ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

EXPERIMENTAL PLAN BASED ON THE RANDOMIZED COMPLETE BLOCK METHOD FOR THE DEVELOPMENT OF FLEXIBLE MATERIALS FOR ELECTROMAGNETIC ATTENUATION

AILENI Raluca Maria[1], MARIN Cornel Adrian[2], DINCA Laurentiu Cristian[3]

[1, 2, 3]INCDTP, 030508, sector 3, Bucharest, Romania, E-Mail: raluca.aileni@incdtp.ro

Corresponding author: Aileni, Raluca Maria, E-mail: raluca.aileni@incdtp.ro

Abstract: *The negative effects of continuous exposure to electromagnetic waves know a continuous growth on the last years because of new developments in electronics and mobile communication applications in different fields (medical, smart devices for IoT applications). There are some researches concluding that exposure to electromagnetic fields could affect the cells (PMBCs, T lymphocytes, B lymphocytes, NK cells and macrophages) of the immune system including cell proportion, cell cycle, apoptosis, destruction activity and cytokine content. Considering the negative effect of electromagnetic inference, it is necessary to develop advanced materials to attenuate electromagnetic waves to protect electronic equipment and humans.*
In this context, this paper presents an experimental plan based on completely randomized blocks (RCBD) for obtaining adequate textile coating for electromagnetic shielding applications taking into account the design of electromagnetic shielding devices should include the modelling of the attenuation phenomenon of electromagnetic waves using Schelkunoff and Calculation theories.
The proposed experimental plan consists of experiments distributed in blocks, each block corresponding to the technology used. For each experimental block, the factors specific to the technology used (independent variables such as the metals used (Ni, Cu, graphite, Fe_3O_4, Ag, Zn), mass (M), air permeability (Pa), thickness (δ)) that could influence the response variable (electrical resistance (Rs)) have been taken into consideration

Key words: *textile, EM shielding, electromagnetic wave,*

1. INTRODUCTION

Concern about possible health hazards from exposure to electromagnetic waves has increased in recent decades with their widespread application in many fields. The immune system plays a crucial role in maintaining body homeostasis. It is important to note that the immune system is also a sensitive target for electromagnetic fields. In recent years, the biological effects of electromagnetic fields on immune cells have attracted more and more attention. Accumulated data suggest that exposure to electromagnetism could affect the cells of the immune system to a certain extent, including cell proportion, cell cycle, apoptosis, destruction activity, cytokine content, and so on. The research subjects mainly covered all types of immune cells, especially PMBCs, T lymphocytes, B lymphocytes, NK cells and macrophages [1].

Electromagnetic Interference (EMI): EMI is the phenomenon by which electromagnetic waves interfere with other electronic/electromagnetic systems, causing interference in communications or damage to electronic components.

Biological rhythms, physical well-being and mental states depend on the electrical system of brain waves interacting with the extremely weak electromagnetic fields generated by the Earth's telluric and cosmic radiation. We are exposed to a wide range of strong electromagnetic radiation, artificially generated, which negatively affects the subtle balance in the energy fields of nature and has become the source of the so-called "diseases of civilization". This also includes sensitivity to electromagnetism. In general, there is a lack of awareness and understanding of electromagnetic fields' impact on health and well-being [2].

Mobile wireless communication networks have become an important aspect of human life. Electronic products make people's lives easier and more systematic. However, a variety of harmful radiation is produced by this equipment. This electromagnetic radiation (EMR) affects human health, flora, and fauna. Without considering the health effects caused by electromagnetic radiation, considerable investments are made to develop these services. Numerous studies have been conducted to demonstrate the harmful effects of EMR on environmental sustainability and the effects caused by these radiations have been proven [1, 3]. Considering these aspects, it is necessary to develop materials for electromagnetic shielding and electromagnetic wave attenuation for equipment and human protection.

Electromagnetic shielding is based on two fundamental processes - reflection and absorption of electromagnetic waves. The material parameters involved in shielding are electrical resistance, electrical conductivity σ, electrical permittivity ε and magnetic permeability μ. The absorption of electromagnetic waves can be due to conductive, dielectric or magnetic losses, depending on the material parameters important in the interaction of the waves with the electromagnetic shield in question. The appropriate selection of materials, their structure and the geometric configurations in which they are used ensures the design of electromagnetic screens with optimized properties for the fields of application [1-3].

