The design of experiments in the field of technical textiles as an educational module

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ABSTRACT – REZUMAT

The design of experiments in the field of technical textiles as an educational module

Mastering software knowledge for the design of textile fabrics is especially important for students of higher education and offers substantial competitive advantages within the world of work. The Erasmus+ project OptimTex has prepared up-to-date educational materials as a response to the digitization requirements of Industry 4.0 in the textile field. This paper presents the content of an e-learning module conceived by the coordinator of the Erasmus+ OptimTex project. The module addresses the design of experiments in the field of technical textiles for electromagnetic shielding, with the following technical aspects: two input parameters, the weft fabric density (number of yarns per 10 cm) and the thickness of the plasma-coated metallic (copper) layer on both sides of the fabric (nanometre) and one result variable, the electromagnetic shielding effectiveness of the fabrics (dB) at 100 MHz. A Box-Wilson central composite design was applied to optimize shielding effectiveness related to both input parameters. Software such as Excel, MATLAB and MODDE was applied to compute and cross-check the response surface modelling.

Keywords: *technical textiles, e-learning, optimization, EMI shielding, plasma*

Modul educațional privind proiectarea experimentală în domeniul textilelor tehnice

Deținerea cunoștințelor pentru proiectarea materialelor textile prin aplicații software este deosebit de importantă pentru studenții din învățământul superior și oferă avantaje substanțiale de competitivitate pe piața forţei de muncă. Proiectul Erasmus+ OptimTex a pregătit materiale educaționale adaptate la cerințele de digitalizare ale Industriei 4.0 în domeniul textil. Lucrarea prezintă conținutul unui modul de e-learning realizat de coordonatorul proiectului Erasmus+ OptimTex. Modulul abordează proiectarea experimentală în domeniul textilelor tehnice pentru ecranarea electromagnetică, cu următoarele aspecte tehnice: doi parametri de intrare, desimea în bătătură a țesăturii (numărul de fire/10 cm) și grosimea stratului metalic (cupru) depus prin acoperire cu plasma, pe ambele părți ale țesăturii (nanometri) și o variabilă de rezultat, atenuarea electromagnetică a ecranelor țesute (dB) la 100 MHz. A fost aplicat un program central compozit Box-Wilson pentru a optimiza atenuarea electromagnetică în raport cu cei doi parametri de intrare. Aplicații software precum Excel, MATLAB și MODDE au fost utilizate pentru a calcula și verifica modelarea suprafeței de răspuns.

Cuvinte cheie: *textile tehnice, e-learning, optimizare, ecranare EMI, plasmă*

INTRODUCTION

This paper aims to present the content of an e-learning software module for the design of experiments for technical textiles.
The novelty of this contribution related to the state of the art is based on three major pillars: technical/ e-textiles, e-learning and design and modelling software.

Progress in e-textiles

As a vanguard domain, "e-textiles" and technical textiles are a fast-growing and advanced interdisciplinary research field with promising applications in green wearable electronics, multifunctional smart clothes for health care and human movement detection and smart interior design [1, 2].
The synergy between flexibility, ultralight weight, comfort, stretchability, foldability, low cost of the essential textiles for everyday life and advanced electronic functions of the specific materials (carbon nanomaterials, metal oxides, metals, silicones, etc.) generates a wide range of advanced applications to serve and improve lifestyle, including continuous monitoring devices for human physiological signals, piezoresistive sensors, piezoelectrical devices, capacitive sensors, field effect transistors [3] portable displays, advanced sportswear and portable energy collection and storage systems [4]. In recent years, there has been an increase in consumer awareness of technological developments and applications, which has led to investments in portable electronics and smart electronic textile systems, along with associated industries [5].
Today's world is characterized by increasing dynamics and complexity in labour market relations and the increasing complexity of global competition [6]. Since digital and smart transformation has impacted how every industry works, the interest in these new technologies continuously increases among teachers,

students, trainees, etc., for their future careers to stay updated in the face of rapid change [7].

