speed and it will help make efficient decisions in especially manufactural problems [8].

The objective of this study is to raise awareness on the significance of proper cost calculation in workshop-type small-sized weaving enterprises that manufacture on a per order basis and to propose a basic calculation method for the calculation of unit costs. In the application study, the unit costs of "Peshtemal" and "Scarf" products, which were the most popular woven products in the small-sized textile enterprises in Buldan, were determined based on the calculation method.

The calculation method was specifically prepared for small-sized weaving enterprises; there is not any specific study for this purpose in literature.

EXPERIMENTAL PART

Denizli and its surroundings are one of the centers where weaving is the permanent source of income in Anatolia. It is known that city of Buldan is one of the headquarters of weaving in Denizli [9]. Most of the products manufactured in the city today are manufactured in workshop-type small-sized enterprises and semi-automatic weaving looms. According to an inventory research conducted by Ertuğrul and Utkun in 2009, it was confirmed that there were 127 units of semi-automatic weaving looms in the city [10]. The capital structure and output of the small-sized weaving enterprises in the region are not in the level to compete with big weaving enterprises. Therefore, enterprises endeavor to survive within the industry with high costs and low profit margin. Such enterprises need to utilize a calculation method with which they can calculate their unit costs in the most correct way and to have a consistent cost control in order that they can exist in the market for a long term.

Materials

In the application study, the unit costs of "Peshtemal" and "Scarf" products, which were the most popular woven products in the semi-automatic weaving looms in small-sized enterprises operating in Buldan, were determined based on the calculation method. In the study, the data obtained from the Limited Buldan Weavers' Association No: 1 was used. Limited Buldan Weavers' Association, which was founded in 1937 with 195 numbers of shareholders, works to improve weaving in the city. It was the first association in Turkish Republic in weaving area. It also reflects the characteristics of the products in the region.

The images of the products are displayed in figures 1 and 2. The technical details of the products are presented in table 1.

Method

In the study, a calculation method was proposed to use in the calculation of unit costs in workshop-type small-sized weaving enterprises that usually manufacture on a per order basis.

Table 1

TECHNICAL DATA OF PRODUCTS		
	1st product Peshtemal	**2nd product Scarf**
Weaving Preparation (Hour)		
a) Warp **(T_W)**	4	6
b) Drawing in **(T_D)**	2	6
c) Combing **(T_C)**	2	3
d) Knotting **(T_K)**	0	0
Weaving Preparation Labor Hourly Rate ($)		
a) Warp **(C_{WL})**	50	75
b) Drawing in **(C_{DL})**	75	100
c) Combing **(C_{CL})**	45	50
d) Knotting **(C_{KL})**	0	0
Technical data of fabrics		
Fabric width (cm)	90	60
Fabric length **(L_{UF})** (m)	1.80	1.80
Weft density in 1 cm **(D_{Wt})**	22	22
Comb width **(W_C)** (cm)	95	62
Weft yarn count **(W_C)**	300 denier = 30 Nm	300 denier = 30 Nm
Wastage Rate of Yarn **(R_{WY})** (%)	7	7
Production quantity **(Q_P)** (Piece)	1000	1000
Type of weft yarn	100% Insect Silk	100% Floss Silk
Type of warp yarn	100% Cotton	100% Floss Silk
Yarn Price – Insect Silk (300 denier) **(P_Y)** ($/Kg)	150	
Yarn Price – Cotton (Nm 40/2) **(P_Y)** ($/Kg)	7.20	
Yarn Price – Floss Silk (300 denier) **(P_Y)** ($/Kg)		19
Warp Length **(L_{UW})** (m)	1.80	1.80
Number of Teeth on the Comb in One cm **(TN_C)**	7	7
Number of Thread in One Teeth in Hem **(Th_{NH})**	4	4
Warp Width of Fabric Hem **(WW_{FH})** (cm)	2	2
Number of Thread in One Teeth in Floor **(Th_{NF})**	2	2
Warp Width of Fabric Floor **(WW_{FF})** (cm)	88	58
Warp yarn count **(CT_{WY})**	Nm 40/2	300 denier = 30 Nm
Shrinkage Amount of Product in Warp Direction **(SA_W)** (%)	0	0
Machine Speed **(S_M)** (turnover/minute)	115	115
Production Efficiency **(E_{MP})** (%)	80	80
Normal Monthly Working Minutes of a Worker **(T_{WM})**	10800	
Monthly Labor Cost of One Worker **(C_{ML})** ($)	600	
Monthly Energy Cost of One Machine**(C_{ME})** ($)	150	
Unit Cost of Semi-Automatic Loom **(C_{UL})** ($)	15000	
Economic Life of Machine **(EL_M)** (year)	10	
Other Costs Rate **(R_{OC})** (%)	10	10
Wastage Rate of Product **(R_{WP})** (%)	2	2
The right and left edges of both products are 1 cm.		
Both products were manufactured in plain weave and their surfaces are smooth.		
After the weaving process was completed, the fabrics were kept in 50ºC water for 90 minutes without adding any substance; following this, they were left to dry.		
The products can optionally have a tassel in their warp length. If a tassel is not requested, these tassels must be tied by knotting as the last process.		

Fig. 1. Peshtemal sample

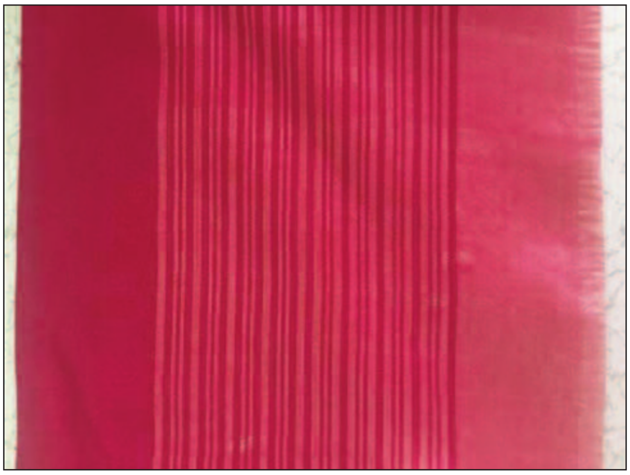

Fig. 2. Scarf sample

When proposing a calculation method to use in the calculation of unit costs in weaving enterprises, the cost items such as yarn cost (weft + warp + wastage + shrinkage amounts), labor cost, energy cost, amortization cost, incalculable small costs and wastage rate of product were considered.

Calculation of the unit cost of woven fabrics

The cost calculation system developed in the study was designed in accordance with the conditions of plain weave system. The most important reason to prefer this method is that it is the most common weaving method in the small-sized enterprises operating in Buldan and its surroundings. This situation constitutes a constraint of the study. In addition, the basic abbreviations, which are used in the cost calculation method developed in the study, and their explanations are given as follows.

C	= Cost	**R**	= Rate
CT	= Count	**S**	= Speed
D	= Density	**SA**	= Shrinkage Amount
E	= Expenses	**T**	= Time
EF	= Efficiency	**ThN**	= Number of Thread
EL	= Economic Life	**TN**	= Number of Teeth
L	= Length	**W**	= Width
P	= Price	**WL**	= Warp Length
Q	= Quantity	**WW**	**=** Warp Width

In weaving enterprises, as in the other enterprises, first of all, the expenses occurring during the manufacturing process of the product must be determined in order to determine the unit costs. As it is seen in equation (1), first of all, Raw Material Cost (C_{RM}) and General Production Expenses (E_{GP}) are divided into Production Quantity (Q_P) in calculation of Total Unit Cost (C_{TU}) of the fabrics woven in semi-automatic looms in small-sized enterprises. Other Costs Rate (R_{OC}) in a definite rate and Wastage Rate of Product (R_{WP}), which may vary from product to product, are added to the unit cost and C_{TU} figure is obtained.

The most important problem in the calculation of unit costs in small-sized weaving enterprises is that the required cost calculation data cannot be obtained in detail. Therefore, at the end of the one-on-one meetings with the industry representatives, it was confirmed that other costs rate as 10% must be added to the total unit cost. Other costs rate include "Incalculable Micro Costs", "Indirect Labor Costs", "Invisible Costs", "Unexpected Costs" and "Possible Calculation Deficits-Errors".

$$C_{TU}(\$) = \left[\left(\frac{C_{RM}(\$) + E_{GP}(\$)}{Q_P\ (\text{Piece})}\right) \times 1,R_{OC}\right] \times 1,R_{WP} \quad (1)$$

where:

C_{TU} = Total Unit Cost
C_{RM} = Raw Material Cost
E_{GP} = General Production Expenses
Q_P = Production Quantity
R_{OC} = Other Costs Rate
R_{WP} = Wastage Rate of Product

Calculation of Raw Material Cost

Raw material cost is generally the cost of the main elements that constitute a product. Considering the woven fabric, the raw material is taken as yarn [8]. As it is seen in equation (2), the order-based raw material cost (C_{RM}) in woven fabrics was determined by adding up Weaving Preparation Cost (C_{WP}) and Yarn Cost (C_Y).

$$C_{RM}(\$) = C_{WP} + C_Y \quad (2)$$

where:

C_{RM} = Raw Material Cost
C_{WP} = Weaving Preparation Cost
C_Y = Yarn Cost

a) Weaving Preparation Cost

Weaving preparation process consists of four main titles as "Warp preparation", "Drawing-in", "Combing" and "Knotting".

The purpose of warp preparation is to allow the warp to feed to the loom in a layer consisting of parallel yarns in equal tension and to maintain this position during the weaving process [11].

The other preparation process right after the warp is prepared is to draw in the warp by framing it in an appropriate level and then to comb it properly [11].

If a new weaving process with a different weaving knit will start on the loom, drawing-in and combing processes are performed; however, if the same product will continue to be woven, only the knotting process is performed.

As it is seen in equation (3), order-based Weaving Preparation Cost (C_{WP}) is calculated by adding up Warp Cost (C_W), Drawing-in Cost (C_D), Combing Cost (C_C) and Knotting Cost (C_K). All of these costs are determined by multiplying the time to be spent for the process with the labor cost.

$$C_{WP}(\$) = C_W + C_D + C_C + C_K \quad (3)$$

where:

C_{WP} = Weaving Preparation Cost
C_W = Warp Cost
C_D = Drawing in Cost
C_C = Combing Cost
C_K = Knotting Cost

$$C_{WP}(\$) = \left[(T_W \times C_{WL}) + (T_D \times C_{DL}) + (T_C \times C_{CL}) + (T_K \times C_{KL})\right] \quad (4)$$

where:

C_{WP} = Weaving Preparation Cost
T_W (Hour) = Warp Time
C_{WL} (\$/Hour) = Warp Labor Cost
T_D (Hour) = Drawing in Time
C_{DL} (\$/Hour) = Drawing in Labor Cost
T_C (Hour) = Combing Time
C_{CL} (\$/Hour) = Combing Labor Cost
T_K (Hour) = Knotting Time
C_{KL} (\$/Hour) = Knotting Labor Cost

b) Yarn Cost

The most important cost item in weaving process is Yarn Cost (C_Y). As it is seen in equation (5), order-based C_Y is determined by adding up Weft Yarn Cost (C_{WP}) and Warp Yarn Cost (C_{WY}).

$$C_Y(\$) = C_{WtY} + C_{WY} \quad (5)$$

where:

C_Y = Yarn Cost
C_{WtY} = Weft Yarn Cost
C_{WY} = Warp Yarn Cost

As it is seen in equation (6), first of all, the weft yarn quantity to be used for the ordered product is specified as kg. in calculation of Weft Yarn Cost (C_{WtY}). The total weft yarn cost as per order is calculated by multiplying the specified quantity with the yarn price [12].

$$C_{WtY} = \left[\left(\frac{L_{UF} \times D_{Wt} \times W_C}{CT_{WtY}} \times 1,R_{WY}\right) \times Q_P\right] \times \frac{P_Y}{1000} \quad (6)$$

where:

C_{WtY} (\$) = Weft Yarn Cost
L_{UF} (m) = Unit Fabric Length
D_{Wt} (in 1 cm) = Weft Density
W_C (cm) = Comb Width
CT_{WtY} (Nm) = Weft Yarn Count
R_{WY} = Wastage Rate of Yarn
Q_P (Piece) = Production Quantity
P_Y (\$/Kg) = Yarn Price

As it is seen in equation (7), first of all, the warp yarn quantity to be used for the ordered product is specified as kg. in calculation of Warp Yarn Cost (C_{WY}). The total warp yarn cost as per order is calculated by multiplying the specified quantity with the yarn price [12].

$$C_{WY} = \left[\left(\frac{L_{UW} \times (TN_C \times Th_{NH} \times WW_{FH} + TN_C \times Th_{NF} \times WW_{FF})}{CT_{WY} \times (1 - SA_W)} \times 1,R_{WY}\right) \times Q_P\right] \times \frac{P_Y}{1000} \quad (7)$$

where:

C_{WY} (\$) = Warp Yarn Cost
L_{UW} (m) = Unit Warp Length
TN_C (in 1 cm) = Number of Teeth on the Comb in One cm
Th_{NH} (in one teeth) = Number of Thread in One Teeth in Hem
WW_{FH} (cm) = Warp Width of Fabric Hem
Th_{NF} (in one teeth) = Number of Thread in One Teeth in Floor
WW_{FF} (cm) = Warp Width of Fabric Floor
CT_{WY} (Nm) = Warp Yarn Count
SA_W (%) = Shrinkage Amount of Product in Warp Direction
R_{WY} = Wastage Rate of Yarn
Q_P (Piece) = Production Quantity
P_Y (\$/Kg) = Yarn Price

Calculation of General Production Expenses

As it is seen in equation (8), General Production Expenses (E_{GP}) in the small-sized weaving enterprises running on a per order basis are determined by adding up the calculated Labor Cost (C_L), Energy Cost (C_E) and Amortization Cost (C_A).

$$E_{GP}(\$) = C_L + C_E + C_A \quad (8)$$

where:

E_{GP} = General Production Expenses
C_L = Labor Cost
C_E = Energy (Electricity) Cost
C_A = Amortization Cost

a) Labor Cost:

In the formula to be used in calculation of the labor cost in small-sized weaving enterprises, first of all, the monthly working hours required for the related order are calculated, and then, the obtained result is multiplied with the monthly labor cost of one worker. In calculation of the labor cost, the social security deductions of the employer must be added to the cost in addition to the gross pay. As there is a workshop-type manufacturing in small-sized weaving enterprises, the calculated labor cost is "Direct Labor Cost". As "Indirect Labor Cost" was very low and incalculable in the total labor cost, it was not included in the calculation. The impact of the indirect labor cost on the manufacturing cost is included in "Other Costs".