2. THEORETHICAL MODELING

The design of electromagnetic shielding devices involves the theoretical modelling of the attenuation phenomenon of electromagnetic waves. This can be achieved using two theories − Schelkunoff theory and Calculation theory [4, 5, 6, 7] both aiming to quantify the shielding effect using the shielding effectiveness parameter (SE) measured in decibels (dB) and defined according to the logarithmic relationship (1).

$$SE[dB] = 10 \cdot lg\left(\frac{P_i}{P_t}\right) \quad \textbf{(1)}$$

Where: P_i and P_t are the incident and transmitted electromagnetic wave power.

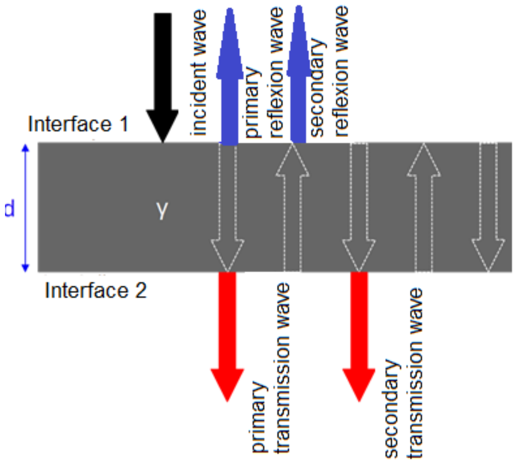
The electromagnetic wave is composed of two coexisting and interdependent wave types (electrical and magnetic) that can interact predominantly electrically or magnetically with matter. Considering this aspect, the electromagnetic wave can be considered to be, as the case may be, an electric or magnetic wave. Thus, the SE parameter can be expressed as a function of the intensity of the type of field (electric or magnetic) underlying the electric or magnetic wave, incident and transmitted [4, 5, 6, 7], according to relation (2):

$$SE[dB] = 20 \cdot lg\left|\frac{E_i}{E_t}\right| = 20 \cdot lg\left|\frac{H_i}{H_t}\right| \quad \textbf{(2)}$$

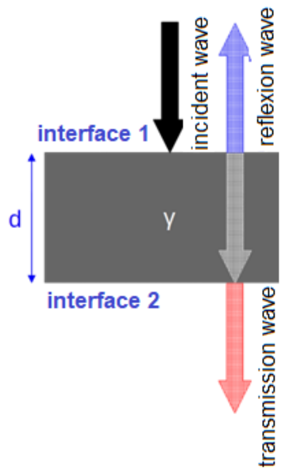
Where E_i and E_t are the electric field intensity of the incident and transmitted electric wave, and H_i and H_t are the magnetic field intensity of the incident and transmitted magnetic wave [4, 5, 6, 7].

According to the "Schelkunoff theory" (figure 1.a), the incident waves are partially reflected by the separating interface between the external environment and the screen material (interface 1), resulting in primary reflection waves. Thus, the non-reflected waves are transmitted through the screen and partially/totally absorbed by it, after which the non-absorbed waves are partially reflected inside the screen at the interface screen - external medium (interface 2). Thus, the waves not reflected by this interface pass through the shielding material in the external environment, resulting in primary transmission waves. The waves partially reflected inside the screen (mentioned before) are transmitted from the interface 2 to 1 and partially absorbed by the material, with a new internal reflection taking place simultaneously with the passage from the screen to the external medium of origin (resulting in secondary reflection waves) [4, 5, 6, 7].