Progress in e-learning

In this regard, e-learning and online education have made great strides in the recent past. It has moved from a knowledge transfer model to a highly intellectual, swift and interactive proposition capable of advanced decision-making abilities [8]. Education software has the primary purpose of teaching or self-learning. Educational software makes learning more effective and attractive, keeping teachers, students, trainees and pupils updated with software technologies, processes, and practices that are popular in industries [9]. Educational software integrates multimedia content and provides users with a high interactivity level. Online education software supports teachers, allowing them to better connect with students and help them keep students interested in a lesson. It also promotes a productive learning environment [10]. There are many examples of educational software, such as GoReact, Canvas, Kahoot!, Edmondo, Socrative, LanSchool, ClassDojo, Dyknow, Workday Student, Wisenet, Litmos, etc., which enable higher educational institutions to support effective learning outcomes, boost stakeholder engagement, increase productivity, and grow businesses [11].

Various software applications provide learners with a portal for taking computerized quizzes and tests and developing interactive didactic applications (IDAs).

Progress in software for modelling & simulation

Computer-aided manufacturing (CAM) and computer-aided design (CAD) apparel and textile software specifically offer the designer a complete design software solution (tools and techniques) to digitally create textile designs from the initial concept to the final presentation [12]. There are numerous textile software programs available in the market, such as Gerber, Lectra, Optitex, Tukatech, CAD CAM Solutions, Assyst, and Polygon, which can be tailored to meet a company's or client's specific needs within any sector of the textile and apparel business.

The educational module presented in this paper is part of the intellectual output of an Erasmus+ project. The project sets out to improve knowledge and skills in the field of software applications for students of higher education, as well as their employability within textile enterprises, by providing six educational modules for their profession. All educational modules were implemented in e-learning format on Moodle (www.advan2tex.eu/portal/) [13] and on the project's website TAB Instrument (www.optimtex.eu) [14]. The module on the design of experiments was prepared by the INCDTP team, and one of the six examples approached the field of technical textiles for electromagnetic shielding, with the following technical aspects: two input parameters, the weft fabric density (number of yarns per 10 cm) and the thickness of the plasma-coated metallic layer on both sides of the fabric (nanometre) and one result variable, the electromagnetic shielding effectiveness of the fabrics (dB) at 100 MHz. Such educational examples are meant for higher education students in the technical engineering field and focus on mastering software applications and statistics. This paper also includes aspects of the impact achieved by presenting the module within the first intensive study programs organized virtually and hosted by the Technical University of Iasi.

THE ERASMUS+ OPTIMTEX PROJECT

The Erasmus+ project "Software tools for textile creatives – OptimTex" is a strategic partnership project in the field of higher education. It has a two-year implementation period (Dec. 2020 – Nov. 2022) and a prestigious partnership of research and educational providers in Europe: INCDTP – Bucharest coordinates the partnership formed by TecMinho-University of Minho – Portugal, Ghent University – Belgium, University of Maribor – Slovenia, Technical University of Iasi – Romania and University of West Bohemia – Czech Republic. More details are provided on the project's website www.optimtex.eu. The website also includes educational resources in e-learning format with free access by an e-learning instrument (figure 1).

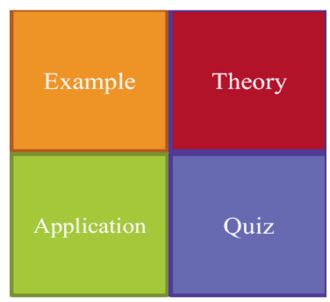

Fig. 1. E-learning instrument in PBL approach

All educational modules were conceived within a problem-based learning approach, starting from examples, the corresponding theory, some of the software applications and quizzes for self-assessment [15].

THE EDUCATIONAL MODULE ON THE DESIGN OF EXPERIMENTS

Software knowledge for design of experiments is useful in the preparation of higher education students. The educational module on the design of experiments addresses four examples with factorial plans and central composite design plans of the practical work within research projects of INCDTP. The second example describes the optimization of a plasma coating for textile fabrics meant for electromagnetic shielding. The rationale of the example is given by the fact that electromagnetic radiation is currently a major problem due to the numerous sources of pollution, mobile phones, Wi-Fi connections, Bluetooth devices, etc. affecting human health [16] and causing interference with the proper operation of other electronic devices [17].