As it is seen in equation (9), first of all, the time to be spent for manufacturing the ordered product is specified in minutes in calculation of the labor cost. The coefficient, which is determined by dividing the specified figure into 10.800 minutes that is the normal monthly working hours of a worker, is multiplied with Monthly Labor Cost of One Worker (C_{ML}), so the total Labor Cost (C_L) as per order is calculated.

$$C_L = \frac{\left(\frac{L_{UF} \times D_{Wt}}{S_M \times E_{MP}}\right) \times Q_P}{T_{WM}^{\,*}} \times C_{ML} \qquad (9)$$

where:

C_L (\$) = Labor Cost

L_{UF} (cm) = Unit Fabric Length

D_{Wt} (in 1 cm) = Weft Density

S_M (Turnover/Minute) = Machine Speed

E_{MP} = Production Efficiency

Q_P (Piece) = Production Quantity

T_{WM} (Minute/Month) = Normal Monthly Working Minutes of a Worker

C_{ML} (\$) = Monthly Labor Cost of One Worker

- **Normal Monthly Working Hours:**

As per the agreement no: 47 acknowledged by International Labor Organization (ILO) in 1935, the normal weekly working hours of workers were determined as 40 hours. Each country throughout the world may apply different normal weekly working hours. As the application study was conducted in Turkey, the normal weekly working hours were defined as 45 hours in the local labor act. Based on that, the normal monthly working hours of a worker were calculated in minutes as follows (This situation constitutes a constraint of the study, and this section must be revised based on the normal weekly working hours in the countries where the cost calculation method is used):

Normal Monthly Working Hours of a Worker (WH_N):

4 Weeks × 45 Hours = 180 Hours × 60 Minutes =
= **10.800 Minutes/Month**

b) Energy Cost

In the formula to be used in calculation of the energy cost in small-sized weaving enterprises, first of all, the monthly working hours required for the related order are calculated and then, the obtained result is multiplied with the monthly average energy cost of one machine. As the proportion of the energy cost to the total cost is very low in the manufacturing in semi-automatic looms, the monthly energy cost of the looms was not calculated in detail in the study and an average cost figure was taken into consideration. This situation constitutes another constraint of the study.

As it is seen in equation (10), first of all, the time to be spent for manufacturing the ordered product is specified in minutes in calculation of the energy cost. The coefficient, which is determined by dividing the specified figure into 10.800 minutes that is the normal monthly working hours of a worker, is multiplied with Monthly Energy Cost of One Machine (C_{MF}), so the total Energy Cost (C_F) as per order is calculated.

$$C_E = \frac{\left(\frac{L_{UF} \times D_{Wt}}{S_M \times E_{MP}}\right) \times Q_P}{T_{WM}^{\,*}} \times C_{ME} \qquad (10)$$

where:

C_E (\$) = Energy Cost

L_{UF} (cm) = Unit Fabric Length

D_{Wt} (in 1 cm) = Weft Density

S_M (Turnover/Minute) = Machine Speed

E_{MP} = Production Efficiency

Q_P (Piece) = Production Quantity

T_{WM} (Minute/Month) = Normal Monthly Working Minutes of a Worker

C_{ME} (\$) = Monthly Energy Cost of One Machine

c) Amortization Cost

Amortization means the depreciation of the fixed assets in enterprises. Enterprises use the tangible assets, which they purchase to utilize, for more than one year under normal conditions. The average life cycle of tangible assets is called as economic life. Therefore, the amortization costs of tangible assets must be added to the production costs based on their economic life and considering their manufacturing time. The most important tangible asset which is subject to amortization in small-sized weaving enterprises is the loom.

In the formula to be used in calculation of the amortization cost in small-sized enterprises, first of all, the monthly working hours required for the related order are calculated and then, the obtained result is multiplied with the monthly amortization cost of one semi-automatic weaving loom. The monthly amortization cost of a weaving loom is calculated by dividing the

Table 2

SAMPLE PESHTEMAL ORDER – UNIT COST CALCULATION TABLE			
	Weaving Preparation		$C_{WP}(\$) = [(\mathbf{4}\,(\text{Hour}) \times \mathbf{50}\,(\$/\text{Hour})) + (\mathbf{2}\,(\text{Hour}) \times \mathbf{75}\,(\$/\text{Hour})) + (\mathbf{2}\,(\text{Hour}) \times \mathbf{45}\,(\$/\text{Hour})) + (\mathbf{0}\,(\text{Hour}) \times \mathbf{0}\,(\$/\text{Hour}))] = \mathbf{440{,}00}$
	Yarn Cost	Weft Yarn Cost	$C_{WtY}(\$) = \left[\left(\frac{\mathbf{1.80}\,(\text{m}) \times \mathbf{22}\,(\text{in 1 cm}) \times \mathbf{95}\,(\text{cm})}{\mathbf{30}\,(\text{Nm})} \times \mathbf{1.07}\right) \times \mathbf{1000}\,(\text{Piece})\right] \times \left(\frac{\mathbf{150}\,(\$/\text{Kg})}{\mathbf{1000}}\right) = \mathbf{20.126{,}70}$
		Warp Yarn Cost	$C_{WY}(\$) = \left[\left(\frac{\mathbf{1.80}\,(\text{m}) \times (\mathbf{7}\,(\text{in 1 cm}) \times \mathbf{4}\,(\text{in one teeth}) \times \mathbf{2}\,(\text{cm}) + \mathbf{7}\,(\text{in 1 cm}) \times \mathbf{2}\,(\text{in one teeth}) \times \mathbf{88}\,(\text{cm}))}{\mathbf{20}\,(\text{Nm}) \times (\mathbf{1-0})} \times \mathbf{1.07}\right) \times \mathbf{1000}\,(\text{Piece})\right] \times \left(\frac{\mathbf{7.20}\,(\$/\text{Kg})}{\mathbf{1000}}\right) = \mathbf{893{,}05}$
RAW MATERIAL COST			$C_{RM}(\$) = 440{,}00 + (20.126{,}70 + 893{,}05) = \mathbf{21.459{,}75}$
	Labor Cost		$C_L(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \mathbf{600}\,(\$) = \mathbf{2.391{,}30}$
	Energy Cost		$C_E(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \mathbf{150}\,(\$) = \mathbf{597{,}83}$
	Amortization Cost		$C_L(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \left[\frac{\left(\frac{15.000\,(\$)}{10\,(\text{Year})}\right)}{12}\right] = \mathbf{498{,}19}$
GENERAL PRODUCTION EXPENSES			$E_{GP}(\$) = 2.391{,}30 + 597{,}83 + 498{,}19 = \mathbf{3.487{,}32}$
TOTAL UNIT COST			$C_{TU}(\$) = \left[\left(\frac{21.459{,}75\,(\$) + 3.487{,}32\,(\$)}{1000\,(\text{Piece})}\right) \times 1{,}10\right] \times 1{,}02 = \mathbf{\$27{,}99/pcs}$

Table 3

SAMPLE SCARF ORDER – UNIT COST CALCULATION TABLE			
	Weaving Preparation		$C_{WP}(\$) = [(\mathbf{6}\,(\text{Hour}) \times \mathbf{75}\,(\$/\text{Hour})) + (\mathbf{6}\,(\text{Hour}) \times \mathbf{100}\,(\$/\text{Hour})) + (\mathbf{3}\,(\text{Hour}) \times \mathbf{50}\,(\$/\text{Hour})) + (\mathbf{0}\,(\text{Hour}) \times \mathbf{0}\,(\$/\text{Hour}))] = \mathbf{1.200{,}00}$
	Yarn Cost	Weft Yarn Cost	$C_{WtY}(\$) = \left[\left(\frac{\mathbf{1.80}\,(\text{m}) \times \mathbf{22}\,(\text{in 1 cm}) \times \mathbf{62}\,(\text{cm})}{\mathbf{30}\,(\text{Nm})} \times \mathbf{1.07}\right) \times \mathbf{1000}\,(\text{Piece})\right] \times \left(\frac{\mathbf{19}\,(\$/\text{Kg})}{\mathbf{1000}}\right) = \mathbf{1.663{,}67}$
		Warp Yarn Cost	$C_{WY}(\$) = \left[\left(\frac{\mathbf{1.80}\,(\text{m}) \times (\mathbf{7}\,(\text{in 1 cm}) \times \mathbf{4}\,(\text{in one teeth}) \times \mathbf{2}\,(\text{cm}) + \mathbf{7}\,(\text{in 1 cm}) \times \mathbf{2}\,(\text{in one teeth}) \times \mathbf{58}\,(\text{cm}))}{\mathbf{30}\,(\text{Nm}) \times (\mathbf{1-0})} \times \mathbf{1.07}\right) \times \mathbf{1000}\,(\text{Piece})\right] \times \left(\frac{\mathbf{19}\,(\$/\text{Kg})}{\mathbf{1000}}\right) = \mathbf{1.058{,}79}$
RAW MATERIAL COST			$C_{RM}(\$) = 1.200{,}00 + (1.663{,}67 + 1.058{,}79) = \mathbf{3.922{,}46}$
	Labor Cost		$C_L(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \mathbf{600}\,(\$) = \mathbf{2.391{,}30}$
	Energy Cost		$C_E(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \mathbf{150}\,(\$) = \mathbf{597{,}83}$
	Amortization Cost		$C_L(\$) = \left[\frac{\left(\frac{\mathbf{180}(\text{cm}) \times \mathbf{22}\,(\text{in 1 cm})}{\mathbf{115}\,(\text{Turnover/Minute}) \times \mathbf{0.80}}\right) \times \mathbf{1000}\,(\text{Piece})}{\mathbf{10.800}(\text{Minute/Month})*}\right] \times \left[\frac{\left(\frac{15.000\,(\$)}{10\,(\text{Year})}\right)}{12}\right] = \mathbf{498{,}19}$
GENERAL PRODUCTION EXPENSES			$E_{GP}(\$) = 2.391{,}30 + 597{,}83 + 498{,}19 = \mathbf{3.487{,}32}$
TOTAL UNIT COST			$C_{TU}(\$) = \left[\left(\frac{3.922{,}46\,(\$) + 3.487{,}32\,(\$)}{1000\,(\text{Piece})}\right) \times 1{,}10\right] \times 1{,}02 = \mathbf{\$8{,}33/pcs}$

unit cost of the loom into the economic life of the machine and then dividing the obtained figure into 12. As it is seen in equation (11), first of all, the time to be spent for manufacturing the ordered product is specified in minutes in calculation of the amortization cost. The coefficient, which is determined by dividing the specified figure into 10.800 minutes that is the normal monthly working hours of a worker, is multiplied with monthly amortization cost of one machine which is calculated via another equation, so the total Amortization Cost (C_A) as per order is calculated.

$$C_A = \frac{\left(\frac{L_{UF} \times D_{Wt}}{S_M \times E_{MP}}\right) \times Q_P}{T_{WM}\,^*} \times \frac{\frac{C_{UL}}{EL_M}}{12} \qquad (11)$$

where:

C_A ($) = Amortization Cost

L_{UF} (cm) = Unit Fabric Length

D_{Wt} (in 1 cm) = Weft Density

S_M (Turnover/Minute) = Machine Speed

E_{MP} = Production Efficiency

Q_P (Piece) = Production Quantity

T_{WM} (Minute/Month) = Normal Monthly Working Minutes of a Worker

C_{UL} ($) = Unit Cost of Semi-Automatic Loom

EL_M (Year) = Economic Life of Machine

RESULTS AND DISCUSSION

In accordance with the data obtained from the Limited Buldan Weavers' Association No. 1, by using the unit cost calculation method developed for small-sized weaving enterprises, the unit cost calculation of the sample peshtemal is given in table 2 and the unit cost calculation of the sample scarf is given in table 3.

In table 2, the unit cost of the sample peshtemal, the weft of which was made of silkworm yarn and the warp of which was made of cotton yarn, was calculated as $27.99/pcs based on the calculation method. In table 3, the unit cost of the sample scarf, the weft and warp of which were made of floss silk yarn, was calculated as $8.33/pcs based on the calculation method.

CONCLUSIONS

There are two basic methods to maximize the profit in manufacturing enterprises. The first one is to increase the selling prices, and the second one is to reduce the costs. Considering that there is a highly competitive environment for the enterprises manufacturing in textile industry and that the selling prices are formed under the market conditions, it does not seem much possible to maximize the profit by raising the selling prices. It is possible to maximize the profit only through the remaining second method, which is to reduce the costs. The main condition for the enterprises to reduce their costs provided that they keep the production quality stable is to have a proper cost calculation method that provides correct results. In most of the big textile enterprises, the costs can be efficiently calculated via computer programs and other calculation methods. But as most of the small-sized enterprises in the industry have a workshop-type manufacturing structure on a per order basis, the cost calculation processes are usually conducted based on professional experiences without a specific method. This complicates the cost control and profit maximization in small-sized weaving enterprises.

The majority of weaving manufacturing is carried out in workshop-type small-sized enterprises and semi-automatic weaving looms in Buldan, which is one of the most important manufacturing centers of textile industry in Turkey and throughout the world from past to present.

Within this study, the objective was to raise awareness on the significance of proper cost calculation in workshop-type small-sized weaving enterprises that manufacture on a per order basis and to propose a basic calculation method for the calculation of unit costs.

The cost calculation method, which was developed considering the requirements of the enterprises in the region, was applied in calculation of the unit costs of peshtemal and scarf which were the most popular woven products in the small-sized weaving enterprises in the city of Buldan.

This cost calculation method could apply for various woven products. Following this study, it is planned to develop a computer program that will calculate the unit costs of the products manufactured in small-sized weaving enterprises.

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Optimising textile industry processes using cloud computing technology

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REZUMAT – ABSTRACT

Optimizarea proceselor specifice industriei textile utilizând tehnologia cloud computing

Contextul economic actual este marcat de nevoia companiilor de a-şi optimiza procesele în vederea creşterii avantajului competitiv. Un posibil facilitator al optimizării proceselor poate fi reprezentat de migrarea, totală sau parţială, către tehnologia cloud computing. Prezentul articol porneşte de la analiza proceselor operaţionale şi de suport din cadrul companiilor ce activează în domeniul industriei textile, pentru a explora soluţii ce pot conduce către optimizarea activităţii, din perspectiva costurilor sau a timpului necesar pentru realizarea anumitor activităţi, prin adoptarea, totală sau parţială, a tehnologiei cloud computing. Pornind de la studiul proceselor dezvoltate în cadrul unei serii de companii ce activează în domeniul industriei textile de pe piaţa românească, articolul supune către analiză diverse modele de reinginerie a acestora din perspectiva migrării către tehnologia cloud computing, în vederea optimizării activităţii, prezentând, într-un mod teoretic, remodelarea acestora şi rezultatele scontate.

Cuvinte-cheie: cloud computing, tehnologie, procese, performanţă, optimizare

Optimising textile industry processes using cloud computing technology

Today's economic context is marked by the companies' need to optimise their processes in order to increase their competitive advantage. A potential driver enabling process optimisation could be represented by total or partial migration towards cloud computing technology. This article commences from the analysis of operational and support processes of companies activating in the textile industry, and explores solutions that may lead towards enhancement of activity, from the perspective of costs and time required to perform a certain task, through adopting, totally or partially, the cloud computing technology. Based on the processes in place within several companies from textile industry on the Romanian market, the study analyses various process reengineering models from the perspective of cloud computing adoption, aiming towards process optimization, presenting, in a theoretical manner, the optimized model and expected results.

