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Impact of Dry Cleaning on the Electromagnetic Shield Characteristics of Interlining Fabric

Abstract

The research deals with the protective properties of sewn interlining fabric (IF) intended for pockets of jackets, trousers and other garments in order to protect the user from the harmful effects of microwave radiation from mobile devices. The IF was produced from polyamide filaments coated with copper. Measurements of the electromagnetic shielding effectiveness of the face and reverse side of the IF were made at frequencies of 0.9, 1.8, 2.1 and 2.4 GHz, which were repeated after the dry cleaning process and also following ironing in 10 cycles. Surface modification of the IF tested was examined by scanning electron microscopy - SEM. The results showed a complete loss of material protective properties after ten dry-cleaning and ironing cycles. Damage to the surface copper layer that allowed the passage of electromagnetic micro waves in the fabric cycles was also confirmed by SEM micrographs.

Key words: interlining fabric, dry cleaning, electromagnetic shield, scanning electron microscopy.

Introduction

The development of textile products that have protective properties against electromagnetic (EM) radiation has excited the interest of scientists for a decade [1 - 3]. In order to produce garments that have partial or complete protection against EM radiation it is necessary to promote and introduce them within the apparel industry. Applications arise from the development of new technologies and electronic devices spreading EM waves that can adversely affect human health. Research applied to different knitting structures produced on a flat knitting machine using stainless steel and copper wires have proved that knitted structures produced from double wires possess higher values of protection against EM radiation [4, 5]. Conductive textile surfaces that are lightweight, flexible and inexpensive have begun to be manufactured instead of electrically - conductive metal sheet or wire mesh shielding materials for various shielding applications within the electrical and electronic industries [6].

Medical research has shown that frequent use of electronic devices can have various health effects on people and cause various health problems such as cardiac arrhythmias, increased stress and an increase in the percentages of cancer, behavioural changes, etc. [7, 8]. In this day and age it is very important to try to reduce the negative effects caused by EM waves on humans, animals, and the environment. When electromagnetic waves occur in the body, vibrating molecules emit heat. In the same way when electromagnetic waves occur in the human body they prevent the regeneration of the DNA and RNA of cells [9]. Based on these

reasons, there is a need for setting the boundaries of electromagnetic emissions from all electrical and electronic devices in order to minimise the possibilities of interference with radio and wireless communications.

Amongst the many solutions offered, the greatest interest for researchers is attraction regarding textiles and composite materials based on textiles because of their diverse and wide ranging applications [10].

In order to protect the human body from these impacts, various research is being conducted resulting in the development of woven and knitted fabrics with protective properties. They are made of composite structures with conductive materials (Cu, Ag, Ti, Ni, etc.), where threads are wrapped in cotton or synthetic yarn [11]. The protective effect is defined as the ratio between the field strength at a given distance from the source without a protective shield and the field strength with a shield. This can be explained as the protective effect of a conductive barrier (dB) being equal to the sum of the reflectance losses (R), the loss of absorption (A) and stated re-reflectance (Rr). Studies that have explored the impact of materials, the number of threads, fabric density, types of dressings and the number of layers of fabric for protecting the effectiveness of textile materials have resulted in the cognitive realisation that the electromagnetic shield's effectiveness increases with the increasing number of layers of fabric and fixator fabric. The number of threads and densities has no significant effect on the EM shield effect [12]. Electromagnetic interference (EMI) has become very serious regarding a variety of different electronic equipment such as personal computers

(several GHz), mobile devices (0.8 to 2.4 GHz) and other devices [13]. Various methods have been developed in order to minimise the effect of the radiation. One protection method is through a variety of technologies that protect equipment and personnel working within electromagnetically contaminated surroundings. Materials recommended for protection are those with high electrical conductivity and magnetic permeability. The electromagnetic protection factor is defined as the ratio between the intensities of the electromagnetic fields measured without the material tested, and the intensities of those electromagnetic fields with the material placed between the sources of radiation and the receivers [14].

