TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Textile Engineering

Polypropylene melt-blown for electromagnetic shielding purposes

Master Thesis

Study programme:	N3106 Textile Engineering
Study branch:	Nonwoven and Nanomaterials
Author:	**B.Sc. Md Abu Sayed Mamun**
Thesis Supervisors:	Ing. Ondřej Novák, Ph.D. Department of Nonwovens and Nanofibrous materials

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Master Thesis Assignment Form

Polypropylene melt-blown for electromagnetic shielding purposes

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Rules for Elaboration:

1. Carry out research on the topic of electromagnetic shielding. Focus especially on nonwoven materials and principles of measurement.
2. Prepare a series of samples with different conductivity methods.
3. Measure the surface and volume conductivity and the level of electromagnetic shielding.
4. Discuss obtained results and try to suggest possible optimizations.

Scope of Graphic Work: dle potřeby dokumentace
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[1] X. C. Tong, Advanced Materials and Design for Electromagnetic Interference Shielding, CRC Press, 2009.
[2] A. P. H. Hulle, "Textiles as EMI Shields," *journal of Textile Science & Engineering,* vol. 8, no. 2, 2018.
[3] M. S. J. C. Hong Xiao, "Electromagnetic Function Textiles," *Electromagnetic Materials,* 2019.
[4] B. S. D. R Perumalraj, "Electromagnetic Shielding Effectiveness of Doubled Copper-Cotton Yarn Woven Materials," *Fibres and Textiles in Eastern Europe,* vol. 18, no. 3, pp. 74-80, 2010.
[5] T. R., I. K., G. M., K. Ś. Stefan Brzeziński, "Textile materials for electromagnetic field shielding made with the use of nano- and micro-technology," *Central European Journal of Physics,* vol. 10, pp. 1190-1196, 2012.

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Liberec August 20, 2019

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Table of content

Abstract

As electric and electronic devices and accessories are increasing rapidly, transmitting electromagnetic power through the different frequency bands used on the markets, restricting and preventing electronic equipment from all sources of interference has become important. Shields are often used for insulation from a room, equipment, circuit, etc. Electromagnetic radiation sources externally or to avoid harmful internal electromagnetic energy emissions. One of the main issues with the introduction of electrical and electronic technology in the world is electromagnetic interference between devices. Different scientists and industrial enterprises were keenly interested in seeking solutions to this problem. Table sheets are traditionally considered to be the best electromagnetic shielding material, but they are expensive, heavy, flexible, and thermally expanded. However, the use of electronic and electrical equipment of textile items is appropriate because they are lightweight, versatile, and cheaper. Researchers have drawn attention to various solutions, including textile products and composite textiles these textile structures include flexibility and conformity. Face Unwanted electromagnetic emission in combination with the specific EMI source radiation or transmittal to the surrounding electrical system is electrical signals. This noise, coil parts, digital devices and long DC or AC cables can be caused by Electromagnets. At frequencies that can emit energy on radio frequency [1]. Ferromagnetic materials in mix with fibres and textiles end up being electrically conducive and effective in protecting from electromagnetic radiation. For electromagnetic shielding silver, Copper or stainless steel are best combined with staple or filament fibres. For different electromagnetic shielding fabric composite yarns made from mixing metal and textile fibres. It’s difficult to weave metallic yarns than the composite yarn. Conducting polymer composites can create better functionality. Moreover, metallic coating over nonwoven fabrics is cost-efficient for commercial use. This paper describes the study on developing metal coating over nonwoven fabric for electromagnetic shielding purposes.

Key words: electromagnetic shielding, nonwoven, copper, polypropylene, melt blown