Keywords: cloud computing, technology, processes, performance, optimisation

INTRODUCTION

In a capitalist economy, marked by the companies' aim to develop their competitive advantage, a new trend seems to gain power against the extensive approach (defined by diversifying the product portfolio, improving the market share, etc.): performance improvement through process optimisation.

Corporate Social Responsibility concept is used by businesses worldwide and is the approach used to rethink the activities of enterprises from the perspective of sustainable development [1].

More and more often, companies are turning to internal resources or external consultants to analyze the existing processes and activities in order to identify opportunities that would enable optimisation in terms of costs, time and resources involved. Thus, the technological perspective brings along a new approach, allowing companies to optimise their processes in terms of costs, resources and lead time: adopting, totally or partially, the cloud computing technology for their operational and/or support processes.

Cloud computing technology is not a new concept, and is often perceived simply as outsourcing of the IT function. Under the purpose of supporting the operational activity, the IT function is vital for the company's business continuity, meant to ensure optimised and correct functioning of the information systems and related operations.

The present paper presents, in a theoretical manner, a series of models that a company can use in order to optimise the operational and/or support processes. The current study was limited to the general processes specific to textile industry companies, through outlining the steps (activities) generally used by this type of companies, and seeks to identify the processes/activities/operations that can be outsourced through cloud computing technology. The paper presents a hypothetical model, and is meant to offer an overview upon the opportunity of migrating towards cloud computing technology as for enabling process improvement, cost reduction, optimisation of resources and lead time.

CLOUD COMPUTING – A TECHNOLOGICAL TREND

Cloud computing represents a new generation of internet-based systems that use remote servers for data storage and management, and through which shared resources, software products and information are supplied on-demand towards computers and other devices, thus optimising the energy consumption [2].

Table 1

<table>
<tr><th colspan="5">MAIN CHARACTERISTICS OF CLOUD COMPUTING MODELS</th></tr>
<tr><td>Development models</td><td>Public Cloud</td><td colspan="2">Hybrid/Community cloud</td><td>Private cloud</td></tr>
<tr><td>Service models</td><td>IaaS (Infrastructure as a Service)</td><td colspan="2">PaaS (Platform as a Service)</td><td>SaaS (Software as a Service)</td></tr>
<tr><td>Main characteristics</td><td colspan="2">– Pay as you use
– Elasticity
– Measured service
– Geographic distribution
– Advanced Security</td><td colspan="2">– Pay as you use
– Broad network access
– Resource pooling
– Homogeneity
– Virtualisation
– Low cost</td></tr>
</table>

A Deutsche Bank report dated March 2012 presents the framing definition of Cloud Computing, as elaborated by the National Institute of Standards and Technology (NIST), together with its main functions presented in table 1.

In his book, Miller M. (*Cloud Computing – Web-based applications that change the way you work and collaborate online*) presents the advantages and disadvantages that the use of cloud computing technology brings [3]. The main cloud computing adoption drivers are thus represented by the opportunities of cost reduction (in terms of software and hardware), increasing of the workstations' capacity, reduction of maintenance issues, universal access to the information (the only condition being the internet connection), improving the collaboration with business partners, or ensuring permanent update of software programs used. On the other side, the main challenges are: the need for a permanent, stable and relatively strong internet connection, as well as the security and control of data thus handled.

A study performed by A.K. Damodaram and K. Ravindranath (*Cloud Computing for Managing Apparel and Garment Supply Chains – an Empirical study of Implementation Frame Work)* shows that organisations assign a 80/20 ratio between the IT processes regularly developed within a company, including hardware operations, software licenses, development, maintenance and other operations, and new investments meant to ensure the business' survival [4].

Cloud computing may prove a significant impact upon the reduction of IT operations volume through elimination of costs regarding hardware and software licenses [5]. This allows the use of new cost models, such as "Use what you need" and "Pay for what you use", making room for investing in new, innovative solutions seeking to satisfy the clients' needs [6].

A study conducted in 2013 by Accenture Company (*A New Era for Retail – Cloud Computing Changes the Game)* regarding the retail organizations' capacity to deliver services to clients revealed the fact that 74% from the retailers interviewed ranked as "underdeveloped". Moreover, 72.5% described as non-existent or underdeveloped the capability to deliver a shopping experience interconnected between the channels, while, 81% of the respondents reported as non-existent or underdeveloped capabilities in tailoring assortment or establishment of prices. Currently, cloud computing represents an efficient model for retailers to develop capabilities at a pace as to retain the customers' interest. Given the circumstances it is expected a widespread with regards to cloud computing adoption in retail industry, with an increase in cloud market from 4.2 billion dollars in 2011 to 15.1 billion dollars in 2015 [7].

The actual context within the retail market comprises of standardised and fragmented information systems used in different locations (for example, the systems used in two different stores may operate at different parameters) [8]. Operations such as tracking of inventory, delivery, data collected from the cash registers, etc. are all locally stored at each shopping point without a global system capable of centralizing data in real time. The use of cloud computing technology may contribute to data centralization and unification of business processes without geographical limitations, which resides into time and cost savings through eliminating the need for local servers in each store.

However, a study conducted by IDC (*Global IT Technology and Industry Research Organization Survey, 2013*) showed that cloud adoption is quite low among the textile industry companies compared to other business sectors. Long-term expectations of retailers related to cloud show that 66.2% of retailers will be limited to using of private cloud services, a very small amount of cloud or no cloud in the next 5 years.

Specifically, the Accenture study (*A New Era for Retail – Cloud Computing Changes the Game*) mentions the channels where retailers can use the cloud and associated technologies to improve business results, as below:

– channel operations: process optimisation through management enabling, global applicability based on local focus, rapid store opening in multiple locations, reduced CAPEX, faster speed to market
– trading and marketing (products catalogue, allocation, loyalty programmes): better understanding of shopping habits and trends of customers, fewer

- stock-outs, access to global markets with minimum investments
- supply chain management: reduced overheads, cost cutting, efficient and more sustainable supply chain
- sales (ecommerce): reduced IT budget greater adaptability and flexibility, reduced response times, easier integration [7]

In a world where digital technology buyers can purchase directly from online stores, the limitations of these channels are rarely taken into account. Customers seek for access to retailers with no limitation regarding space and time. We consider that by using the cloud technology retailers come to meet customer needs and preferences regardless of the selected channel. Moreover, the Accenture study (*A New Era for Retail – Cloud Computing Changes the Game)* further shows that devices like tablets or smartphones can be used as POS systems for concluding payments. POS device management was headed to adoption of cloud, about 25% of retailers making the transition by the end of 2012 [7].

Experimental part

The present study is focused on creating a theoretical model for companies activating in the textile industry to optimise their operational and support processes through the use of cloud computing technology. This was performed through analysing the supply chain management and financial accounting processes as performed in textile industry companies, and assess the possibility to migrate activities towards cloud computing. Where migration was possible, the analysis also focused on the possibility of process optimisation in terms of cost cutting, reducing the process lead time and involved (financial and material) resources.

RESULTS AND DISCUSSIONS

Despite being a highly industrialised sector, the textile industry can easily be subject of process optimisation. The present section approaches the general processes existing in textile industry companies, as for analysing potential improvement opportunities in terms of lead time, cost reduction and involved resources.

Textile industry domain may be regarded as a supply chain aggregating a series of activities. More and more often, the supply chain for raw materials, starting from the planning and production, up to distribution chain and marketing, is organised as an internal network in which production is split on specialised activities, each activity being localised where it adds the greatest value to the final product. Thus, the cost, quality, delivery, transport and other operational expenses become critical variables.

Supply Chain Management concept

Concepts meant to address the optimisation of operational activity (such as Lean Six Sigma, JIT, etc.) focus their approach on cost reduction, increasing the income while maintaining the fixed costs at a constant level, decreasing the processes' lead time, etc. [9]. Supply Chain Management concept was developed as for sustaining these approaches under the purchase-delivery chain [10]. The present study performs an analysis of the activities and characteristics of the supply chain, as for identifying process optimisation opportunities through total or partial migration towards cloud computing technology.

The analysis takes into focus the entire process flow of a textile industry company, from the raw materials purchasing activities, production, warehousing, transport and distribution of goods to clients.

Koch C. (*The ABCs of Supply Chain Management*) has identified five functional areas on which the company's supply chain is based, as presented below:

- Planning – elaboration of the strategy, the management's decision regarding the level, means and approach for satisfying clients' demand, represent the starting process of the operational processes of the company.
- Suppliers' management – is based on the relationship with suppliers, from their selection up to formalising the agreements, management of purchase orders, qualitative and quantitative reception of materials, warehousing and preparation of those as for including them in the production process, and ends with the payment of business partners.
- Production – is based on the planning of production activities, qualitative checks throughout the entire process flow, packing the goods and preparing them for delivery towards the clients.
- Distribution – focuses on the transfer of products towards the clients, from the pre-warehousing of goods, distribution/delivery, invoicing and collection of clients' payments.
- Returns – management of products returned/refused by clients, as well as the management of the relationship with clients found in this situation [11].

On a daily basis, companies of all sizes and domains have difficulties in their relationships with suppliers/clients, usually caused by delays in supply of materials from suppliers, respectively of issues regarding clients' orders (long production/distribution/cash collection time) [12]. The authors of this article consider that cloud computing technology could lead to process optimisation in such a way that would enable reduction of costs and time required for undertaking certain activities.

Within a company, a smooth management of suppliers' relationship is essential for ensuring the materials enter the production process in the expected time and quality. For numerous companies, the only interaction of the IT function with the suppliers' management process is from a financial point of view, through the accounting application. Nevertheless, using a software program dedicated to manage the relationship with the business partners may help optimising the purchasing process through reducing delays due to order processing, materials delivery from suppliers, delays in collection and sign-off of contracts/agreements with the suppliers, etc.

In his book, Miller M. (*Cloud Computing – Web-based applications that change the way you work and collaborate online*) outlines the fact that cloud computing technology may prove to be particularly helpful for the collaboration with business partners [3]. Applied on the textile industry sector, the theory may be focused on the relationship with clients/suppliers, as for managing the product orders (for clients) or materials orders (for suppliers), for delivery preparation, final reception (towards clients, respectively by the company), as well as for the management of financial accounting supporting documents.

The main advantages of such a product (EDI – Electronic data interchange) resides in the cost reduction, optimisation of resources and rationalisation of operations enabled by automated communications through information systems used by companies and their business partners (clients/suppliers).

The authors believe that cloud computing solutions covering the supply chain management may represent an efficient and effective option for the management of suppliers and clients. As a practical example, in the 2012 Deutsche Bank report, it is stated that a network connected to the cloud allows a more collaborative approach among all supply chain levels. Thus, a constant manual update of orders to/from business partners is no longer required, as posting the change into a single dedicated location allows all business partners to view the updated information.

Nowadays, consumers may purchase goods directly through the online environment through the use of computers, mobile phones, laptops, tablets or other devices. This fact, together with the identification of efficient distribution channels, encourages the retailers to adopt new ways of selling and delivering the products. Thus, a retailer has to know the exact location and stock level for each item, and ensure the expected time, quality and distribution channel are respected [13].

In this point of the supply chain, authors believe that cloud computing technology may change the operational way of business. As an example, if a product order is made through an online cloud-based platform, using a dedicated website, the order may be sent directly to the brand, and be posted directly into the supply chain system, with no manual intervention. Authors believe that using cloud computing technology may support the automation of this process starting from the final client, online environment (websites), product brand and all the way to the producer. The ordered good may then be sent directly from the production plant to the final client, as cloud environment may provide a variety of distribution channels, from distribution to order centres, shops or directly to the clients.

Through selecting the plant-client direct distribution channel, a major step from the supply chain process may be bypassed, thus being reflected into a significant economy of financial and material resources.

Delimitation of two technologies is required at this point: EDI and cloud computing. As EDI concept was developed prior to the deployment of cloud computing technology, it may be used without adopting cloud computing technology for the management of stock and related documents and internal activities. However, authors consider that cloud computing in the supply chain management is key for enabling two process improvement drivers:

- Real-time information – through the characteristic of offering no physical limitation (the only prerequisite for using the technology being the internet connection), activities regarding customer orders, stock inventory update, etc. will no longer require waiting time for being analysed and processed.
- Inter-organisational relationship management – while EDI concept may prove as an efficient way to improve processes from an internal perspective, cloud computing enables a faster, thus improved, inter-organisational relationship, allowing the company to avoid delays within processes related to business partners (customers, suppliers, etc.) [4].

Financial-accounting function

The financial-accounting function represents the interface between activities performed within the company and the (internal and external) users of financial statements, thus being a vital function for all companies.

Depending on the company's size, region, business sector etc., the IT infrastructure dedicated to the financial-accounting function may vary from a simple, off-the-shelf application, supporting a reduced number of journal entries, and dedicated to a single user, up to a series of applications supporting various projects (e.g. fixed assets management, stock management, clients and suppliers management etc.) interconnected through an interface/system meant to consolidate the information as for financial reporting purposes.

The accounting postings volume, automation level of the financial-accounting function, as well as the decision factors' abhorrence towards risk, are key drivers in the selection of the operating model (traditional, respectively cloud computing).

The following section presents a series of ideas and reengineering models based on the analysis of the financial-accounting function and supply chain process.

REENGINEERING MODELS – THEORY AND ANALYSIS

Process reengineering models can vary depending on the size, geographical positioning and business activity sector of each company, as well as depending on the preferences of the decision factors. The present article starts from the general processes of a company activating in the textile industry, as for outlining reengineering opportunities through total or partial migration of operations, activities, processes, towards cloud computing technology.

It is also to be mentioned that here is a great variety of cloud computing models and architectures which companies may choose to adopt, thus the models presented by authors are not exhaustive, as the aim is not to limit the companies' possibilities, but to open their horizons as for acknowledging the existing opportunities.

Supply Chain Management

Miller M. (*Cloud Computing – Web-based applications that change the way you work and collaborate online)* analyses the advantages and disadvantages posed by the use of cloud computing technology, outlining, at the same time, that this technology may prove to help improve the collaboration with the business partners (suppliers, clients) [3]. The same idea is outlined by Jun C. and Wei M. (*The Research of Supply Chain Information Collaboration Based on Cloud Computing*), stating that the supply chain management process can be optimised through the use of cloud computing technology, focusing on the EDI (electronic data interchange) products, which can be synthetized as presented in figure 1 [8].

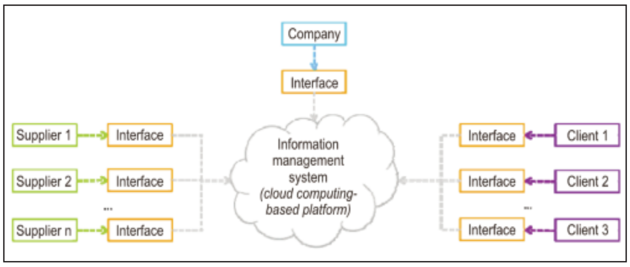

Fig. 1. Supply Chain managed through EDI

Applying these theories upon a textile industry company, the suppliers/clients management process may be modelled, at a general level, as presented in figure 2.