The research presented deals with the protective properties of interlining fabric (IF) produced from polyamide filaments coated with copper. Sewn interlining is intended for the pockets of jackets, trousers and other garments in order to protect the user from the harmful effects of microwave radiation from mobile devices. The protective properties of the initial interlining fabric were measured at frequencies of 0.9, 1.8, 2.1 and 2.4 GHz. These measurements were repeated after the dry cleaning process and also following ironing. Tests were conducted within the Microwave laboratory of the Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia.

Method work

Material – textile interlining

Research into EM shield effectiveness was performed on sewn interlining fabric, labelled as B961 A Cu

and supplied by tt. Kufner, GmbH, Germany. The manufacturer's specification consists of 100% PA filament which is metallised with Cu. The same filament in the warp and weft directions was applied to *IF* of surface mass $52 \pm 5 \text{ g/m}^2$. Technical documentation of the *IF* consisted of certificates for the protective properties accredited by ASTM-D-4935-89 within different frequency ranges from 0.45 to 10 GHz, and from 0.45 to 2.45 GHz.

Dry cleaning

Although the *IF* label allows washing and dry cleaning, this paper deals with the dry cleaning impact on *SE* properties only, performed using perchlorethylene (PERC) in a two - bath procedure. A special dry cleaning substance (w = 2%), Seecapur Mega Star, from the German company Büfa, was added to first PERC bath. This agent is formulated with new, better biodegradable cationic surfactants intended for antistatic effects and good cleaning effect. The process specified in **Table 1** was performed in a dry cleaning machine with a load of 16 kg. *IF* samples of dimensions $1 \times 1 \text{ m}$ were dry-cleaned in 10 cycles and ironed in between at 110 °C following the suppliers labelled instructions.

The electromagnetic interference (EMI)

Electromagnetic interference (*EMI*) can be seen as a kind of environmental pollution with significant consequences for human health. The electromagnetic spectrum is a natural source that has been heavily exploited over the last century, but newer technologies are now being used more and more frequently. Excessive exposure to electromagnetic radiation can lead to serious injury, illness and even death. Interaction between the human body and external electromagnetic fields in today's world is inevitable because of the world we live in. Everyone is, in some way, exposed to the activities of electromagnetic fields through various electrical and electronic devices (cell phones, computers, electrical appliances, radio and TV receivers, etc.). *EMI* introduces unwanted voltages and currents into hardware equipment. The higher the level of voltage or current, the higher the level of interference radiated or conducted [15]. Electromagnetic fields are used for various purposes such as in medicine, the chemical industry, textile industry, and others. Electromagnetic fields cannot be detected by human senses, but in some cases can be felt directly in strong

Table 1. Dry cleaning process.

Dry cleaning	1st bath	2nd bath	Drying
	Pre-cleaning	Cleaning	
Temperature, °C	20	20	60
Time, min	4	6	30 (5/5)
min ⁻¹	300	360	-
PER, l	20	40	-
Detergent	Mega super star	-	-
Bath ratio (BR)	1:2	1:4	-

magnetic or electric fields at low frequencies (a few or dozen Hz). Persons exposed may have visual sensations (so-called magneto- or electrofosfen) or pulse microwave fields can cause auditory sensations (the so-called Frey effect). Therefore prevention protection is required. Interaction between the human body and the electromagnetic field is mutual: electromagnetic field has effect on the human body but human body also changes the distribution of electromagnetic field as well. This means that any foreign object inside the electromagnetic field changes the value of this field simply by being in this field. The higher conductivity of the object inside the field - the higher is the impact on the electromagnetic field. The vector quantity that indicates the level of the electric field as determined by the force of the stationary electrical charge is called the electric field strength (*E*) and is expressed in volts per metre, V/m [16].

The shielding effectiveness of the protection shield (shield effect *SE* in dB) of the interlining fabric is calculated by:

$$SE = 20 \log \frac{E_1}{E_2} \quad (1)$$

where E_1 is the level of those fields without a shield and E_2 the field level with a shield.