Abstrakt

Protože se elektrické a elektronické přístroje a příslušenství rychle vyvíjejí, je důležité přenášet elektromagnetickou energii prostřednictvím různých frekvenčních pásem používaných na trzích, omezovat a zabránit elektronickým zařízením ze všech zdrojů rušení. Štíty se často používají k izolaci z místnosti, zařízení, obvodu atd. Zdroje elektromagnetického záření externě nebo k zamezení škodlivých vnitřních emisí elektromagnetické energie. Jedním z hlavních problémů se zavedením elektrické a elektronické technologie ve světě je elektromagnetické rušení mezi zařízeními. Různí vědci a průmyslové podniky se intenzivně zajímali o řešení tohoto problému. Tabule jsou tradičně považovány za nejlepší elektromagnetický stínící materiál, ale jsou drahé, těžké, flexibilní a tepelně expandované. Používání elektronických a elektrických zařízení textilních předmětů je však vhodné, protože jsou lehké, univerzální a levnější. Vědci upozornili na různá řešení, včetně textilních výrobků a kompozitních textilií, které tyto textilní struktury zahrnují flexibilitu a shodu. Nežádoucí elektromagnetická emise v kombinaci se specifickým zdrojem záření EMI nebo přenos do okolního elektrického systému jsou elektrické signály. Tento šum, části cívek, digitální zařízení a dlouhé kabely stejnosměrného nebo střídavého proudu mohou být způsobeny elektromagnety. Při frekvencích, které mohou vysílat energii na rádiové frekvenci [1]. Feromagnetické materiály ve směsi s vlákny a textiliemi jsou nakonec elektricky vodivé a účinné při ochraně před elektromagnetickým zářením. Pro elektromagnetické stínění se stříbro, měď nebo nerezová ocel nejlépe kombinují se střižovými nebo filamentovými vlákny. Pro různé elektromagnetické stínění tkaniny kompozitní příze vyrobené ze směšování kovových a textilních vláken. Tkaní kovových přízí je více obtížné než kompozitních přízí. Vedení polymerních kompozitů může vytvořit lepší funkčnost. Navíc je kovové potahování netkaných textilií pro komerční použití nákladově efektivní. Tato práce popisuje studii vývoje kovového povlaku na netkané textilii pro účely elektromagnetického stínění.

Klíčová slova: elektromagnetické stínění, netkaná textilie, měď, polypropylen, foukané taveniny

1 Introduction

A spark gap can generate a spectral-rich electromagnetic wave which can cause interference in electronic devices. It is dangerous to the living organism, too. Because of the molecule vibration when the electromagnetic (EM) comes into contact with the body the start heating. It stops the regeneration of human body RNA & DNA. Figure 1 shows the impact on human body. It may have different sources, such as lightning, relays, fluorescent lights, and so on, which can be rich spectral content and conflict with the devices. High-frequency waves often pose extreme health risks. Electromagnetic waves tend to be a concern for device designers. The electromagnetic wave defence is complex and the sources are various. The quality of EMI depends on the type of source, material used and other material. EMI depends on the type of source. The EMI barrier is built of rigid and heavy nonmagnetic conductive materials or ferromagnetic materials. More lightweight and functional are the barriers produced by polymer composites or conductive fabrics. More efficient are metallic coatings, conductive polymers, and conductive filler materials. Because of their low cost, nonwovens, in particular polypropylene nonwovens, are often used in technical applications.