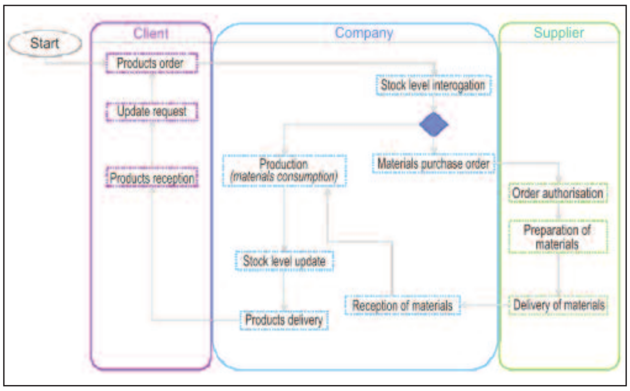

Fig. 2. Supply Chain Management process

The present study is based on two main aspects considered by Lean methodology, namely optimisation of the process lead time, respectively of the involved (financial and material) resources.

The process synthetized in figure 2 can be measured from an end-to-end time perspective (lead time) from the initial step (client order) and until the accomplishment of the final objective (reception of products by the client), or from a perspective focusing on involved resources.

Focusing on the lead time perspective, the following hypotheses can be addressed:

1) Either fully manual, or partially supported by the use of IT systems, there is a gap between the moment when the order was received and its materialisation (processing of information and production preparation).
2) The production process may be interrupted in case required materials are lacking or insufficient, thus causing the entire process to be delayed.
3) The materials purchasing order also involves gaps, from the company – the non-productive time spent between identification of the need, filling in (manually or through the use of dedicated systems) the purchase order, analysis and authorisation of the order, communication with the supplier etc. – as well as from the supplier – the time spent between the order processing, preparation of the materials and delivery of these towards the company).

Starting from the above mentioned hypotheses, the authors consider that implementation of an EDI system for collaboration with the clients and suppliers may lead to the optimisation of process lead time and involved resources, as follows:

1) The client order is performed directly through EDI platform, and automatically processed. Thus, waiting time between the issuance and processing of order is significantly reduced.
2) The system allows real-time update and interrogation of stock level. Thus, whenever a client submits an order, the system will identify (and reserve) all materials required for production, thus the risk of production process interruptions due to insufficient materials is substantially reduced.
3) In case the inventory stock has reached the minimum acceptable level, the system automatically issues a new purchase order and sends it towards the supplier via the EDI platform, thus generating a substantial decrease of waiting time and avoiding process delays.
4) The financial documents supporting the order, delivery, reception etc. are automatically issued by the system, thus supporting the optimisation of time and resources involved in the analysed process.

The process managed through an EDI platform may be modelled as presented in figure 3.

The present analysis takes into account the use of an EDI system for the full management of relationship with both clients and suppliers, as below:

– The client order will be automatically issued through EDI system, when the need for products is identified (e.g. the system may interrogate at certain moments in time the existing level of products, so that, once the minimum acceptable level is reached, the order is automatically issued by the

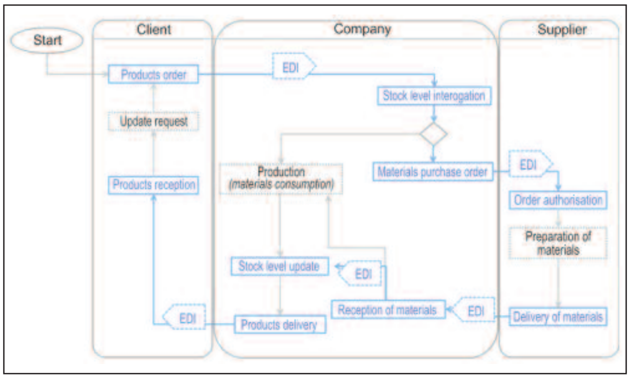

Fig. 3. Migration of Supply Chain Management process activities towards cloud

client's system, and sent towards the producing company).

– When the client order reaches the company, the system automatically interrogates the products existing stock, and if the order cannot be covered, it further analyses the existing level of materials required for the production process. Existing inventories will be automatically reserved (in order to avoid duplicate allocation of materials to goods to be produced).
– When, as a result of material reservation, the material stock level has reached the minimum allowed level, a new purchase order is automatically issued by the system and sent towards the respective supplier through EDI.
– The supplier's system receives the order and automatically analyses it, reserving all required materials.
– Delivery and reception will involve simply modifying the status of the orders/stocks in the system, and will not require any manual work for issuing/verifying of documents.
– Once materials are received by the company, the system automatically updates the stock level of available, reserved and into production materials.

Although the analysis is based on the use of EDI for the management of both suppliers and clients, this is not exhaustive, and may be limited only to one of the parties. At the same time, it is possible that, depending on the company and its business partners, the fully integration of all suppliers/clients into the EDI system be impossible, so the system may be used only for a limited number of business partners.

Regardless of the level and manner in which the EDI system is used, a series of benefits may be obtained, including:

– Goods and materials stock level is automatically updated, in real-time.
– On-going production and planning (based on client orders and material reservations) are optimised and extremely easy to monitor.
– Resource optimisation is enabled through reducing the time for issuing purchase orders, analysing and processing client orders, etc.
– The process is optimised from a lead time perspective, through reducing the time for issuing, sending and processing orders towards suppliers, respectively receiving, processing and analysing client orders.
– The risk of production interruption and delays due to lack of materials is significantly reduced.

Nevertheless, this system may only prove to work with a series of imperative conditions, including:

– Both the company, and its business partners, need to use supply chain management information systems compatible with the EDI platform.
– For optimum functioning of the process, it is necessary that a minimum acceptable stock level is set as a system parameter based on which materials/products orders are automatically issued.
– The company has to permanently ensure that a valid contract/agreement is in place with the business partners, in order to enable optimum, correct and legal functioning of the business relationship.

Accounting function

The technological evolution of the last years bring into discussion concepts such as cloud accounting or real-time accounting. Numerous local and international studies made upon companies considering adopting cloud computing technologies reveal interesting results [12].

According to Accenture case study conducted in 2013 (*A New Era for Retail – Cloud Computing Changes the Game)*, retail companies may use cloud technologies in order to improve their financial and business perspective in the following areas:

– Operation channels (store management, ecommerce, lower CAPEX, faster speed to market, real-time reporting). Currently, numerous companies are using fragmented systems in stores for running operations in relation to inventory, time tracking, shipment, point of sale terminals, etc. Cloud computing may help organizations to unify and standardize the systems. The study shows that by using virtualized servers Target Company in United States managed to reduce its number of servers in each store from 7 to only 2. The company thus eliminated a total number of 8650 servers and had saved millions of dollars for hardware, electricity and maintaining costs.

– Trading and marketing (product catalogue, appropriation, greater ROI from loyalty programs).

– Supply chain management (warehouse, transportation, reduction in overheads, optimizing the store and shelf space). For example, Del Monte Company in United States implemented a trading and logistic platform in the cloud and managed to capture in real time information and virtualized documents from suppliers, carriers, brokers or US government. Data is standardized in online environments and available for a large spectrum of the companies departments. Therefore Del Monte has a wide visibility on inventory and transportation means from order to final destination.

– Sales, services and support (e-commerce, ownership cost reduction given the optimized cost regarding infrastructure and cloud capabilities) [1].

The accounting function is particularly complex, comprising of activities from daily operations, posting of journal entries, management, recording and monitoring of supporting documents, up to month/year closing, consolidation or reporting processes [13]. Thus, the analysis starts with the question: what is the extent in which the accounting function may be migrated towards cloud?

Although apparently concepts such as cloud computing or cloud accounting seem far from becoming a daily reality among companies, recent studies show the fact that more and more companies, of all sizes and business sectors, chose to migrate their accounting function towards the cloud. The main driver towards migrating the accounting function towards cloud is the opportunity of process improvement through cutting costs and time for performing accounting activities.

From a cost perspective, numerous recent studies focused on comparing costs from the traditional model against cloud accounting outline the opportunity of process optimisation through the use of cloud computing in terms of cost reduction.

From a time reduction perspective regarding the financial accounting/audit activities/operations, the technological progress is a good example for process optimisation. From the inception of cloud computing technology, initially being represented by the virtualisation of certain components of the IT environment, it was just a matter of time until it all developed into concepts such as cloud accounting or real-time accounting. The latter comprises of the possibility of gaining a fair idea of the company's financial image, thus requiring a highly optimised process in terms of time for processing financial-accounting activities/operations. Reduction of time through migrating the financial-accounting function [14] towards cloud may be justified through:

- Documents from/to business partners – migration of financial-accounting function towards cloud may involve the implementation of e-archiving, thus meaning a minimum (or even non-existent) time for printing, preparing and transmittal of documents towards suppliers/clients, physical archiving of documents and identification/accessing of these when needed (after archiving).
- Authorisation of transaction – certain transactions require authorisation prior to being processed. The best example is probably represented by payment processing. In the traditional practice, there may be a gap between payment operations and their authorisation by the supervising factor, usually represented by lack of timely access to the authorising/financial information system. Through the use of cloud computing, access to information systems thus used is not conditioned by physical positioning into a certain location, thus being more flexible and permissive. Therefore, delays into authorising accounting operations due to physical access to the company's programs and data may be avoided through the use of cloud computing technology.
- Automated transactions – despite the technological evolution, the accounting practice shows that some companies still prefer basic software systems (Microsoft Excel etc.) to specialised accounting systems. Hence, migrating towards cloud accounting involves the use of advanced applications, dedicated to financial-accounting transactions, capable to support daily accounting operations, as well as consolidation and reporting activities. Most of these applications are based on automated transactions (posting of journal entries automatically or semi-automatically, through a minimum intervention of the operator), thus leading to the reduction of time for posting and processing journal entries.
- Month/Year closing – for numerous companies, the monthly/yearly closing is a long, tough process, meeting obstacles such as high volumes of data, various reconciliation errors etc. Cloud accounting may facilitate the process through automated checks and reconciliations, thus facilitating the time reduction.

CONCLUSIONS

The technological evolution, the current economic context, the experience of developed states (US, The United Kingdom, Germany) are all premises of a conclusion reached by more and more companies from the Romanian market, namely the fact that partial or total migration of operational and support processes towards cloud computing may facilitate process optimisation, in terms of cutting costs and non-productive time, as well as optimisation of resources (financial and material) involved in the operational and support activities of the company. The article supports this idea, providing a theoretical model focused on textile industry companies, but that may be generalised as for being applied to all production companies as for reengineering processes in order to optimise the operational activities.

However, companies deciding to adopt cloud computing technology for their operational and/or support processes should not neglect the challenges and implications of the decisions. Firstly, cloud computing technology poses specific risks and challenges, mainly related to the need for permanent and relatively strong internet connection, as well as the fact that data access and controls are shared with the service provider, thus leading to risks regarding the ownership, responsibility and commitment of the third party with regards to the confidentiality, integrity and availability of the data managed through cloud. Moreover, the proposed model regarding migration of supply chain management towards cloud computing requires management of several aspects, including: data standardisation, process reengineering, training requirements for both business users and support staff, time and resource allocation for design and migration phases, etc. All in all, the companies' decision factors should take into account the risks and challenges posed by the cloud computing technology, and carefully analyse the implications regarding the migration phase prerequisites and activities, as well as the redesigned processes requirements and arising risks.

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Romania's participation to the 7th E.U. Framewok Programme

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REZUMAT – ABSTRACT

Participarea Romaniei la Programul Cadru 7 de Cercetare al U.E.

În cadrul acestei lucrări, se prezintă o analiză a participării universităţilor şi organizaţiilor de cercetare din Romania la Programul Cadru 7 pentru Cercetare al Uniunii Europene (2007–2013), în contextul situaţiei generale a participării României la acest program. Analiza evidenţiază contribuţia distinctă a institutelor de cercetare, universităţilor şi IMM-urilor. Principalele concluzii ale lucrării sunt: (1) rata de succes a participării României la PC7 a fost sub media europeană; (2) institutele de cercetare dezvoltare (INCD) au performat cel mai bine în cadrul programelor europene de cercetare (PC7); (3) universitățile performează similar, trebuind să fie motivate să întărească cooperarea cu INCD.

Cuvinte-cheie: Programul Cadru 7, Europa Centrala și de Est, organizații de cercetare, universități

Romania's participation to the 7th E.U. Framewok Programme

In this paper is performed an analysis of Romanian universities and research organizations' participation to the 7th EU Framework Programme (2007–2013), within the context of Romania's participation to this programme. The analysis highlights the separate contribution of research institutes, universities and SMEs. The main conclusions are: (1) Romania's success rate to FP 7 is below the European one; (2) research & development institutes (INCD) have better performed than other organizations to European research programs; (3) universities are also similarly performing, but they have to be motivated to strengthen their cooperation with INCD.

Keywords: 7th Framework Programme, Eastern and Central Europe, research organisations, universities

INTRODUCTION

The main objective of this paper is to offer a global view to Romania's participation to the 7th Framework Programme for research, technological development and demonstration activities (FP 7) with highlighting the separate contribution of research institutes and universities.

Based on results of this research and conclusions that are drawn out from this research, several distinct measures to increase the participation of organizations based in Romania. The work is structured as follows: in the first part, the program and its specific programs are presented, in the second part is presented the reference literature and methodology. The third part is focused on the Romanian participation to FP 7 and on a comparative analysis of universities and research organisations. The work ends with discussions and conclusions.

FP 7 was the main instrument of European Union for research funding in Europe during 2007 – 2013, with a total budget of 53.2 billion euro.

The specific program dedicated to pre-competitive research and almost entirely dedicated to cooperation projects among institutions active in research (universities, research institutes, companies, non-governmental organisations, etc.) of FP 7 is *Cooperation Program (RO: Cooper are)* which had the objective was the stimulation of collaborative research in the whole Europe and other partners is a few key thematic areas.

This program includes also the participation to the new Joint Technology Initiatives, those being coordinated by industrial organisations (companies), with multiple funding sources, supported in some cases by a mix of public and private funding.

Other main points of this program include coordination of non-community research programs, aiming at getting closer the national and regional European research programs (e.g. ERA-NET).

The second component of FP 7, the specific *Program Ideas (RO: Idei)* funded the basic research, at the frontier of science and technology, independently by thematic priorities. The *Specific Program People (RO: Oameni)*, the third component of FP 7, ensured a significant support to mobilities and career development, both for researchers from the EU as well as on foreign plans. It was implemented by a coherent set of Marie Curie actions, designed to support researchers to develop their skills and competencies during their whole career.

Other component, the *Specific program Capacities (RO: Capacităţi)* was designed to help to strengthening and optimizing of research capacities that Europe needs, if it wants to become a growing knowledge based economy. The program approached six specific knowledge areas, including research infrastructures, research in the benefit of SMEs, knowledge regions, research potential, science and society and activities of international cooperation.