Measurements of the electromagnetic shielding effectiveness of the interlining fabric (B961 A Cu) on the face and reverse side were made at the Microwave laboratory of the Department of Wireless Communications, Faculty of Electrical Engineering and Computing in Zagreb. The measurement mode in which the measurements were conducted was set according to the recommendations of international standards IEE-STD 299-97, MIL STD 285, and ASTM D 4935-89. The measurement setup consisted of a signal generator, horn (waveguide) and dipole antennas, shield placed fabric,

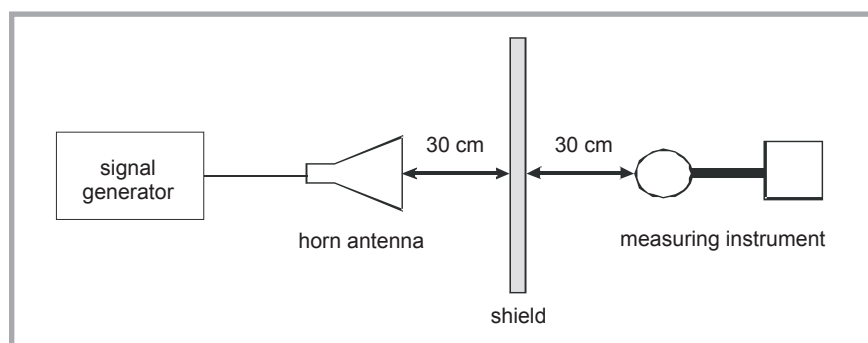


Figure 1. Measurement setup.

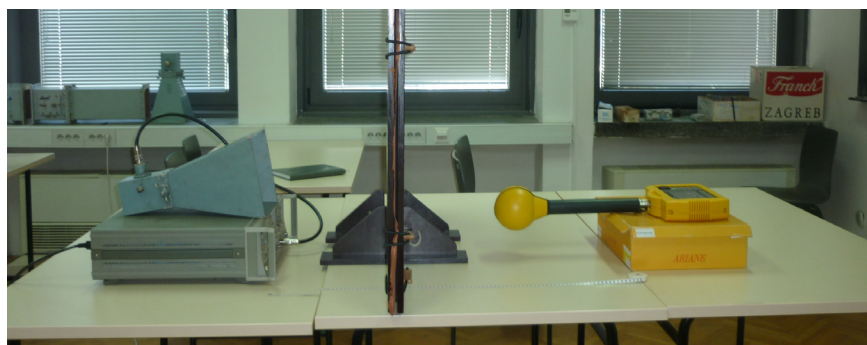


Figure 2. Photo of measurement setup.

Table 2. Field level of the IF (face and reverse side) at frequencies from 0.9 to 2.4 GHz.

f, GHz	E field level, V/m				
	without shield	face		reverse side	
		IF	SE, dB	IF	SE, dB
0.9	0.0222	0.0070	5.18	0.0084	8.46
1.8	1.9000	0.1424	22.50	0.0889	26.59
2.1	2.7000	0.2434	20.90	0.2487	20.71
2.4	2.2000	0.2207	19.97	0.2265	19.75

and measuring instrument NARDA SRM 3000 (USA), a vector spectrum analyser (Figures 1 and 2, see page 105). The shielding of the interlining fabric (B961 A Cu) was measured on the face and reverse side after 1, 3, 5, 7 and 10 dry cleaning cycles and ironing.

Scanning electron microscopy - SEM

A Tescan SEM VEGA 5136 MM (Czech Republic) scanning electron microscope was used for surface examination of the IF samples before and after the dry cleaning cycles and ironing. Samples were fixed on the sample holder and sputter-coated with a palladium-gold alloy. The samples were examined using 2 types of signals produced by SEM including secondary electrons (SE) with an acceleration voltage of 20.0 kV and magnification of 500 \times .

Results

The electromagnetic shielding effectiveness (SE) of the interlining fabric (IF)

B961 A Cu was measured on the face and reverse side. The measurements were compared with aluminum plates (Figure 1). In addition the protective properties of the IF against electromagnetic radiation were measured on the face and reverse side after the first (1), third (3), fifth (5), seventh (7) and tenth dry cleaning cycles (10), within the frequency range of 0.9 to 2.4 GHz (Table 2).