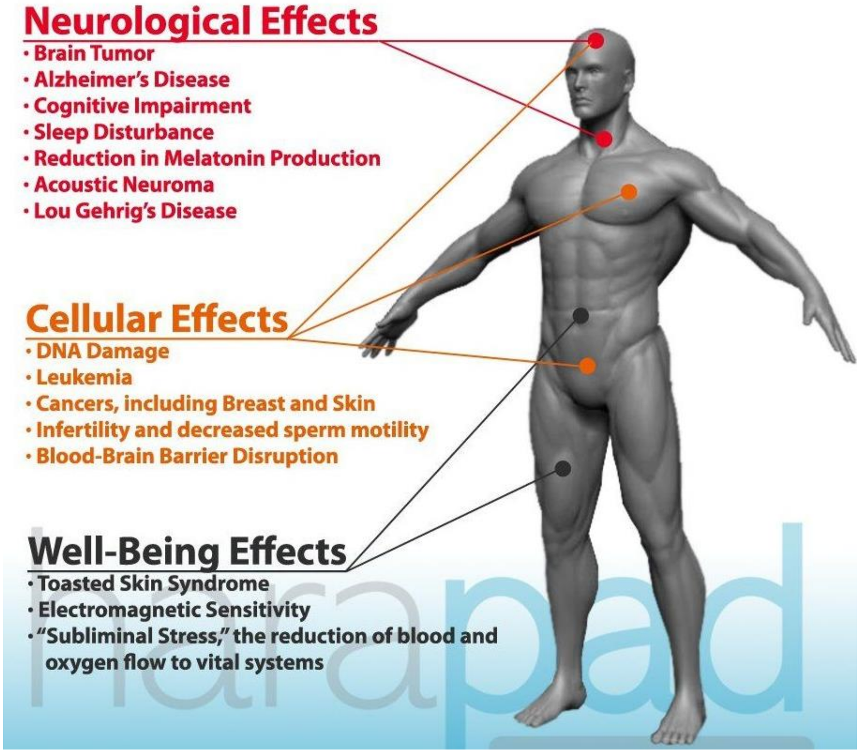


Figure 1: Electromagnetic effect on human body [2]

Multilayer Fabrics are also effective for electromagnetic wave attenuation. This study correlated with textile application in the EMI shielding process [2].

2 Electro Magnetic shielding

The purpose of the defence is to restrict radiated energy to the limits of a certain area or to prevent the risk of radiation reaching a specific region. Shields may be formed as partitions and frames, cable shields, and connector shields. Solid, unsolid, and tissue types, as is used on cables, include shield types. In both cases, the protective efficiency may be described by the amount of decibels in which, due to its installation, the shield decreases field strength. The usefulness of defence appears to rely not just on the substance whose shield, its thickness but also its size, the distance from source to the shield, and the quantity and shape of any discontinuities in the shield. The first step in a shield design is to define the undesirable field amount that is appropriate at a time without shielding, the difference is the required shielding efficiency [1].

Electronics and cables with conductive or magnetic materials that protect against input or output electromagnetic frequency (EMF) emissions (EMF) are the activities of electromagnetic shielding. Mixed electric and magnetic fields are produced by electromechanical radiation. The electric field causes forces inside the conductor on the carriers (i.e. electrons). When an electric field has been added to the ideal conductor surface, the driver may generate a current that induces load displacement and cancel the current inside the added region. Likewise, numerous magnetic fields generate eddy currents which cancel the magnetic field applied. It transmits electric energy from the top of the conductor. Internal fields reside, and external fields carry on outside. (The conductor does not respond to static magnetic fields unless a conductor shifts with the magnetic field.)

EM shielding is done for many reasons. The general purpose is to avoid electromagnetic interference (EMI) affecting sensitive electronics [3].

2.1 Principles

The couples of electric field E and magnetic field H produce an electromagnetic field. The magnetic field is generated from the moving charge and the electric field is generated from voltage difference. Electromagnetic radiation consists of waves it’s categorized according to the frequency of the wave. Figure 2 depicts the electromagnetic spectrum range.