The presented educational example includes some technical aspects, such as the following:

- A solution to avoid undesired EMI pollution by shielding with flexible textile fabrics [18].
- Electric conductivity represents a main property characterizing electromagnetic interference (EMI) shielding textiles [19].
- Fabrics with enhanced electric conductive properties create eddy currents in reaction to the incident electromagnetic (EM) field, which yields an opposite EM field with a shielding effect [18].
- The effect of shielding can be expressed by measuring the quantity of electromagnetic shielding effectiveness (EMSE), which is defined as:

$$EMSE = 10\log_{10}\left(\frac{\text{power of incident signal}}{\text{power of transmitted signal}}\right) \text{ [dB]} \quad (1)$$

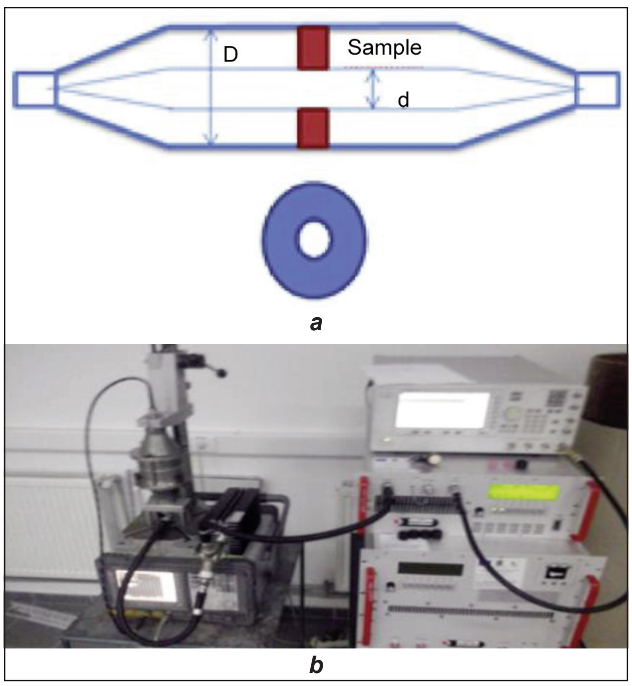

Fig. 2. TEM cell equipment of ICPE-CA: *a* – operating principle; *b* – photo of apparatus of the National Institute for R&D in Electrical Engineering – ICPE-CA, Romania

For the measurement of the EMSE, according to the ASTM ES-07 standard, the power of the signal with and without a washer-shaped textile sample within a TEM cell (figure 2) was considered, and the ratio according to equation 1 was computed.

Furthermore, the magnetron plasma deposition of nanometre metallic layers onto the fabric surface was proven to be an advanced technique for enhancing electric conductivity [22] to be used in EMI shielding. Magnetron plasma deposition is a low-pressure plasma technique by which the metallic particles of a target are dislocated by argon ions and driven towards the textile fabric surface. By this technique, using magnetron plasma equipment (figure 3), very thin layers of metallic coating, in the range of 400–6000 nm, can be deposited on the fabric surface.

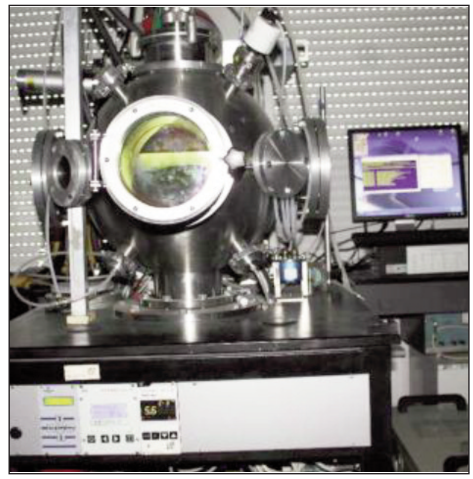

Fig. 3. Magnetron plasma equipment of The National Institute for Laser, Plasma & Radiation Physics – INFLPR, Romania

To optimize the shielding effectiveness of fabric samples, two input parameters were considered: the weft fabric density (number of yarns per 10 cm) and the thickness of the plasma-coated metallic layer on both sides of the fabric. The fabric density was considered a parameter of the fabric structure, while the layer thickness was a parameter of the plasma process. A central composite design (CCD) was applied to optimize the shielding effectiveness related to both input parameters.

CCD is also named the Box-Wilson experimental plan, after the names of the authors. It is one of the most popular experimental plans to optimize a result and determine the response surfaces. There are 3 types of CCD: circumscribed central composite design (CCC), face-centred central composite design (CCF) and inscribed central composite design (CCI). CCD is capable of seizing, in addition to interactions between factors (input parameters), the nonlinear evolution of the response within the experimental domain because it is used for fitting a polynomial equation of second degree or higher. CCD is applied for deep analysis of a phenomenon or in optimization processes. Figure 4 presents the variation levels of the circumscribed central composite design (CCC).