Fields measured are those that pass through the shield of IF before and after 1, 3, 5, 7 and 10 cycles of dry cleaning. It can be seen in Table 2 that the SE at frequency 0.9 and 1.8 GHz shows better results than for the IF's reverse side, whereas the frequencies of 2.1 GHz and 2.4 GHz score better on the face than on the reverse side IF. The best shielding effectiveness for the face and reverse side were obtained at a frequency of 1.8 GHz.

Based on the results obtained it can be concluded that the SE at frequencies of 0.9 GHz and 1.8 GHz decreased with

the increasing number of dry cleaning cycles. On the face side of the IF, the SE gave satisfactory results at a frequency of 1.8 GHz before dry cleaning and when the SE was greater than 20 dB. After the tenth dry cleaning, the SE at 0.9 GHz (Figure 3.a) was close to zero, and at a frequency of 1.8 GHz somewhat better (Figure 3.b).

The results for SE before dry cleaning were above 20 dB at frequencies 2.1 GHz and 2.4 GHz on the IF's face side. With the increasing number of chemical cleaning cycles, the value of SE also declined proportionally with these frequencies, as can be seen in Figures 3.c and 3.d. After the tenth dry cleaning, the SE at 2.1 GHz frequency was equal to zero, whilst at a frequency of 2.4 GHz it was about 2 dB.

Figure 4.b shows that the value of SE before dry cleaning for the IF's reverse side of 25 dB at a frequency of 1.8 GHz, whilst at a frequency of 0.9 GHz, the SE value was less than 10 dB (Figure 4.a). There was also a noticeable decrease in SE with an increase in the number of dry cleaning cycles at both frequencies.

At frequencies of 2.1 GHz and 2.4 GHz for the reverse side of the IF, the SE value before dry cleaning was about 20 dB. Increasing the number of dry cleaning cycles reduced the value of SE at both frequencies. At 2.4 GHz after the tenth dry cleaning cycle the SE value was