Participation to FP 7 was opened to a wide range of organisations and individuals: universities, national research and development institutes, multinational corporations, SMEs (small and medium size enterprises), public administrations, individual persons, etc. that meets the participation criteria. „Funding schemes" are the project types that were based on, for its implementation. They are:

– **Collaborative projects**: research projects with scientific and technological objectives clearly defined and specific expected results. They are carried out in consortia with participants from several countries from industry and university environment.
– **Network of excellence**: is a scheme designed for research organizations willing to combine and functionally integrate a significant part of activities and capacities from a certain area, with the aim to create a European "virtual research centre".
– **Coordination and support actions**: actions that do not cover research itself but coordination and linkages between projects, programs and policies.
– **Individual projects**: projects carried out by individual research projects teams, national or multinational, coordinated by a "principal investigator", funded by European Research Council (ERC).
– **Support for training and development of researchers careers:** Support by a range of actions named Marie Curie
– **Research in benefit of specific groups (SME):** research and technological development projects, in the benefit of certain groups, especially SME or for civil society organisations and their networks.

Literature references and methodology

There are only a few studies regarding the involvement of EU 28 member states in FP 7 and their partners. Therefore, Furtunescu (2012) analyses in its paper the implication of Romania to FP 6 and FP 7 and reach the conclusion that Romania's participation is a modest one. In this respect, Romania attracted the lowest budget per capita from FP 6, but the author had not had complete data on FP 7.

Florescu and Visileanu (2012) present the statistics of Romania's participation in FP7 for the period 2007–2009. Upon a SWOT analysis, these authors concluded that the main barriers to success are insufficient financial and material resources, limited connectivity to European research networks and researchers' lack of experience.

Vught (2009) focused on EU Framework Programme in terms of innovation. The EU research organisations act in a multi-system governance where member states should align their policies to the EU agenda. Participation to framework programmes led to a stratification and increase on their stratification on vertical.

In other words, such participation can be considered as a signal for quality of research and education establishments. More than that, participation to previous framework programmes could influence the success rate for future ones (Matthew Effect). The same author underlines the difference at regional level across EU regarding research-innovation, under the conditions that EU research policy in EU seems to have stimulated research concentration in the richest and most academically equipped. Poor regions had low access to framework programs, which means an academic stratification which is not in their favour.

The European Commission monitoring report (2013) shows that in 2012, higher and secondary education establishments were the main beneficiaries of FP 7, followed by private organisations and research organisations. The academic participation and of research organisations show the stratification that was presented above, on the first place being Great Britain in the case of universities (to a high distance of the others) and France (who leads both for industry and SME) and in the case of research organisations.

Rauch and Sommer-Ulrich (2012) evaluates the participation of countries from Eastern and Central Europe (ECE) to FP 7 and formulate recommendations both for national policies and from the perspective of the programme HORIZON 2020. They observe that in the case that it will take into account the specialised human resources in research & development, EC countries are only slight under the EU15 average, mainly because the low number of researchers. If it is compared the ECE implication to FP 7 to the GDP of ECE in total of EU GDP, it will be observed that their performance is above the human resources measured by GDP.

Additionally, involvement is higher than expectations if it is considered the expenditure of those countries for research & development. An explanation of their low success is the human, financial, and managerial capacities. Another explanation of low success rate of these countries stays in the scientific quality measured by the impact factor of 10 out of the most important national publications and by average expenditures for research & development per researcher (Romania is on the last place to these indicators in EU 27).

In addition, an explanation for Romania (but also for Bulgaria, Slovakia and Poland) is dependency by the past.

Saublens (2014) is the author of a report regarding on EU 13 (EU 12 + Croatia) participation to FP 7. This shows that EU 12 contributed with 6.3% to the EU budget, but benefited by only 4.7% from FP 7 grants during 2007–2012. Romania had the lowest success rate during the mentioned period, about 7 percent less than EU 12. From the financial point of view, the EU 12 average is les 7 percent below the EU 15.

If the financial contribution is reported to the number of inhabitants, the EU13 average is 5.14 times less than the EU 15, Romania being again on the last place (followed by Poland, both of them with less than 10 EUR per inhabitant). From the perspective of categories of beneficiaries, in Romania, as many other countries in the region, private companies are on the first place, followed by research centres and universities. In this paper is calculated also the optimum theoretical participation, measured by the quota relatively to the whole population adjusted to the human capital from research & development, number of researchers and high-tech companies.

Romania, together with other 9 countries in the region, negatively deviates from the theoretical optimum (being on the third place from bottom to the top, after the Czech Republic and Poland). Starting with the above mentioned studies and the available databases, this paper presents a detailed and actual picture of universities, research organisations and SME participation to FP7. Data for Romania were taken from the EC internet page, entered in a Microsoft® Excel® spreadsheet and processed using the above mentioned program. All projects with Romanian participation compared with the total number of projects funded by the European Commission during 01 January 2007 – 30 July 2013 were taken into account.

The Situation of Romania's participation to FP7

So far, the European Commission funded 19,920 projects with 103,889 participants in FP 7, out of which Romania was participating in 694 projects, representing 3.32 %, with 858 participants, representing 0,82% out of total. This situation is presented in figure 1. The European Commission (EC) contribution for the 103,889 participants is 34,160,622,225 euro, and for the 858 Romanian participants is 114,865,043 euro, representing 0.33% of total.

The partial results of EU member states to FP 7, best seen in success rates per participants (all coordinators and partners) and per EC contribution are presented in figure 2. It notes that Romania has a success rate below the European average of 21.32% (for 2013). During 2008 – 2013 the values of these rates were remarkable stable: 14.4% for 2008; 14.5% for 2009; 14.9% for 2010, 14.57% for 2011, 14.92% for 2012 and 14.6% for 2013.

In financial terms the performance indicator „success rate" is much below the European average of 19.3% (for 2013), with the values 9.27% for 2008; 7.9% for 2009; 9.33% for 2010, 9.16% for 2011, 8.95% for 2012 and 9.03% for 2013. Romania was on the last place in EU 27 from the perspective of these indicators. This situation comparing with the European average is presented in figure 3.

The success of Romanian organisation to participate to FP 7, presented in figure 5, shows that regarding the number of participations, on the first place are the research organisations, followed closely by private companies and universities, similar to the former communist countries. Regarding the EC contribution for Romanian participants on type of organisation, in figure 6 is shown that the biggest share is for research organisations, followed by universities and private organisations.

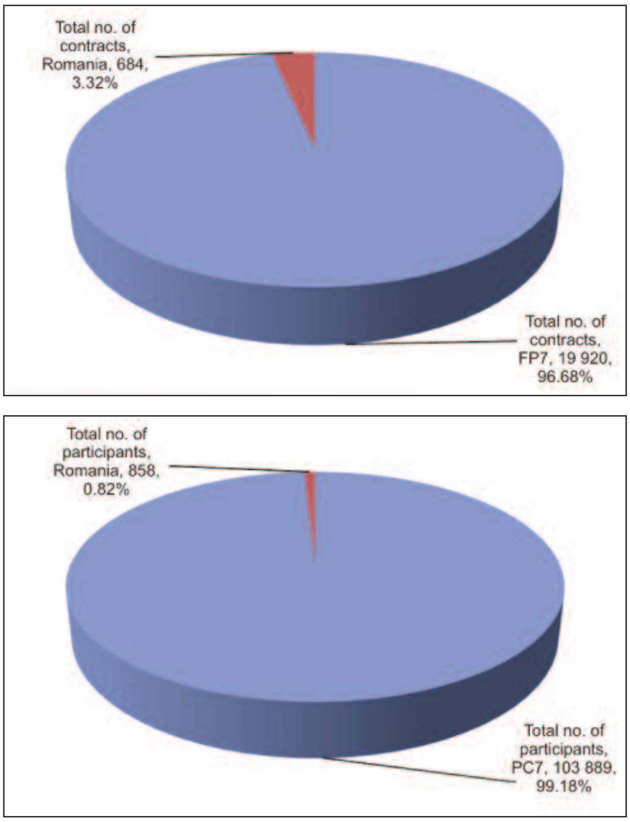

Fig. 1. Romanian participation to FP7: contracts and participants
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

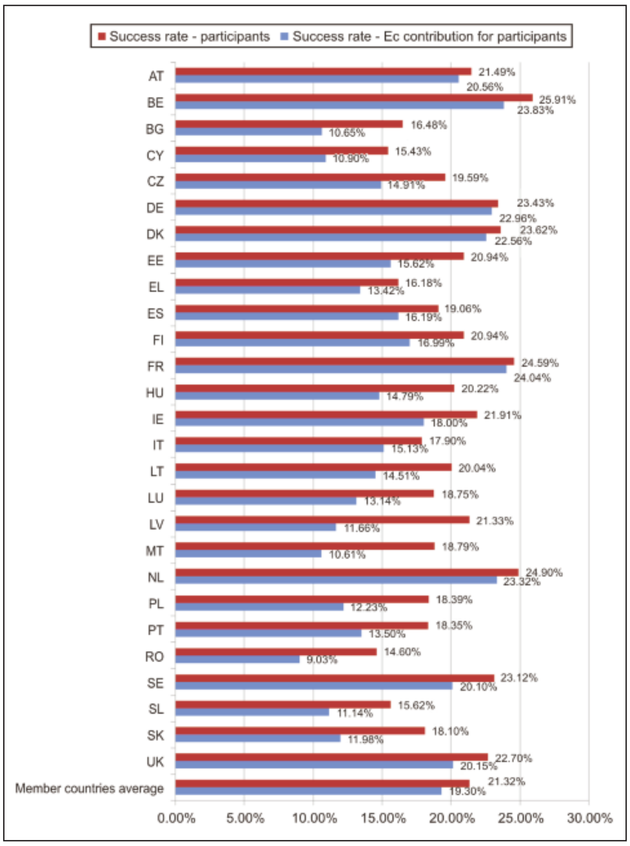

Fig. 2. FP 7 Success rates
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

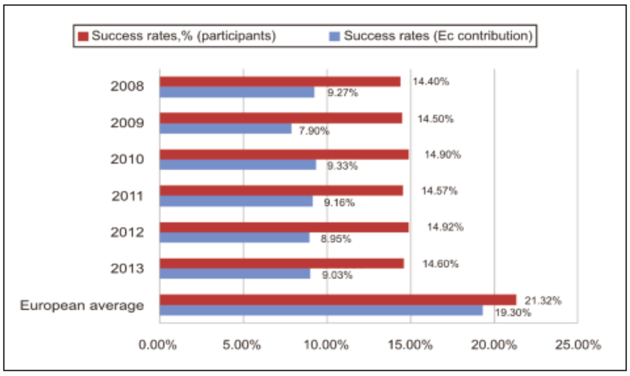

Fig. 3. Romania's position towards the european average, 2008–2013
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

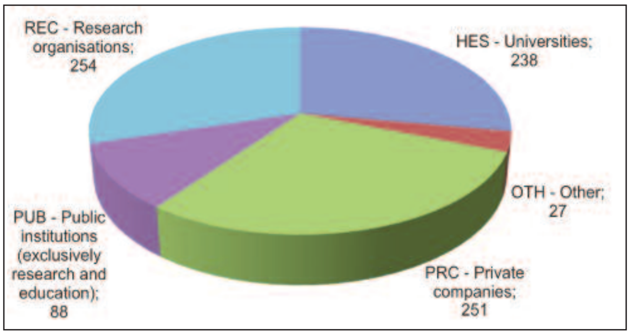

Fig. 4. Number of participations per organisation type
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

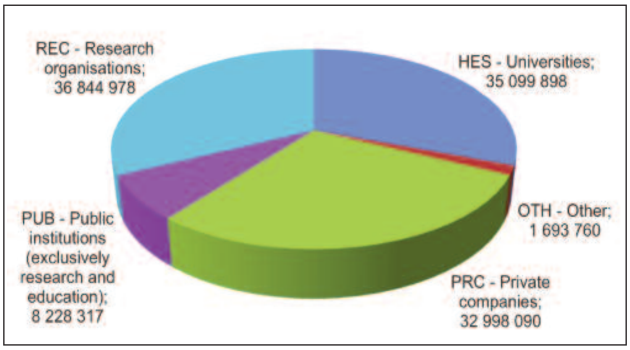

Fig. 5. Romania's participation considering the organisation type: financial contribution (euros)
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

Out of research organisations, 37 were involved in one project, 10 in two projects and 76 were involved in more than 3 projects, and this situation is presented briefly in figure 7. It can be shown that 10% of participation is concentrated at UEFISCDI and the firsts 5 organisations concentrate more than 31% of total participation. The participation of UEFISCDI on the first place can be explained by the fact that, as an organisation which funds research, its involvement in FP 7 is mainly in ERA-NET type of projects (17 projects), implemented by "coordination and support actions – coordination" (CSA-CA).

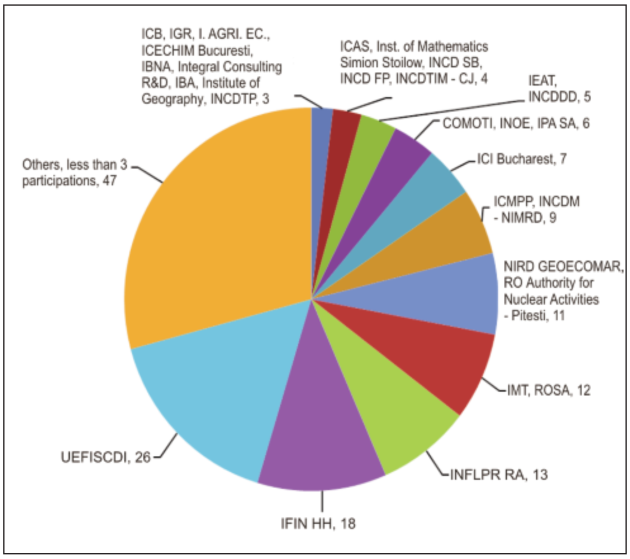

Fig. 6. No of participations of Romania's research organisation
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

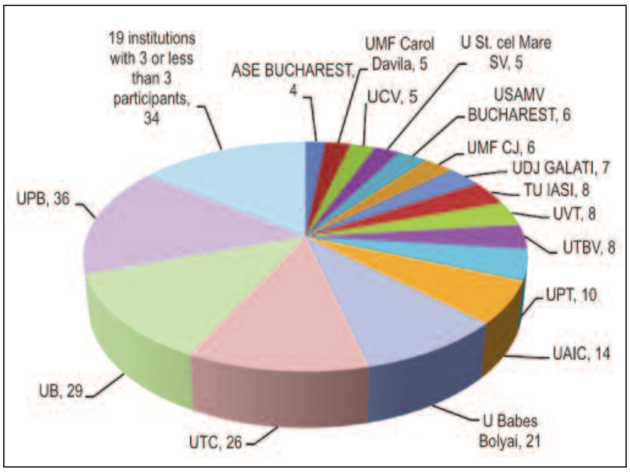

Fig. 7. No. of participations of Romanian universities
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

Regarding universities, situation is the following: there are 19 organisations with 3 or less participations, meaning 15% of the total number of projects with involvement of higher education establishments from Romania. The leaders of this ranking have 40% of the total number of the academic environment to FP7.