According to "Calculation theory" (figure 1.b), the incident waves are partially reflected by the separating interface between the external environment and the screen material (interface 1), resulting in reflection waves. Unreflected waves are transmitted through the screen and partially/totally absorbed by it, after which they exit the shielding material into the external environment, resulting in transmission waves. The theory does not consider the phenomenon of multiple reflections separately but includes it in a global reflection and absorption [4, 5, 6, 7].



a. Schelkunoff theory



b. calculation theory

Fig.1: *Schematic representation of the electromagnetic shielding phenomenon [4, 6]*

Each of the two theories uses one effectiveness term related to reflection and one related to absorption, but without being identical because, unlike the second theory, the first theory considers multiple internal reflections in the calculations. Schelkunoff's theory is suitable for monolayer electromagnetic shields with homogeneous and isotropic properties due to the importance given to multiple reflections, which in the model are considered to occur only between two separation interfaces between different media. Instead, the calculation theory lends itself to single-layer screens as well as multilayer ones, presenting at the same time the additional advantage of a more straightforward calculation than in the case of the other theory, a better correspondence of the physical meaning of the quantities $SE\rho$ and $SE\alpha$ with the notions of attenuation by reflection and absorption [4, 5, 6, 7].

3. EXPERIMENTAL PLAN BASED RANDOMISED BLOCKS

The experimental plan with completely randomized blocks (RCBD) [8], was obtained by the distribution of experiments in blocks was used, each block corresponding to the technology used (ultrasound, screen printing, lamination or magnetron spraying). For each experimental block, the factors specific to the technology used were taken into account (independent variables (table 1) such as the metals used (Ni, Cu, graphite, Fe_3O_4, Ag, Zn), mass (M), air permeability (Pa), thickness (δ)) that can influence the response variable (electrical resistance (Rs)). The experimental plan, based on completely randomized blocks (RCBD), was achieved using the design of blocks with 2 factors with replication (table 2) was used. Table 3 presents the analysis of variance for completely randomized blocks with replication.

Table 1. *Parameters used for the RCBD experimental plan*

Metal	**Mass (M)**	**Thickness (δ)**	**Air permeability (Pa)**	**Surface resistance (Rs)**
Ni	1159	2.13	9.29	1000
Cu	1587	4.48	33.9	1E+07
Cu	1431	3.34	31.7	1.1E+07
Grafit	709	0.915	45.46	1E+11
Fe3O4	515	1.011	5.755	1E+07
Ni	556	4.385	16.8	1000
Cu	650	1.527	8.876	1E+07
Cu	658	1.847	6.123	1000
Ag	476	1.304	4.27	1E+08
Cu	760	2.25	9.52	1000
Cu	776	1.77	33.16	1000
Cu	702	3.52	31.92	1000
Cu	780	5.38	264.8	1000
Ni	828	4.42	109.1	1000
Ni	950.4	3.9	10.148	1000
Ag	1020.4	3.248	3.248	1000
Cu	1125.2	4.106	90.3	1E+10
Ni	966.4	4	90.383	1000
Ag	1002.8	4.762	141	1000
Ni	590.8	1.5	113.4	1000
Ni	623.2	1.424	109.4	1E+07
Cu	623.6	1.42	121.8	1E+10
Fe3O4	602.8	2.408	55.73	1E+08
Ag	769.6	3.878	143	1000
Ni	577.2	1.25	88.14	100000
Zn	559.2	1.684	16.2	100000

Table 2. *Experimental design - completely randomized blocks with replication*

SUMMARY	**M**	**δ**	**Pa**	**Rs**	**Total**
Ni					
Count	45	45	45	45	180
Sum	37290.4	123.113	1975.577	5.45E+12	5.45E+12
Average	828.6756	2.735844	43.90171	1.21E+11	3.03E+10
Variance	55463.26	1.504862	2862.662	9.95E+22	2.72E+22
Total					
Count	45	45	45	45	
Sum	37290.4	123.113	1975.577	5.45E+12	
Average	828.6756	2.735844	43.90171	1.21E+11	
Variance	55463.26	1.504862	2862.662	9.95E+22	

Tabel 3. *Analysis of variance - completely randomized blocks with replication*

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Sample	0	0	65535	65535		
Columns	4.96E+23	3	1.65E+23	6.639405	0.000284	2.655938877
Interaction	0	0	65535	65535		
Within	4.38E+24	176	2.49E+22			
Total	4.88E+24	179				

Where: SS-experimental error; p-value represents the statistical significance of the test and shows the probability of an error observed by chance; Df represents the number of degrees of freedom; Fcrit represents the critical value, MS represents the square mean and is the expression of the dispersion of the analyzed sample.