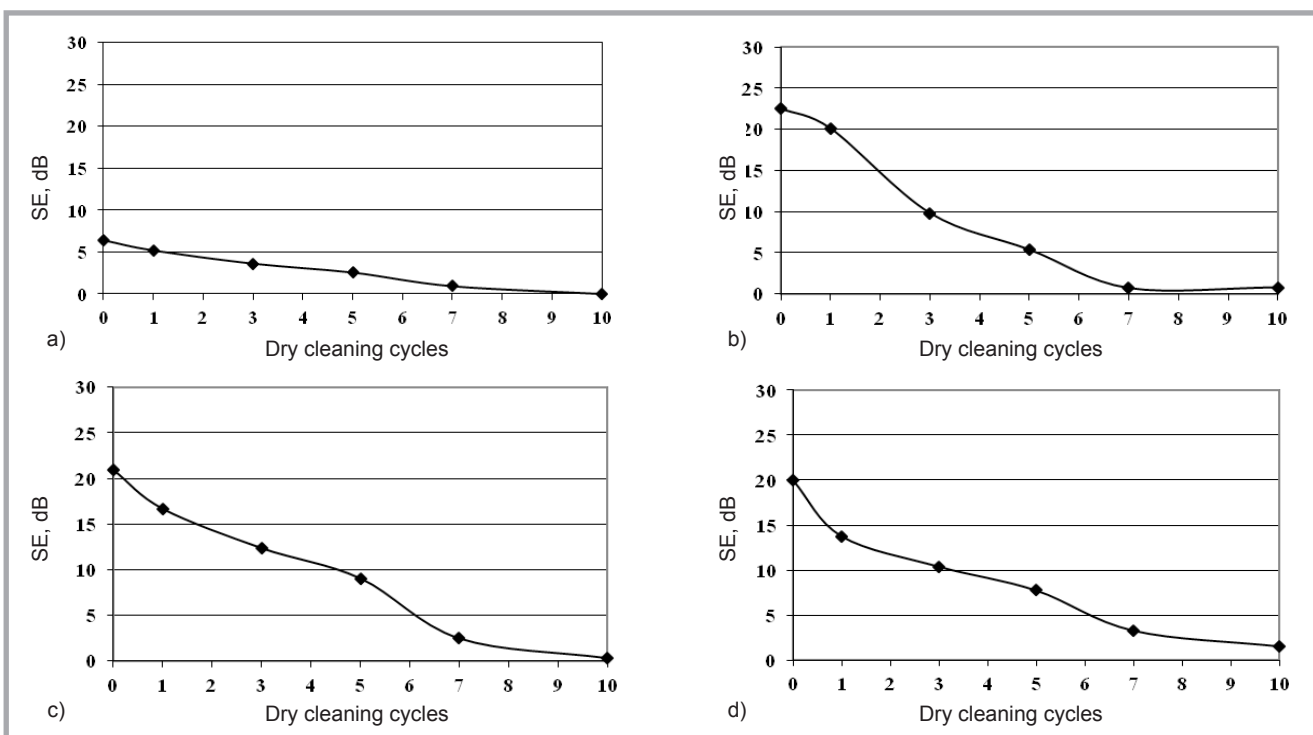


Figure 3. Impact of dry cleaning on SE on the IF's face side at a frequency of: a) 0.9 GHz, b) 1.8 GHz, c) 2.1 GHz, d) 2.4 GHz.