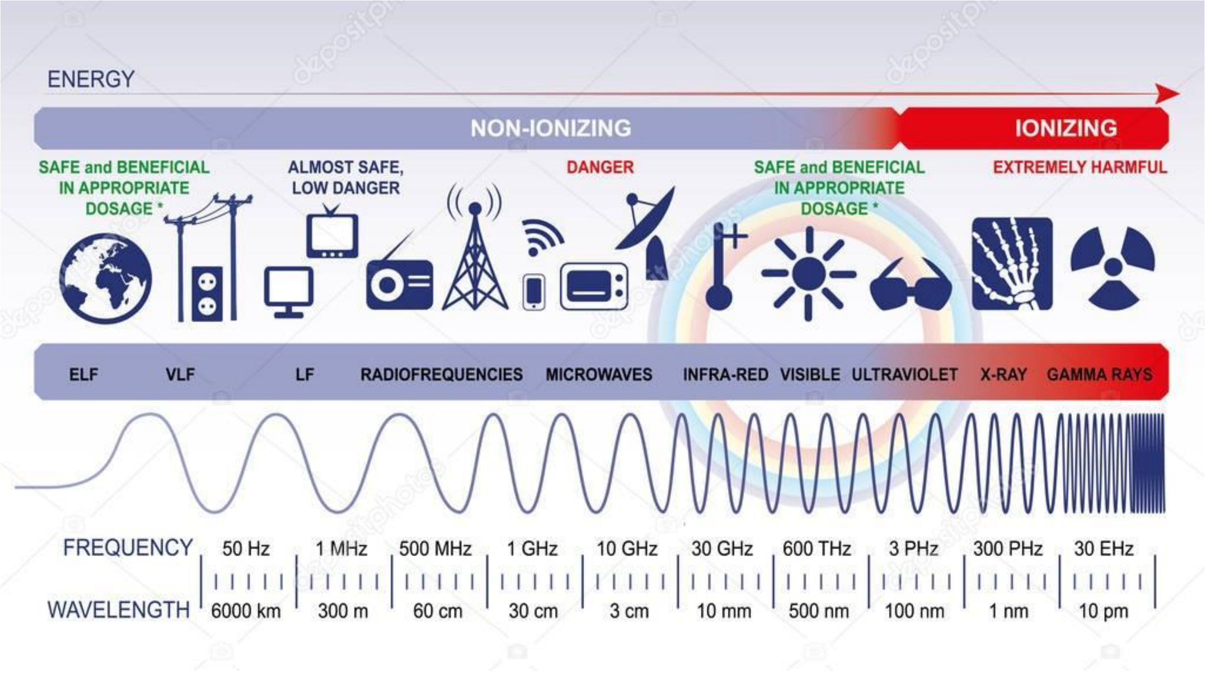


Figure 2: electromagnetic spectrum [4]

The EMI shielding consists of two region

- Near field region
- Far-field region

The degree of attenuation depends on the reflections from the surface of the shield. The shield blocks other electric waves and other surface reflections. For multiple reflections, a large surface or interface region in the shield is crucial. As an example, Foam can provide wider surfaces and fillers may have broader contact areas for composites. [3]. If the distance between the reflective surfaces is larger than the skin depth, the loss due to reflection may be ignored, which defined as equation 1.

$$\delta = \frac{I}{\sqrt{\pi f \mu \sigma}} \tag{1}$$

Here, δ = skin depth (mm)

ω = angular (radian) frequency

μ = material permeability

σ = material conductivity

f = frequency (hertz)

μ_0 Is the absolute permeability.

$$\mu_0 = 4\pi 10^{-7}$$

[5]

When the wave penetrates the conductor, the strength of the wave reduces exponentially.

The efficiency of electromagnetic shields is referred to as shielding effectiveness SE [dB]

$$SE = 10 \log \frac{\mathrm{P}_2}{\mathrm{P}_1} \tag{2}$$

Here, $P_2$is the power obtained with the barrier P_1 is the power obtained without the barrier.

$$SE = 20 \log 10 \frac{E_i}{E_t} = 20 \log 10 \frac{H_i}{H_t} = 10 \log \frac{P_i}{P_t} = \mathrm{R} + \mathrm{A} + \mathrm{B} \tag{3}$$

Here, $\mathrm{E_i}$ demonstrates electric field intensity.

$\mathrm{H_i}$ Demonstrates Magnetic field intensity.

$\mathrm{P_i}$ Represents the Power without substance being examined.

$\mathrm{E_t}$,$\mathrm{H_t}$,$\mathrm{P_t}$ are the same physical quantities of the substance being examined.

B demonstrates multiple reflections, R represents the reflection loss, and A illustrates the absorption loss.

For a metalized fabric SE can be calculated from the equation below:

$$\mathrm{SE} = \mathrm{A_a} + \mathrm{B_a} + \mathrm{R_a} + \mathrm{K_1} + \mathrm{K_2} + \mathrm{K_3} \tag{4}$$

A_a is the reduction of a certain discontinuity, R_a is the aperture of a substance for the single reduction of reflection, B_a is the multiple correction coefficient for the reflection, K_1 is the correction coefficient to compensate for the amount of identical discontinuities, K_2 is the low-frequency correction coefficient to compensate for the depth of the skin and K_3 is the correction coefficient to account for the coupling between the adjacent holes. [6].

Term A_a

Suppose the accident wave is under cuts,

$\mathrm{f_c}$ = c / α. A rectangular gap has two times the maximum duration of the cut off wavelength.