As seen in figure 8, the absolute leader is Polytechnic University of Bucharest (UPB) with 36 participations. It should be mentioned that, out of them, 20 were collaborative projects (CP) and 13 were support actions (CSA). Also, 14 projects were in the Information and Communication Technologies Area (ICT), 5 projects were in *People* program, 4 projects were in the area of Nanotechnologies, Advanced Materials and Production (NMP).

The following 3 organisations in this ranking sums up 76 funded projects, as follows: University of Bucharest (UB) has 29 projects (out of which 7 on

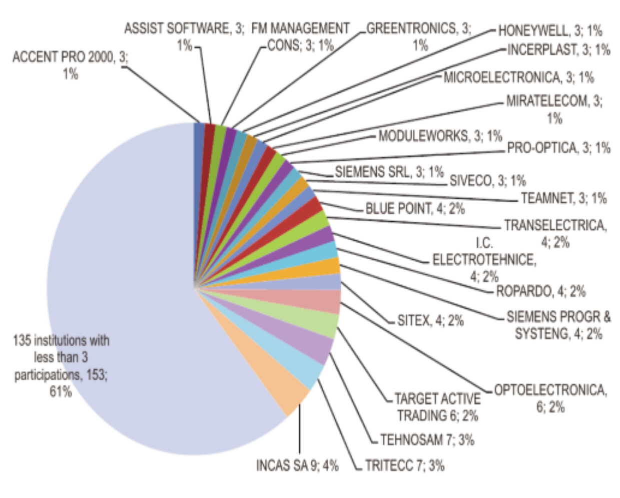

Fig. 8. No. of participations of Romanian private companies
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

calls for proposals from theme Environment from the *Cooperation* Programme), Technical University of Cluj Napoca (UTC) with 26 projects (out of which on theme ICT from the *Cooperation* Programme) and Babes Bolyai with 21 projects (out of which 5 on calls for proposal from theme Health from *Cooperation* programme).
Out of the 251 participation of private companies, it is worth to be mentioned that 117 organisations participated in one project, while 17 organisations participated in 2 projects. In figure 9 it is clearly shown that these 135 companies have 61% out of the total number of private companies' participation to FP7.
By far, the most important player with 9 projects is the national R&D Institute “Elie Carafoli” – INCAS, who, even though is a research institute, was registered in Participant Portal as a private participant. The main private companies with more than 6 participations are: TRITECC (7 projects out of which 2 were submitted to the theme KBBE – Knowledge Based Bio-Economy), Tehnosam (7 participations in projects submitted to the programme people, being the coordinator of 4), Optoelectronica (6 participation in projects, out of which were submitted to the call dedicated to SME funding).

CONCLUSIONS AND DISCUSSIONS

The comparative analysis of participations show that the most important concentration, measured by the share of the first 5 organisations in total number of participations, is in universities (about 53%), followed to a significant distance by research organisations (31%) and very far by the private companies (about 14%), even overall universities are on the second place (see figure 10).
As the *Cooperation* programme is the main pillar of FP7, representing two thirds of the total budget, the research organisations had the most participation – with 163 participations, universities performed the

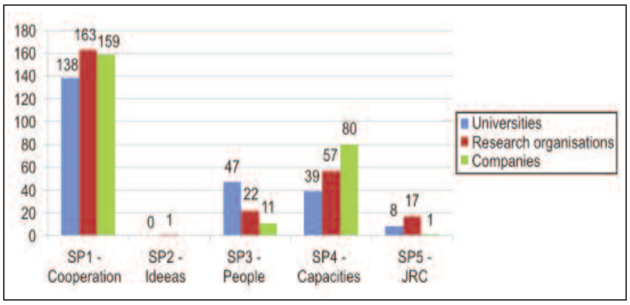

Fig. 9. No. of participations of the universities, research org. and companies to FP7, in each specific programme
Source: processed information from CORDIS (http://cordis.europa.eu/projects)

weakest from this perspective with 138 funded projects. Because the structure of the programme, also private companies have had a large number of participation, respectively 159.
Concerning funding schemes, the research organisations had the best results in programme Capacities, in calls dedicated to research infrastrcutures. Universities performed the best to the programme *People* with 47 participations, while private companies have had most of their participation to calls dedicated to research in benefit of SME.
It is worth to be mentioned that there are research institutions that are wrongly registered in Participant Portal, regarding the type of organisation. It is especially the case of research organisations that are public but also public organisations that have research departments (e.g. hospitals, public authorities, etc.). Once the information on participation to FP 7 of all eligible states will be updated, it will be taken into account the correct statute of those institutions.
From the analyses and figures presented, results that research & development institutes (INCD) have performed the best to the European research programmes (FP7) and they should be encouraged and supported also in the future. Universities performed similarly, they also should be motivated to strengthen cooperation with INCD. Additionally, INCD could also facilitate technology and knowledge transfer towards end-users.
Universities showed a very good participation to the specific programme People. A possible explanation might be that most of the Doctoral Scholls are within universities and not within an INCD. Exceptions from this situation are research institutes subordinated to Romanian Academy.
Concerning the specific programme Capacities, in figure 10 is presented that most of the participation is from companies. The explanation is that the specific program to encourage SMEs is part of it. Regarding participation of INCD and universities, the firsts have a significant advantage on the last ones; therefore we can conclude that research infrastructure is significant to INCD. Based on this, and having in mind that INCD got the highest number of projects (funded contracts) in FP 7, it is imperative to ensure the basic

funding and to facilitate cooperation in science and technology at European level.

Possible measures to stimulate the participation to future EU research programs (at this stage the ongoing program is HORIZON 2020) are:

1. **Grants funding for support action leading to new project proposals that will be submitted in response to calls opened to the new EU research programme, Horizon 2020 (H2020).** Few examples are: to cover the travel costs to participation at pre-meetings for project writings, cover the costs of organisation of meetings organised in Romania for project writing, organisation of brokerage events, etc.
2. Granting awards (as a grant) for those persons that are project coordinators, no matter the type of projects.
3. Granting state aid to companies that participate to H2020 projects.
4. Granting additional points at evaluation of national project proposal to those organisations that implements FP 7 or H2020 projects.

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Influence of process parameters on the morphology of polyacrylonitrile electrospun fibers

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REZUMAT – ABSTRACT

Influența parametrilor de proces asupra morfologiei fibrelor electrofilate din poliacrilonitril

Electrofilarea reprezintă una din cele mai promițătoare metode pentru obținerea de fibre utilizând soluții sau topituri polimerice. Diametrele reduse ale fibrelor polimerice obținute prin electrofilare le recomandă pentru o serie de aplicații avansate, ce acoperă o multitudine de domenii, ca de exemplu: filtrări selective pentru lichide, membrane cu afinitate pentru recuperarea ionilor metalici, inginerie tisulară, senzori sau materiale pentru aplicații de stocare a energiei. Proprietățile și performanțele fibrelor obținute prin electrofilarea soluțiilor de polimeri sunt determinate de o serie de parametri, cum sunt: caracteristicile soluției de polimer (natura polimerului, solventul, concentrația, vâscozitatea, conductivitatea electrică), potențialul electric aplicat, distanța dintre duză și colector. Procesul de electrofilare este caracterizat de o versatilitate ridicată, prin varierea parametrilor fiind posibilă obținerea de fibre de diferite morfologii, cu diametre de dimensiuni nanometrice sau submicronice. Scopul acestui studiu a fost de a investiga influența caracteristicilor soluției de poliacrilonitril (concentrație, vâscozitate, conductivitate electrică) și a tensiunii aplicate în procesul de electrofilare asupra morfologiei fibrelor obținute. Prin urmare, patru soluții de poliacrilonitril (PAN) de concentrație 3, 5, 7 respectiv 10% masice au fost preparate și caracterizate din punct de vedere al conductivitatii electrice și al comportarii reologice. Soluțiile astfel preparate au fost electrofilate la potențiale electrice de 15, 16, respectiv 18 kV, distanța dintre electrozi 18 cm, debitul de soluție 2 ml/h, diametrul duzei 0,8 mm, regim de lucru staționar, colector plan din aluminiu. Fibrele rezultate prin electrofilarea solutiilor astfel preparate au fost caracterizate din punct de vedere morfo-structural prin microscopie electronica de baleiaj.

Cuvinte-cheie: electrofilare, fibre electrofilate, poliacrilonitril

Influence of process parameters on the morphology of polyacrylonitrile electrospun fibers

Electrospinning is one of the most promising methods for the production of fibers, using polymeric solutions or melts. The very small diameters of electrospun fibers recommend them for advanced applications in selective filtration of liquids, affinity membranes for metallic ions recovery, tissue engineering, sensors or materials for energy storage applications. The properties and performances of electrospun fibers are influenced by polymer solution, solvent, solution concentration, viscosity, electrical conductivity, electrical voltage, spinneret to collector distance etc. The electrospinning process has high versatility, allowing the obtaining of different morphology fibers with diameters from nanometers to sub-microns, by varying process parameters. The aim of the present study was to investigate the influence of polymer solution characteristics (concentration, electrical conductivity, viscosity) and the applied voltage on the morphology of the obtained electrospun fibers. Therefore, four polyacrylonitrile (PAN) solutions with 3, 5, 7 and 10% wt. concentration were prepared and their electrical conductivity and viscosity were measured. The PAN solutions were electrospun under processing conditions with an applied voltage of 15, 16, 18 kV, a spinneret-to-collector distance of 18 cm, a flow rate of solution of 2 mL/hour, a spinneret diameter of 0.8 mm and stationary copper substrate. The morphology of the electrospun fibers was observed by scanning electron microscopy (SEM).

Keywords: electrospinning, electrospun fibers, polyacrylonitrile

INTRODUCTION

In the last years, the electrospinning technique has been receiving renewed attention due to its potential of producing polymer nanofibers [1–3]. The electrospun nanofibers are of interest for a wide range of applications in tissue engineering, drug delivery, textiles, filtration, composite reinforcements, etc. [4–6] due to the small fiber diameter (usually 20 nm – 1 μm), high specific surface area (tens to hundreds m^2/g), high porosity and small pore size. Many applications require however high mechanical property nanofibers and for applications like air filtration systems [7], microfibers are used as supports for electrospun fibers as these nanofibers are often too weak to be used independently [8].

The electrospinning is the most suitable technique for production of nanofibers. The advantages include its relative ease, low cost, high speed, vast materials selection, and versatility [9]. Additionally, the technique allows control over fiber diameter, microstructure, and arrangement [5, 10, 11].

The electrospun nanofibrous membranes have unique and interesting features, such as high surface area to volume ratio, large porosity, good mechanical

properties and good water permeability, which provides a major contribution towards water treatment [12]. The high porosity implies a higher permeability to fluid streams and the interconnected pores can withstand fouling better. These characteristics bring about low energy consumption. Furthermore, not only the small pore size, but also the huge available surface area, flexibility in surface functionalities, and design of the nanofibrous membranes optimize their adsorptive nature and selectivity [9, 11, 13–19].
Electrospinning process is applicable to many polymers, for example: polyethylene terephtalate (PET), polystyrene (PS), polymethacrylate (PMMA), polyamide (PA), polyvinylchloride (PVC), cellulose acetate (CA), polyvinil alcohol (PVA), polyether imide (PEI), polyethylene glycol (PEG), nylon 6 (PA-6), polyacrylnitrile (PAN), polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), etc. [20].
The aim of the present study was to investigate the influence of PAN polymer solution characteristics (concentration, electrical conductivity, viscosity) and the applied voltage on the morphology of the obtained electrospun fibers.

EXPERIMENTAL WORK

Materials and Method

In this study, polyacrylonitrile (PAN) fibers obtained from Bluestar Fibres Co. Ltd were used as polymer source. The solvent used for dissolving PAN fibers was dimethylformamide (DMF) with 0.94 g/cm^3 density, purchased from Alfa Aesar. All reagents were used as received, without further purification. Four PAN solutions in DMF with concentrations 3, 5, 7 and 10% wt. were prepared by dissolving PAN filaments in DMF; followed by homogenization by magnetic stirring at 420 rpm, 8 hours at 50°C.

Table 1

COMPOSITION AND PROCESSING CONDITION OF PAN SOLUTION

Sample	P3	P5	P7	P10
PAN concentration, % wt.	3	5	7	10
Rotational speed, rpm	420			
Homogenization time, min	480			
Temperature, °C	50			

Electrical conductivity of PAN solutions was measured with a VARIO COND portable conductivity meter model 340i with the cell constant K = 0,469 cm^{-1}.
The rheological behavior of PAN solutions was studied using a rotational viscometer BROOKFIELD DV-II+ Pro, by measuring viscosity, shear rate and shear stress.
Thus prepared solutions were electrospun using NaBond unit under processing conditions with an applied voltage of 15, 16 and 18 kV, a spinneret-to-collector distance of 18 cm, a solution flow rate of 2 ml/h, a spinneret with a nozzle size of 0.8 mm and stationary substrate. Aluminum foil served as the substrate for fiber collecting.
Morphological characterization of the polyacrylonitrilebased electrospun fiber webs by scanning electron microscopy (SEM) was performed with a FESEM/FIB/EDS Workstation Auriga produced by Carl Zeiss Germany, with an acceleration voltage of 5 kV, using the SESI detector.

RESULTS AND DISCUSIONS

PAN solution electrical conductivity

The results regarding the electrical conductivity of PAN solutions (P3, P5, P7 si P10) are presented in table 2.