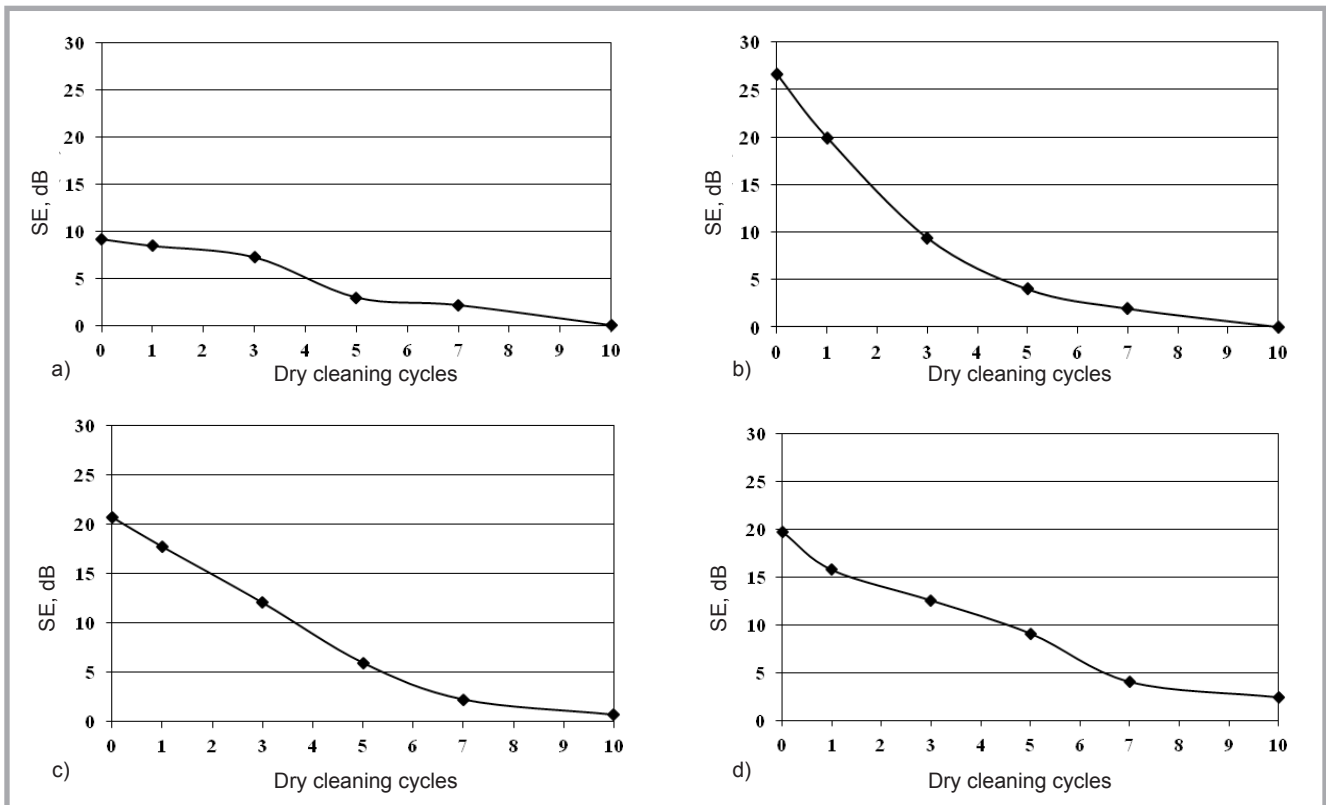


Figure 4. Impact of dry cleaning on SE on the IF's reverse side at a frequency of: a) 0.9 GHz, b) 1.8 GHz, c) 2.1 GHz, d) 2.4 GHz.

slightly higher than the SE value for the IF face, whilst the SE value at frequency of 2.1 GHz was almost zero (Figures 4.c and 4.d).

Discussion

SEM micrographs of IF samples before (Figure 5) and after 1, 3, 5, 7 and 10 dry cleaning and ironing cycles are presented in Figures 6 - 10.

After the first dry cleaning there were some minor changes in the surface structures of the IF (Figure 6).

Further dry cleaning (3) caused small changes in the morphology of the IF observed (Figure 7.a). The ironing of the

dry-cleaned IF accelerated the degradation (Figure 7.b).

It is clear that the integrated and compact copper layer had cracks and an initial light level of disintegration. The formation of these small cracks allowed partial passage of electromagnetic waves through the IF.

Five dry cleaning cycles caused further degradation of the IF (Figure 8.a). Ironing resulted in stronger cracking of the copper layer (Figure 8.b), and therefore enhanced the passage of EM waves through the IF, lowering the SE of the IF after the fifth cycle.

Seven dry cleaning and ironing cycles caused further damage to the copper lay-

er, which could be characterised by specific peeling, which certainly caused the significant passage of EM waves, with a weaker SE of the IF as a result (Figure 9.a, 9.b).

The IF surface was completely destroyed after 10 dry cleaning and ironing cycles. Ironing caused stronger changes in the morphology and compactness of the copper layer (Figures 10.a, 10.b). Therefore strong degradation completely disturbed the protective properties of the IF.

Conclusions

The aim of this study was to investigate the protective properties of sewn interlining fabric (IF) produced from polyamide filament coated with copper before and

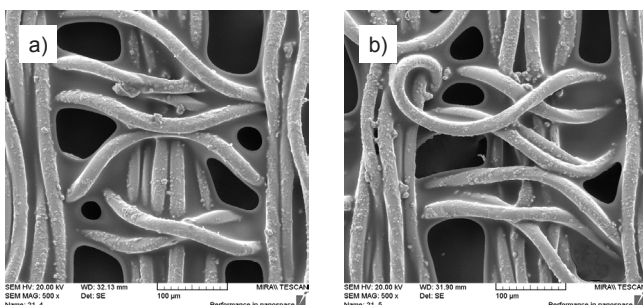


Figure 5. SEM of the IF before dry-cleaning: a) initial, b) ironed.

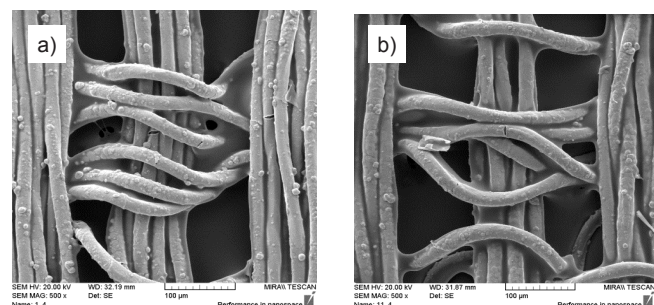


Figure 6. SEM of the IF after: a) first dry cleaning, b) first dry cleaning and ironing cycle.