A_a = 27.3 dB (d / W)

Where, d- Fabric opening depth in cm,

W- Opening width in cm, perpendicular to the E-field,

Term R_a

The concept of opening single reflection loss depends on the incident wave impedance and the form of the fabric opening. The term is defined By equal treatment

$R_a = 20 \log_{10}[(1 + 4K^2) / 4\mathrm{K}]$ dB

Where,

K = j 6.69 × 10^{-5}f W for plane waves and rectangular apertures f - Frequency in MHz

Term B_a

The following equation provides the multiple reflection correction expression

$B_a = 20\ \log_{10}[1 - (K - 1)^2\ /\ (K + 1)^2\ \times\ 10^{-Aa/10}$ dB, for $A_a < 15$ dB

Term K_1

The correction expression for the amount of discontinuities is determined by a large distance to the opening distance.

$K_1 = -10\ \log_{10}$ an dB, r >> W, r >> D

Where: where: where:

A-area of each fabric hole (sq. cm)

N-number of holes / sq. cm of fabric.

Term K_2.

When the skin depth adjustment is the same as the copper wire width or thickness between the gaps at low frequencies, defence performance is decreased. The analytical framework has been established for the word skin depth correction Equation [1].

Reducing either the E-field or H-field can reduce the emissions of EMI energy and is the basis for EMI control with the following suppression techniques:

-- Reduce the voltage and current drive levels of the EMI source.

-- Include differential mode filters and standard mode for high-speed signals or use balanced differential pairs for monitoring EMI emissions from signal lines, antenna routes, power cables, and even ground connections from sensitive equipment.

-- Reduce the combination of EMI power between modules, circuits, or devices having some reciprocal impedance in which the currents or voltages of one circuit may cause other currents or voltages. The shared impedance can be capacitive, inductive, or mixed.

-Reduce and/or shield emission from any form of opening in equipment enclosure; ventilation, entry, wire, or meter holes; doors and hatches around the sides, drawers, and panels; improper joints in enclosures.

-EMI shielding is also the best protection against EMC and an effective way of addressing EMI issues.

More generally, the efficiency of EMI control and the implementation of an EMC-compliant device such as blinding, gasketing, grounding, filtering, decoupling, isolation and separation, the impedance of the circuit, interconnect design and proper PCB layout can involve multiple deletion or blinding techniques. EMI shielding can be minimized by proper electronic design according to system complexity, operating speed, and the EMC requirement [7].

2.2 Electromagnetic properties of textile materials

Textiles provide various raw fibre resources used in textiles and various goods processed from textile fibres. Textile materials vary from traditional engineering materials, textile materials are typically flexible, simple to change their structure and generally lightweight, characteristics which are primarily attributable to construction material defects. Textile fabrics are naturally capable of holding electrical charges. Electrifiability means a clothing's ability to produce and maintain a substantial force electrostatic field for a very long time. The interest in investigating the electrical properties of the fibres has been developed by using fibres as insulating materials. Earlier, the methods of resistance and efficiency were used in instruments to assess the moisture content and fibre assembly irregularity. Conductive textile applications are increasingly numerous in technological fields and cater for functions such as heating, conduction, or EMI shielding, prevention of build-up of static charges. Earlier, devices used the resistance and efficiency methods to determine the moisture content and irregularity of the fibre assembly. In technical fields, conductive textile applications are increasingly numerous and cater for functions such as heating, conduction, or EMI shielding, prevention of static charge build-ups. In many practical applications such as electromagnetic shielding, electrostatic disposal, conveyor belts, aviation/space suits, dry filtration, carpets etc. low and restrictive electrical conduction is required. For this purpose different products are needed with relatively good electrical conductivity. It can be done by the application of metal fillers or a coating with some agent [8].

2.2.1 Conductive properties of fibre

The electrical conductivity of synthetic fabrics shows relevant resistance. There are typically three depictions, basic volume resistance, density resistance and rising surface resistance.