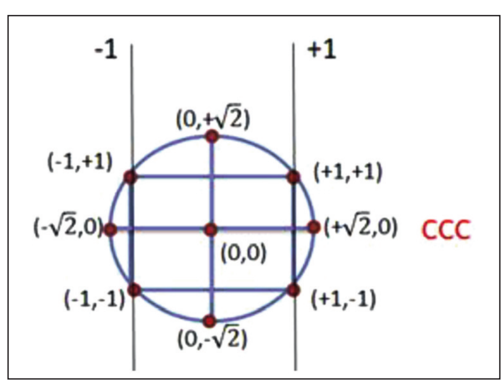

Fig. 4. Variation levels of the circumscribed central composite (CCC) design

Table 1

VARIATION LEVELS OF THE TWO INPUT PARAMETERS		
Level	**Fabric density, F_d (No. yarns/10 cm)**	**Layer thickness, L_t (nm)**
upper: +√2	404	1975.5
upper: +1	360	1750
medium: 0	260	1200
lower: –1	160	650
lower: –√2	116	424.5

The following variation levels were set for fabric density and layer thickness (table 1).

Encoding of the variables fabric density (F_d) and layer thickness (L_t) is used to reach the variation levels (–√2, –1, 0, +1, √2):

$$x = \frac{F_d - 260}{100} \quad (2)$$

$$y = \frac{L_t - 1200}{550} \quad (3)$$

where F_d is the value of the fabric density and L_t is the value of the layer thickness. The cotton fabrics were designed with different fabric densities in weft according to the experimental matrix (a grid of 4 mm was kept for all fabric samples). The copper plasma coating was subsequently applied to both sides of the fabric with the specified thicknesses in the range of 400–2000 nm according to the experimental matrix. The EMSE was measured for the cotton fabrics with conductive yarns of silver inserted into the warp and weft with a grid of 4 mm and copper plasma coating. The EMSE was measured via TEM cell equipment at 100 MHz as a reference frequency for optimizing the EMSE for these electromagnetic shields. EMSE was expressed in dB (table 2).

Table 2

EXPERIMENTAL MATRIX WITH FABRIC DENSITY AND COATING THICKNESS							
Sample code		**Density**	**Thickness**	**Parameters**			**Result**
		x	y	xy	x^2	y^2	Z (dB)
P01	1	–1	–1	1	1	1	42
P02	1	1	–1	–1	1	1	35
P03	1	–1	1	–1	1	1	56
P04	1	1	1	1	1	1	55
P05	1	–√2	0	0	2	0	52
P06	1	+√2	0	0	2	0	48
P07	1	0	–√2	0	0	2	40
P08	1	0	+√2	0	0	2	62
P09	1	0	0	0	0	0	50
P10	1	0	0	0	0	0	51
P11	1	0	0	0	0	0	53
P12	1	0	0	0	0	0	49
P13	1	0	0	0	0	0	50

The polynomic equation of the second degree for fitting the experimental plans with two input parameters has the following coefficients:

$$f(x,y) = a_0 + a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y \quad (4)$$

By regression in Excel, we obtain the following coefficients for the polynomic equation (table 3).

Table 3

COEFFICIENTS OF ENCODED POLYNOMIC EQUATION					
a_0	a_1	a_2	a_3	a_4	a_5
50.60	–1.18	–0.67	1.50	–1.71	8.15

By decoding the polynomic equation according to equations 2 and 3, we obtain the following expression of the polynomic model for EMSE:

$$EMSE = 34.61 + 0.012F_d + 0.013L_t + 0.000027F_dL_t - 0.00011F_d^2 - 0.000022L_t^2 \quad (5)$$

The response surface plot of equation 5 may be graphically represented in MATLAB (figure 5).