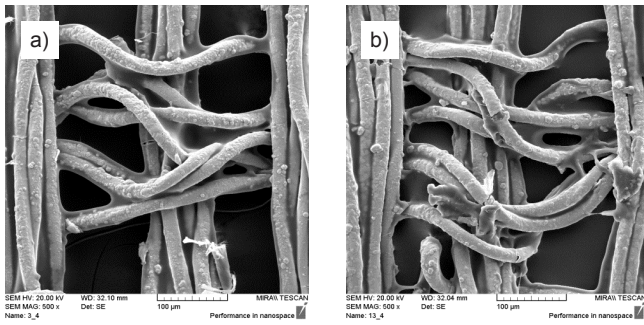


Figure 7. SEM of the IF after: a) three dry cleaning, b) three dry cleaning and ironing cycles.

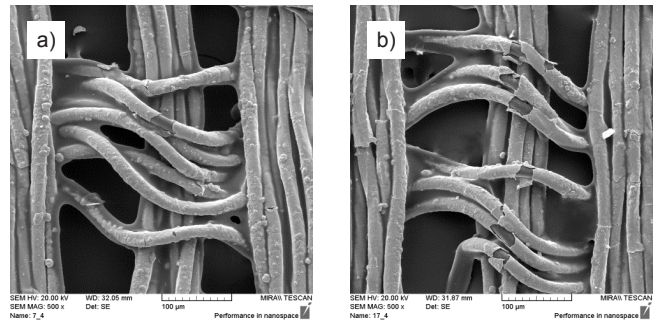


Figure 8. SEM of the IF after: a) five dry cleaning, b) five dry cleaning and ironing cycles.

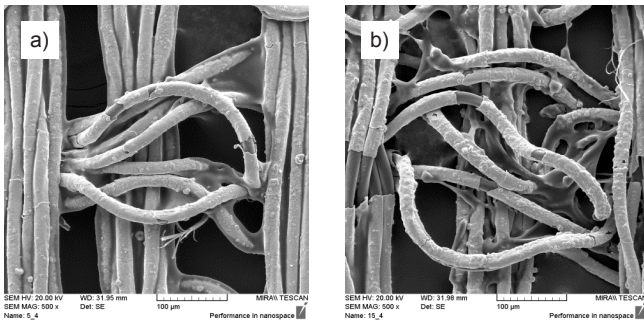


Figure 9. SEM of the IF after: a) seven dry cleaning, b) seven dry cleaning and ironing cycles.

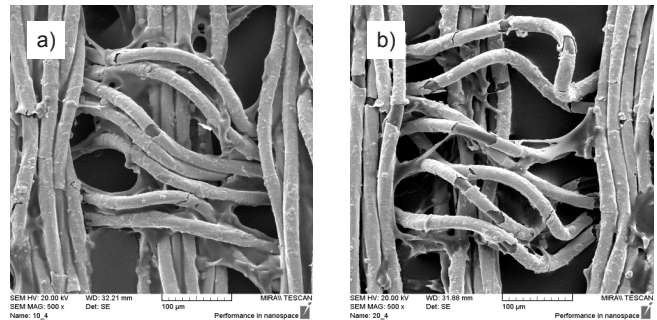


Figure 10. SEM of the IF after: a) ten dry cleaning cycles, b) ten dry cleaning and ironing cycles.