Analyzing the obtained data, it is observed that between F and F_{crit} there is the following relationship (3):

$$F_{crit} > F \quad \textbf{(3)}$$

Where:

$$F_{crit} = F_{\alpha, df_m, df_e} \quad \textbf{(4)}$$

In the randomized block analysis, the following assumptions were used:

- The significance level is 0.05;
- The population of experimental parameters is divided into a number of 4 homogeneous subpopulations (blocks);
- Variation within blocks can be minimized by reducing experimental error (MSE).
- Treatments based on different metal microparticles are randomly assigned to the experimental parameters on each block. Because a randomization was used for each block.

Analyzing the randomized blocks, it is observed that using the RCBD method without replication, the P value is equal to 0.000328 ($p<0.001$) and it follows that the null hypothesis is eliminated. Thus, depending on the metal used, the electrical resistance of the screen can be defined by the following regression equations (5-10) presented in Table 4.

Table 4. *Regression equations (Rs = f (metal, M, δ, Pa))*

Metal	**The relationship between the response variable Rs and the independent parameters**	
Ag	X = 41258168986 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(5)**
Cu	X = 171796334327 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(6)**
Fe_3O_4	X = 4119780818 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(7)**
Grafit	X = 38987685750 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(8)**
Ni	X = 41263747348 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(9)**
Zn	X = 484992709600 + 179372247 * Y - 54617856694 * Z - 356077211 * W	**(10)**

Where: x represents electrical resistance, y represents mass, z represents thickness and w represents air permeability.

5. CONCLUSIONS

In conclusion, to reduce the consumption of raw materials (textiles, chemicals), an experimental design based on randomized blocks will be used, which will allow the selection of appropriate experiments based on the parameters or materials used to reduce experiments with the null hypothesis. In both analyzed cases, the inequality $0.0002 < \text{p-values} < 0.05$ means that the results will only contain the null hypothesis for a percentage less than 5% (unfavourable hypothesis for electrical resistance values (Rs) > 10^5 Ω).

ACKNOWLEDGEMENTS

This work was carried out through the Core Programme within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MCID, project no. 6N/2023, PN 23 26 01 03, project title " Electroconductive materials based on multilayer metallizations for thermoelectric systems, electromagnetic shielding and biomedical sensors integrated in IoT systems (3D-WearIoT)". The publication of the scientific paper is funded by the Ministry of Research, Innovation and Digitization within Program 1 - Development of the national R&D system, Subprogram 1.2 - Institutional Performance - RDI excellence funding projects, Contract no. 4 PFE/2021.

REFERENCES

[1] C. Yao, L. Zhao, R. Peng, R., *"The biological effects of electromagnetic exposure on immune cells and potential mechanisms"*, Electromagnetic Biology and Medicine, 41(1), pp. 108-117, 2022.

[2] J. G. Van Bladel, *"Electromagnetic fields"*, vol. 19, John Wiley & Sons, 2007.

[3] K. Ongel, N. Gumral, F. Ozguner, *"The potential effects of electromagnetic field: a review"*, Cell Membranes and Free Radical Research, 1(3), pp. 85-89, 2009.

[4] M. Peng and F. Qin, *"Clarification of Basic Concepts for Electromagnetic Interference Shielding Effectiveness"*, Journal of Applied Physics 130, 22, AIP Publishing, 2021.

[5] H. Vasquez, L. Espinoza, K. Lozano, H. Foltz and S. Yang, *"Simple Device for Electromagnetic Interference Shielding Effectiveness Measurement"*, IEEE, pp.62-68, 2009.

[6] C. Morari and I. Bălan, *"Methods for Determining Shielding Effectiveness of Materials"*, Electrotehnică, Electronică, Automatică 63, 2, 2015.

[7] Z. Kubík, P. Karban, D. Pánek and J. Skála, *"On the shielding effectiveness calculation"*, Computing 95, pp.111-121, 2013.

[8] G. Shieh, G., S. L. Jan, *"The effectiveness of randomized complete block design"*, Statistica Neerlandica, 58(1), pp. 111-124, 2004.