Table 2

ELECTRICAL CONDUCTIVITY OF PAN SOLUTIONS

Electrical conductivity, S/m	**Values**
P3	$2.15 \cdot 10^{-3}$
P5	$1.96 \cdot 10^{-3}$
P7	$1.86 \cdot 10^{-3}$
P10	$0.98 \cdot 10^{-3}$

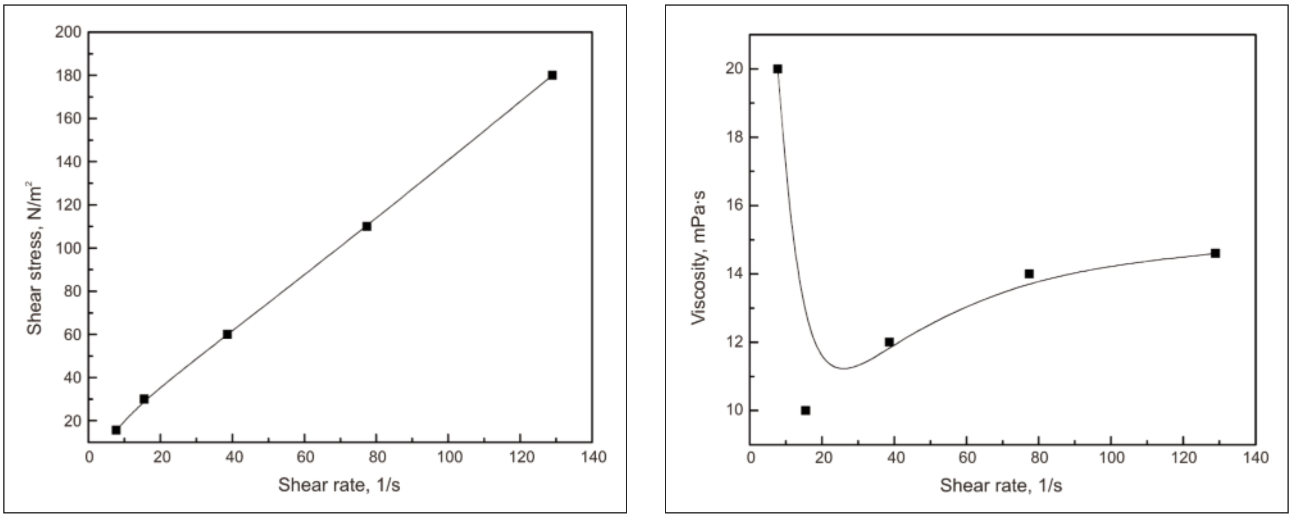
As shown in the table 2, the PAN solutions present low electrical conductivity values. Increasing of PAN concentration determines the decreasing of electrical conductivity of corresponding solution.

PAN solution rheological behavior

The viscosity of polymer systems is one of the parameters that determine their behavior under external electric fields applied. The rheology of polymeric systems is influenced by the molecular weight of the polymers dissolved, the shape and rearrange macromolecules, and polymer-solvent interactions. For a given polymer molecular weight the viscosity of the solution increases monotonically with concentration up to a critical value. These observations reflect the consequences of macromolecular associations and are valid for studying polymer solutions to a range of low to high shear rates.
The experimental results regarding the rheological behavior of PAN are presented in figures 1–4.

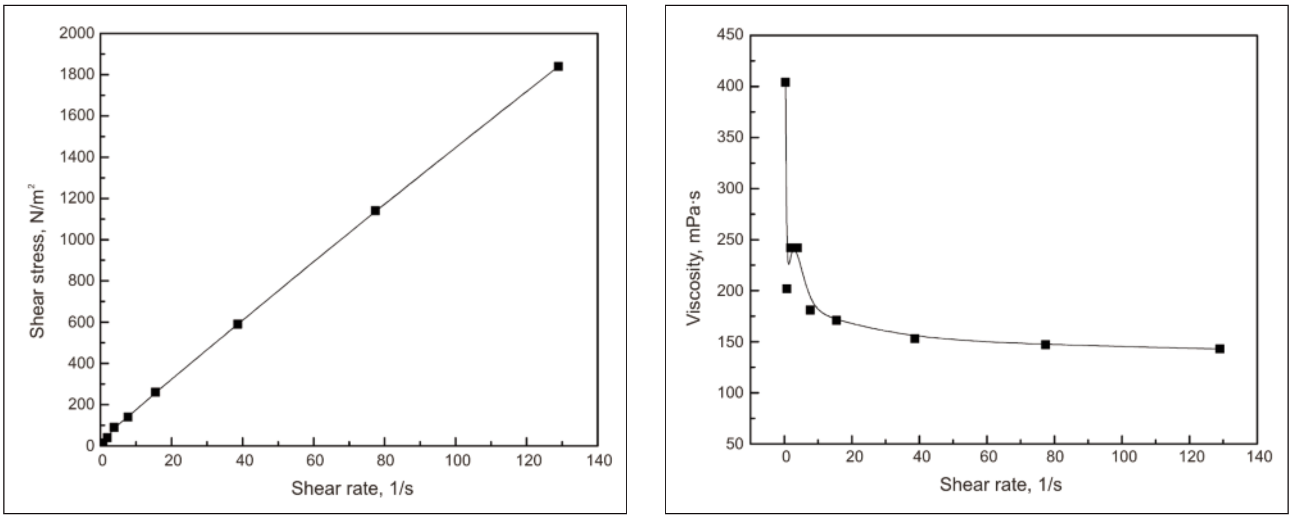
Influence of polymer concentration

Figure 5 shows the morphology of electrospun nanofiber sheets with variation of polymer concentration.
The influence of PAN concentration on the viscosity had been studied because this is an important factor for the behavior of the polymer solution in electrospinning (fig. 6).
Figure 5 shows SEM images of PAN electrospun nanofiber sheets from prepared solutions, using the same processing conditions, with stationary substrate



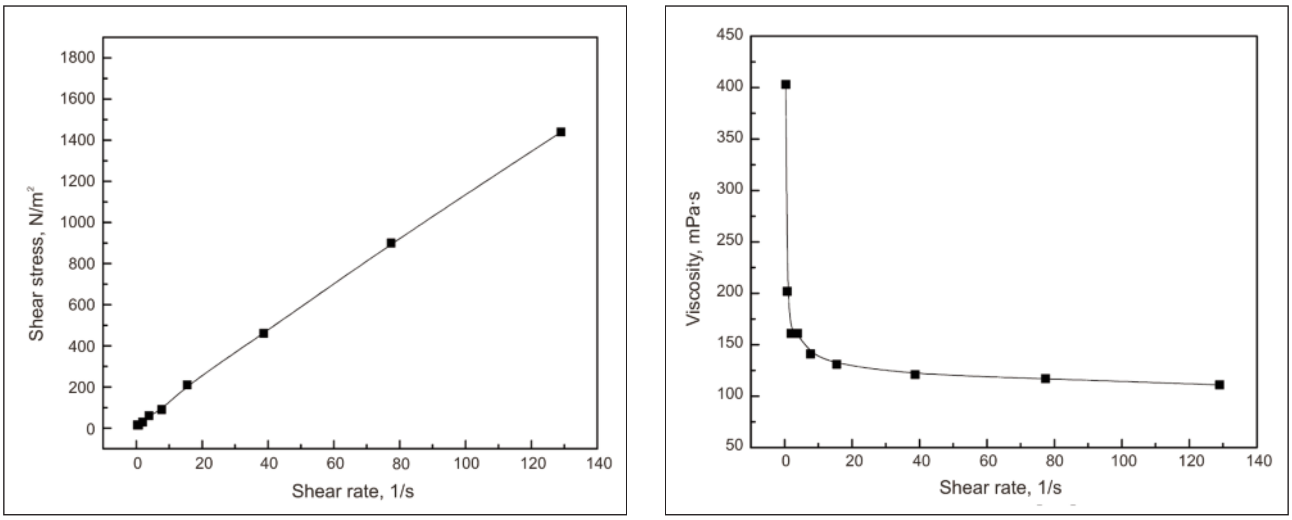
a *b*

Fig. 1. Rheological profile of P3 solution:
a – shear stress – shear rate model; *b* – viscosity – shear rate model



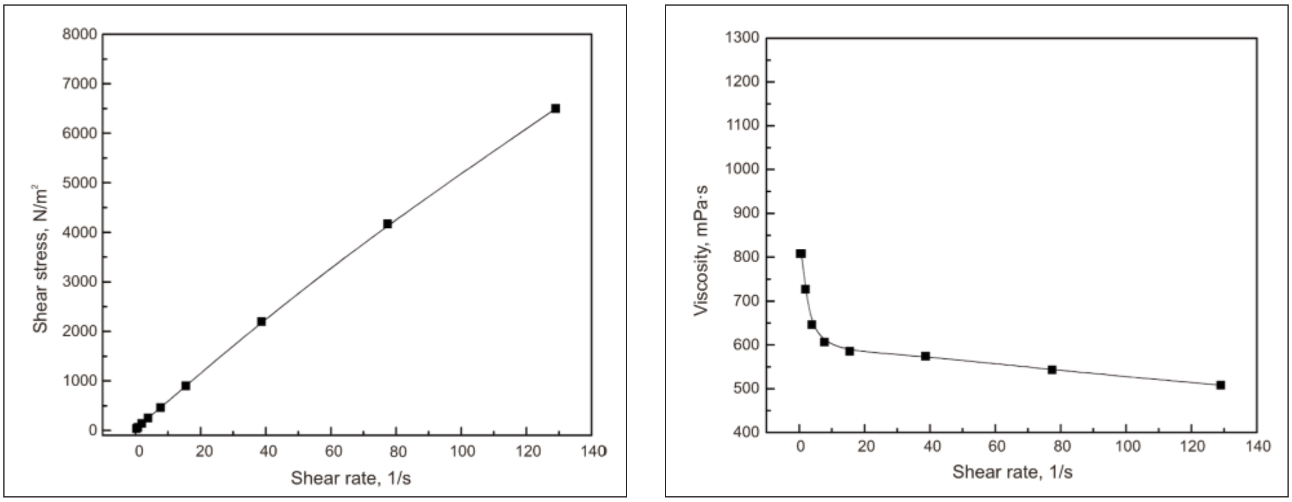
a *b*

Fig. 2. Rheological profile of P5 solution:
a – shear stress – shear rate model; *b* – viscosity – shear rate model



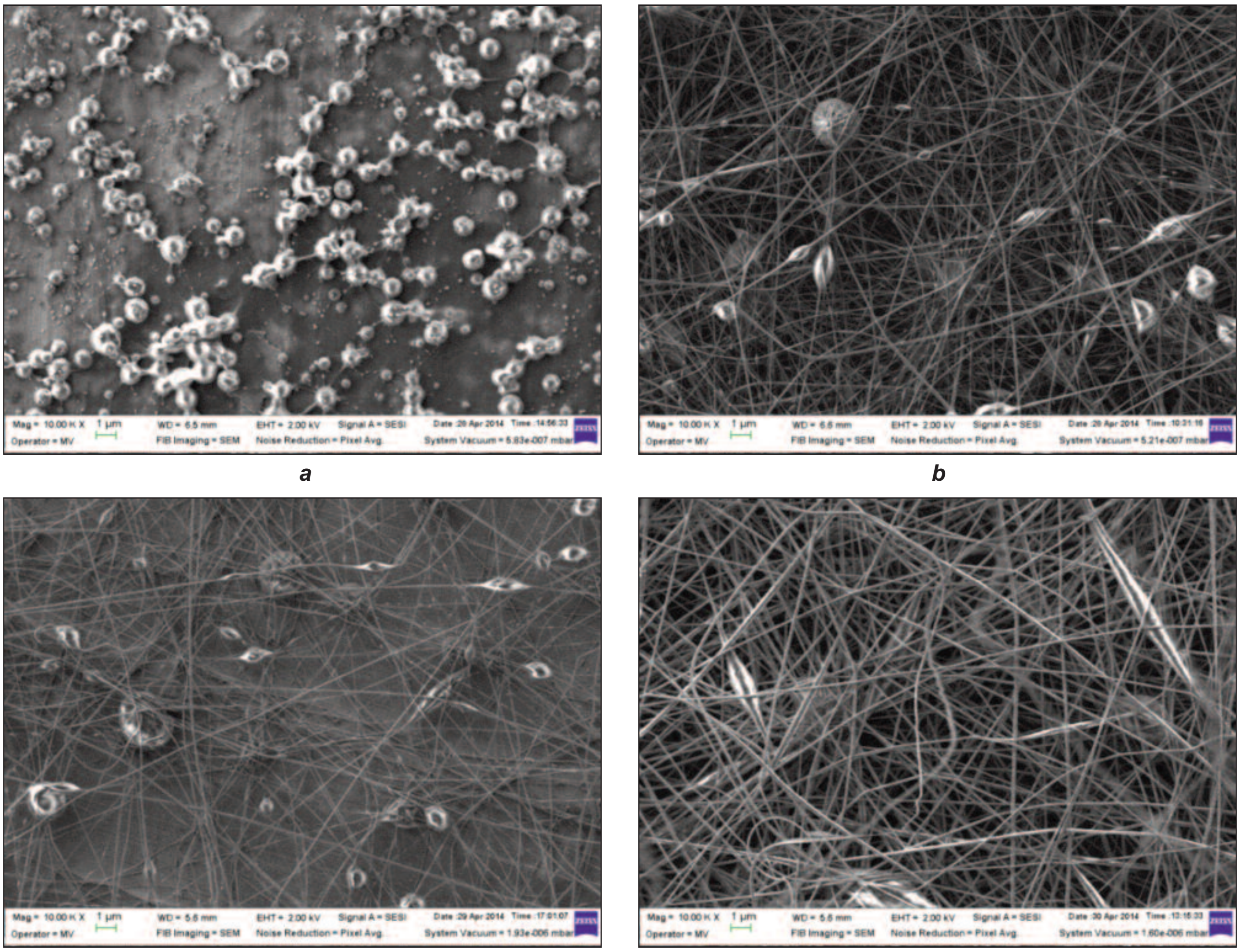
a *b*

Fig. 3. Rheological profile of P7 solution:
a – shear stress – shear rate model; *b* – viscosity – shear rate model



a *b*

Fig. 4. Rheological profile of P10 solution:
a – shear stress – shear rate model; *b* – viscosity – shear rate model



a *b* *c* *d*

Fig. 5. SEM images of nanofiber sheets electrospun from (*a*) 3% PAN, (*b*) 5% PAN, (*c*) 7% PAN and (*d*) 10% PAN, in DMF under the conditions: applied voltage 16 kV, a spinneret-to-collector distance of 18 cm, a solution flow rate of 2 ml/h, a spinneret with a nozzle size of 0.8 mm and stationary substrate

set-up. The solution with 10% PAN in DMF can be electrospun into well-defined nanofibers (figure 5 d) and the image analyses gave fiber diameters between 100 and 170 nm. As shown in figure 5 decreasing of PAN concentration up to 3%, the overall morphology is changed from a fiber network into spherical particles connected by fibers, according to previous works in literature [21, 22].