after the dry cleaning process. Measurement of the Shield Effect (*SE*) was performed on untreated and dry-cleaned *IF* after 1, 3, 5, 7 and 10 cycles at frequency ranges of 0.9 to 2.4 GHz. The results obtained demonstrated the proper application of selected *IF* at frequencies greater than 0.9 GHz, to frequencies 1.8, 2.1 and 2.4 GHz, respectively. The reverse side of the *IF* had better protective properties against electromagnetic microwave radiation than the face side. After seven dry cleaning and ironing cycles, the protective properties decreased significantly. Cracking of the copper layer resulted in a higher passage of electromagnetic microwave radiation. Damage to the surface's copper layer, allowing passage of electromagnetic micro waves through the fabric, due to multiple processes of dry cleaning and ironing was also confirmed by SEM micrographs. Ten dry-cleaning and ironing cycles caused a complete loss of material protective properties due to the synergism of the solvent action, mechanical agitation, as well as the heat produced by drying and ironing, relieving the *IF* of its shielding effect.

2. Brzezinski S, et al. Textile Multi-layer Systems for Protection against Electromagnetic Radiation. *Fibres & Textiles in Eastern Europe* 2009; 17, 2, 73: 66-71.
3. Koprowska J, Pietranik M, Stawski W. New Type of Textiles with Shielding Properties. *Fibres & Textiles in Eastern Europe* 2004; 12, 3, 47: 39-42.
4. Çeken F, et al. The Electromagnetic Shielding Properties of Copper and Stainless Steel Knitted Fabrics. *Tekstil* 2011; 60, 7: 295-354.
5. Ceken F, et al. Electromagnetic Shielding Properties of Plain Knitted Fabrics Containing Conductive Yarns. *Journal of Engineered Fibers and Fabrics* 2012; 7, 4: 81-87.
6. Ozdemir H, Ozkurt A. The Effects of Fabric Structural Parameters on the Electromagnetic Shielding Effectiveness. *Tekstil* 2013; 62, 3-4: 134-144.
7. Ammari M, et al. Exposure to GSM 900 MHz Electromagnetic Fields Affects Cerebral Cytochrome Coxidase Activity. *Toxicology* 2008, 250: 75-74.
8. Sage C, Carpenter DO. *A Rationale for Biologically-based Exposure Standards for Low-Intensity Electromagnetic Radiation*. Prepared for the BioInitiative Working Group, July 2007. <http://www.slt.co/Downloads/News/1058/BioInitiativeReport2012-7.5%20Megs.pdf>
9. Shangcheng X, et al. Exposure to 1800 MHz Radiofrequency Radiation Induces Oxidative Damage to Mitochondrial DNA in Primary Cultured Neurons, *Brain Research* 1311, 2010, pp. 189-196.
10. Özen MS, et al. An Investigation of Electromagnetic Wave Absorption Potential of Woven Fabrics with Stainless Steel Wire. In: *RMUTP International Conference Textiles & Fashion* 2012, July 3-4, 2012, Bangkok, Thailand.
11. Sonehara M. et al. Development of an Electromagnetic Wave Shielding Textile by Electroless Ni-Based Alloy Plating, *IEEE Transactions on Magnetics*, 2009, Vol. 45, No. 10, pp. 4173-4175
12. Das A, et al. Effect of Various Parameters on Electromagnetic Shielding Effectiveness of Textile Fabrics. *Indian Journal of Fibers & Textile Research* 2009; 34: 144-148.
13. Sonehara M, et al. Preparation and Characterization of Nanofiber Nonwoven Textile for Electromagnetic Wave Shielding. *IEEE Transactions on Magnetics* 2008; 44, 11: 3107-3110.
14. Rau M, et al. The Study of the Electromagnetic Shielding Properties of a Textile Material with Amorphous Microwire. *Advances in Electrical and Computer Engineering* 2011; 11, 1: 17-22.
15. Malaric K. *EMI Protection for Communication Systems*. Ed. Artech House, 685 Canton Street, Norwood, MA 02062, Boston, USA, 2010.
16. Malaric K. *Protection of Radiocommunication Systems, Faculty of Electrical Engineering and Computing*. Ed. University of Zagreb, Croatia, 2005.

References

1. Duran D, Kadoglu H. A Research on Electromagnetic Shielding with Copper Core Yarns. *Tekstil ve Konfeksiyon* 2012; 4: 354-359.

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