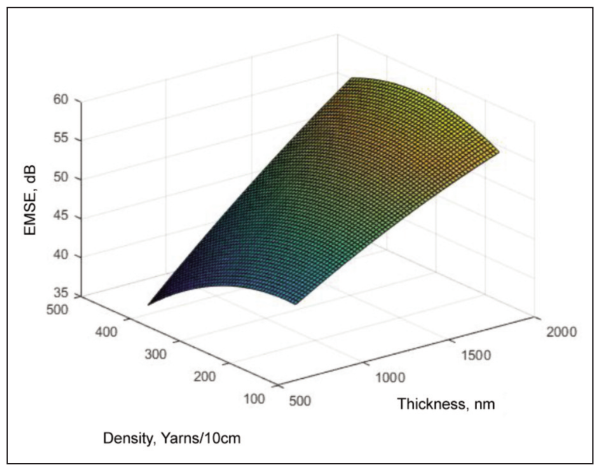

Fig. 5. MATLAB plot of the EMSE response surface

However, there are dedicated software applications for the same procedure. The MODDE software includes a design wizard, which guides the user in the selection of the input parameters, the type of experimental design and the result variables. The first graph generated by the software is the summary of fit, which presents four statistical indicators related to how well the model fits the data (figure 6). High values of the four indicators indicate a good fit of the model to the data.

A second graph shows a 3D response surface plot of the result variable in relation to both input parameters (figure 7). The software computes the values of parameters for optimized EMSE:

EMSEmax = 59.90 dB for density = –0.021 and thickness = 1.147.

Considering equations 6 and 7, we can decode the input parameters:

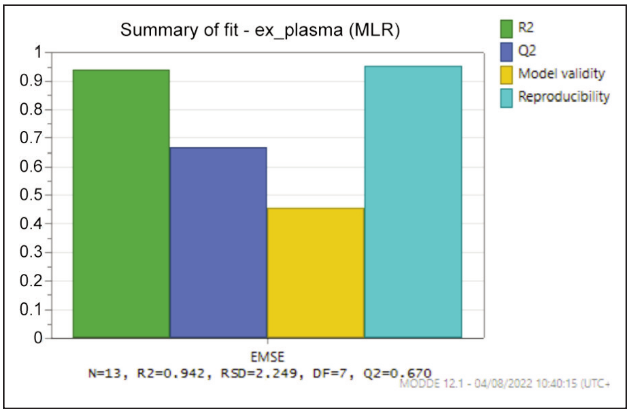

Fig. 6. The four statistic indicators of the summary of fit

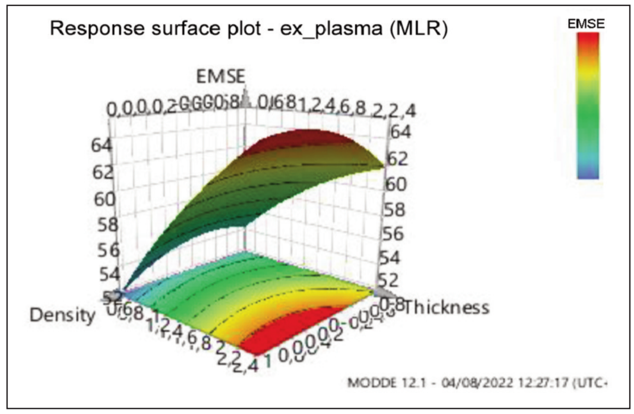

Fig. 7. MODDE plot of the EMSE response surface

$$\frac{F_d - 260}{100} = -0.021 \quad (6)$$

$$\frac{L_t - 1200}{550} = 1.147 \quad (7)$$

By computing the parameters, the maximum obtained value of EMSE = 59.90 dB at 100 MHz, with the following values for the input parameters: fabric density: F_d = 257.9 yarns/10 cm and plasma coating thickness: L_t = 1830.85 nm.

This experimental plan was conceived only for educational purposes, and both MODDE and MATLAB software offered the same results. The experimental plan was conducted only partially in practice because the nanometre thickness of the copper layer yields similar EMSE results with reduced practical relevance.

There are various methods used to address the design of experiments in the field of technical textiles. The educational module uses the software EXCEL, MATLAB, and MODDE. Different methods yield similar mathematical results. The knowledge of software applications for regression computing and plotting the response surface are useful tools for preparing higher education students.

CONCLUSIONS

This paper presents an educational module in the field of design experiments for manufacturing technical textiles. The educational module is meant for higher education students and is focused on software for the design of experiments in the context of the digitization trend of Industry 4.0. It is part of the Erasmus+ OptimTex project, having as its main aim to present software for the design and modelling of textiles. Software knowledge offers many competitive advantages for students within the world of work and boosts employability. The initial impact of the prepared educational materials achieved good results within a virtual intensive study program.

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Software tools for textile creatives

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