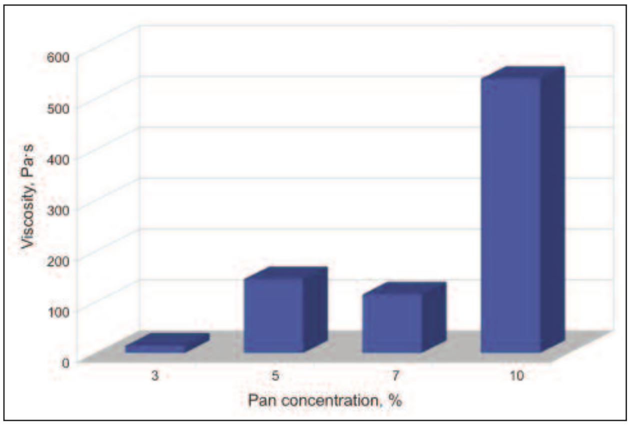
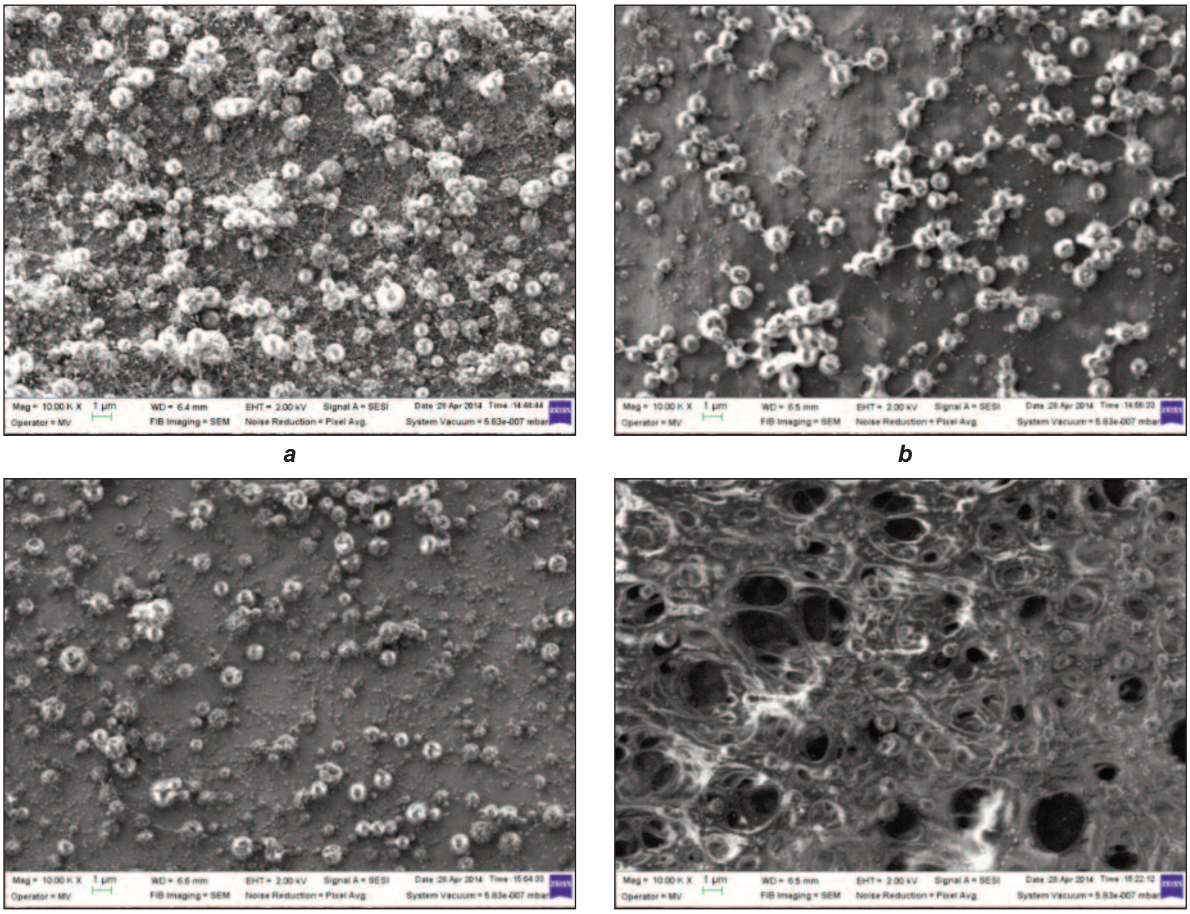


Fig. 6. Dependence of viscosity on the PAN concentration (sheart rate 80 s^{-1})

Figures 7–10 (a–d) show SEM images of the nanofibers sheets resulted at the electrospinning of PAN solutions under applied voltages of 15 kV, 16 kV, 17 kV, 18 kV respectively. It can be seen that PAN solution with 10% concentration can be electrospun in a well-defined fiber network, at applied voltage in the range of 16–18 kV. În the case of PAN solution with low concentration (3%) the overall surface of electrospun sheets resulted in a beaded-morphology, independent on the applied voltages (figure 7, a–d). In the case of PAN solutions of 5%, respectively 7%, a fiber network containing interconnected small beads is obtained. The appearance of the beads is lower corresponding to the increasing of the applied voltage.



a *b* *c* *d*

Fig. 7. SEM micrographs of nanofiber sheets electrospun from P3 solution:
a – 15 kV; *b* – 16 kV; *c* – 17 kV; *d* – 18 kV (10000 x)

CONCLUSIONS

The results of the experiments have shown the effect of process variables (concentration of the polymer solution reflected in their rheological behavior and viscosity, the electrical conductivity, the applied voltage) on the morphology of the nanofiber sheets resulted by the electrospinning of polyacrylonitrile solutions with concentrations of 3, 5, 7 and 10%.

In terms of the formation of nanofibers by electrospinning, the behavior of studied solutions was different, as evidenced by microscopic studies. PAN solutions with concentration of 5, 7 and 10% could be electrospun in a well-defined network, while, at concentrations of 3%, a beaded fiber morphology is formed, according to the decrease in the solution viscosity.

Acknowledgements

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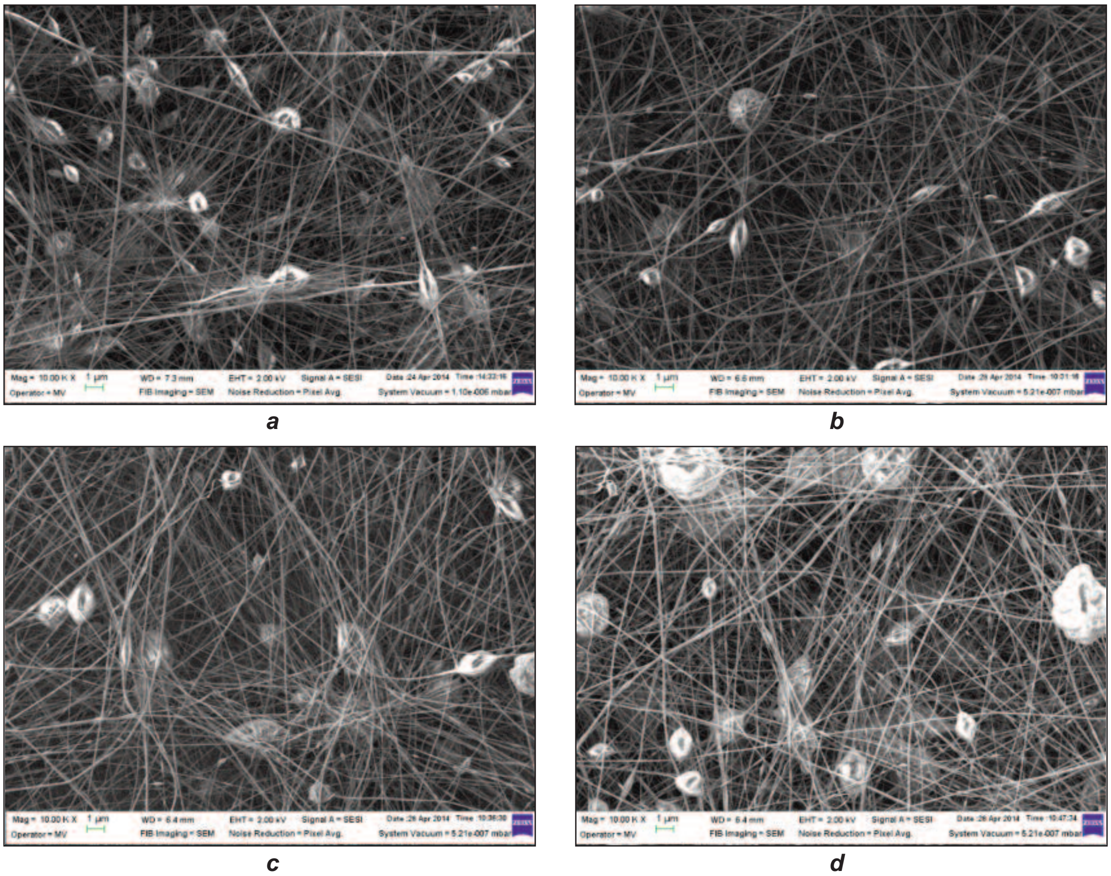

Fig. 8. SEM micrographs of nanofiber sheets electrospun from P7 solution:
a – 15 kV; *b* – 16 kV; *c* – 17 kV; *d* – 18 kV (10000 x)

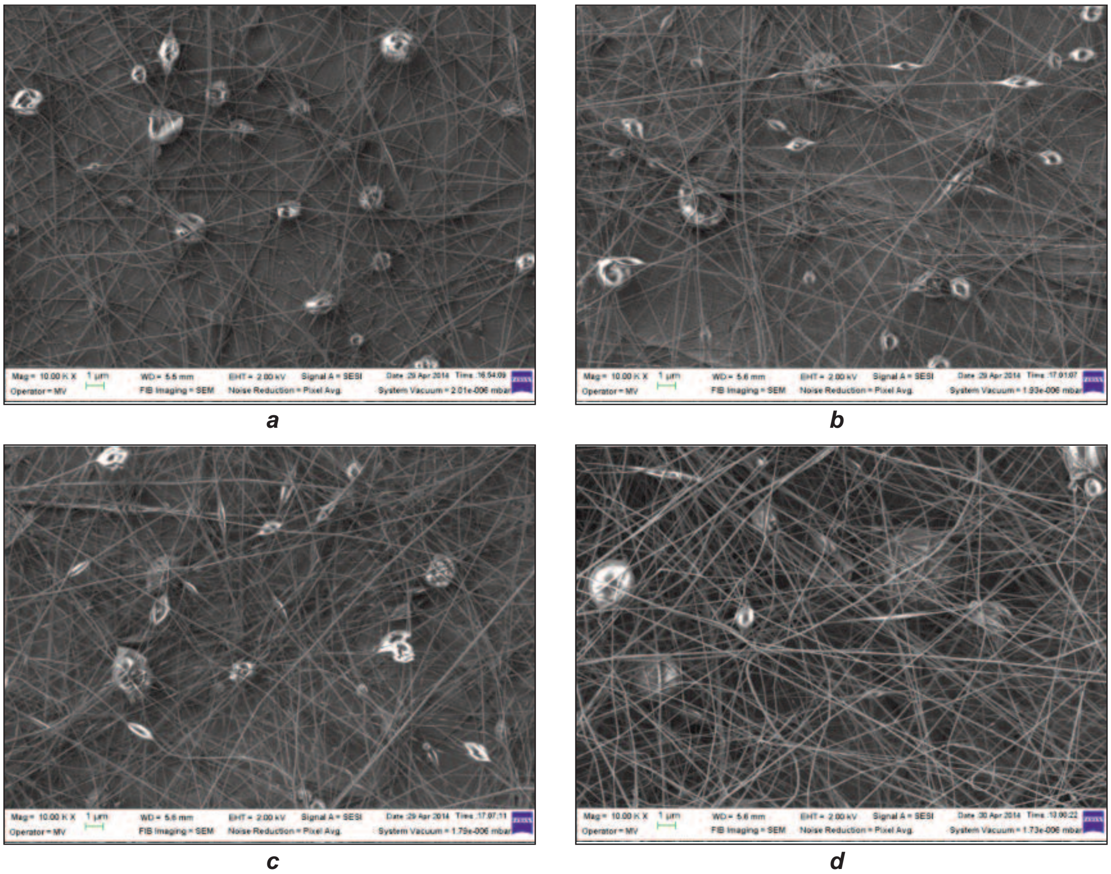

Fig. 9. SEM micrographs of nanofiber sheets electrospun from P5 solution:
a – 15 kV; *b* – 16 kV; *c* – 17 kV; *d* – 18 kV (10000 x)

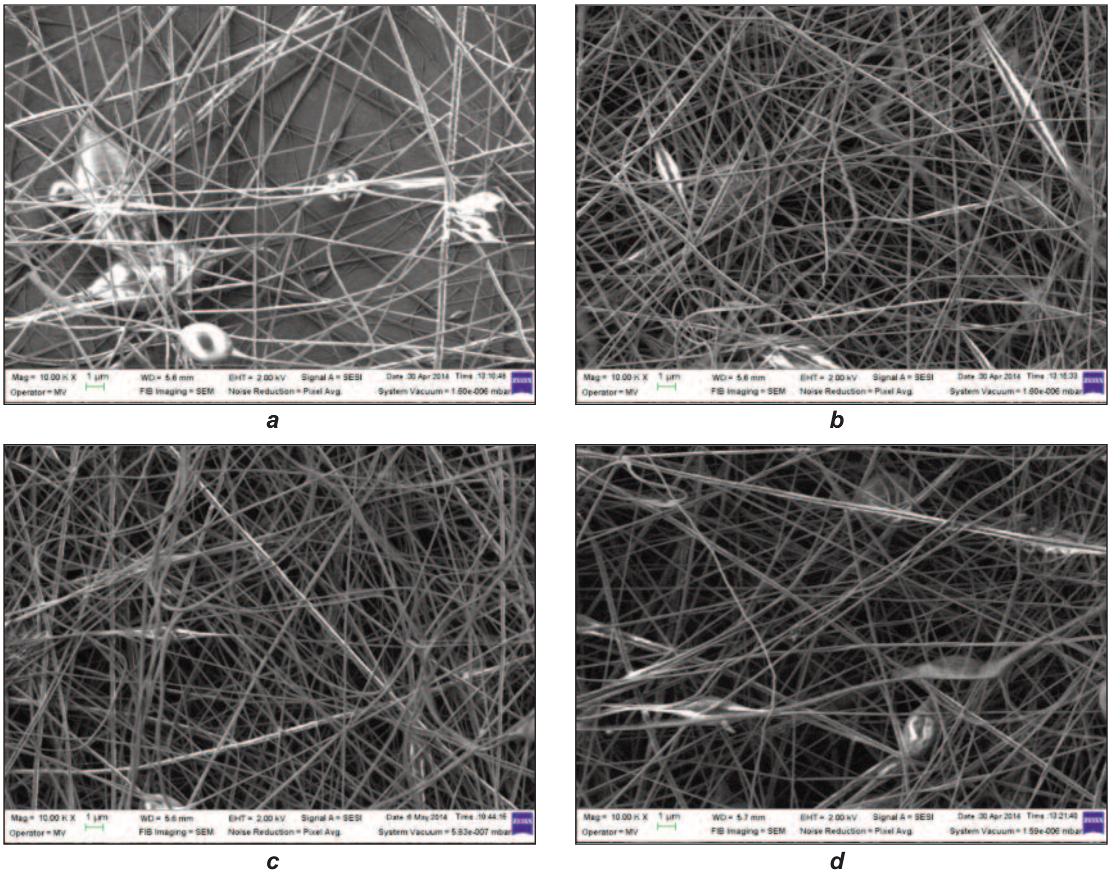

Fig. 10. SEM micrographs of nanofiber sheets electrospun from P10 solution:
a – 15 kV; *b* – 16 kV; *c* – 17 kV; *d* – 18 kV (10000 x)

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INFORMATION FOR AUTHORS

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