In accordance with the law of resistance, the resistance of driver R is proportional to L the length of conductor, and inversely proportional to S transverse zone and related material properties. Which is,

$$R = \rho_V \cdot \frac{L}{S} \tag{5}$$

When ρV is the fundamental resistivity or volume resistance, its unit for measurement is Ω cm and its physical representation indicates the electrical conductivity of a material. For textile materials, the cross-sectional region or thickness cannot be readily measured. In the case of fibre material conductivity, we usually use mass specific resistance instead of the volume specific resistance ρV.

$$\rho_m = d.\ \rho V \tag{6}$$

Where πm is the mass specific resistance and unit for measurement is Ω cm / cm^2 the material density d is 1 g / cm^3. The real moisture component of the measurements is the fiber or the humidity levels of the air determines the electrical properties. The dried textile fibers are very badly conductive and resistant to specific masses are usually greater than 10. The relation between the moisture levels is estimated as M. textile materials have a mass-specific resistance between 30 and 90 percent of relative humidity.

$$\lg\rho_m = -n\lg M + \lg K \tag{7}$$

Where n and K are constants for experimentation. Table 1 displays textile materials mass specific resistance.

Type of fibre	$\lg\rho_m$	N	lgK
Cotton	6.8	11.4	16.6
Ramie	7.5	12.3	18.6
Silk	9.8	17.6	26.6
Wool	8.4	15.8	26.2
Washed wool	9.9	14.7	26.6
Viscose fibre	7	11.6	19.6
Acetate fibre	11.7	10.6	20.1
Acrylic	8.7	-	-
polyester	8	-	-

Table 1: Textile materials mass specific resistance [9]

2.2.2 Antistatic property

An antistatic agent is a chemical used to treat materials or their surfaces to reduce or remove static electricity accumulation. An antistatic agent is a chemical used to treat materials or their surfaces to reduce or remove static electricity accumulation. [10] The specific resistance of dielectric materials is generally high, especially for low hygroscopic synthetic fibres, including polyester and acrylic fibres. The mass variable tolerance is high or low under normal ambient conditions. Touch and Friction in textile manufacturing tend to cause a transfer of charge between fibres or between fibres and machine components yet electricity generation is static. Static electricity during the manufacturing process is going to cause fibre hairiness, increased hairiness, winding filament process, breakage, etc. Static electricity can affect Fabric during the cycle of taking. Although static energy causes many hazards during textile processing, certain machinery for transportation, such as electrospinning and electrostatic flocking may often gain from the electrostatic properties of textiles. The dielectric constant of specific fibres is shown in Table 2.

Fibre	Di electric constant (ε)
Cotton	18
Wool	5.5
Viscose fibre	8.4
Viscose wire	15
Acetate staple fibre	3.5

Acrylic staple fibre	2.8
Acetate	4
Nylon staple fibre	3.7
Nylon yarn	4
Polyester staple fibre	4.2

Table 2: The dielectric constant of common fibres [9].

2.3 Enhanced Electrical Conductivity of Fabrics

Specific strategies to improve the selected properties of textile fabrics provide the embedment of related non-textile particles covering the surface with or inside the structure Particles through different techniques. the conventional fibres used in the Textiles are materials that are electrically insulated and added New textile use areas may have some conductivity Structures for topics such as anti-static and health-related Electromagnetic protection. The technically widely accepted Approach to increased textile fabric conductivity Inclusion of conductive stainless steel and copper wire The presence of metallic wires triggers fillers, but an increase in the thickness of the fabric acknowledged as a modification Surface resistance link. Therefore, conductive coating Polymers (CP) can contribute to the flow of textiles. Without any wiring being included in the whole Created. Some studies on textile fibre coating are available Conductive materials such as polyaniline (PANI) plates, Electrochemical polypyrene (PPy), polythiophen (PT), and chemical fibre-insulated polymerization Composite conductive fibres preparation by chemical or other means Material Electrochemical pathways. PANI contains these polymers the first inherently dispersible has been described Safe and stable conductive polymer in the atmosphere the terms. You can turn between them very quickly Forms of isolation and conductivity when acidic and the surroundings alkaline. It is both inexpensive and fairly costly Fast polymerization of chemicals and electronics Technical techniques The Cross copolymer or metal particles textile surfaces are expected the electrical conductivity to be good and certain magnetization is key elements for EMR protection Ownership [11]. We can increase the conductivity of textile fabrics in the following ways:

- Use copolymers such as polyaniline (PANI), polypyrene (PPy), polythiophen etc.
- Use metals such as zinc, copper, aluminium, etc.
- Choosing compatible textile fibres such as polyester, polyamide, polypropylene, etc.

2.3.1 Magnetic susceptibility

In electromagnetism, the magnetic susceptibility is a function of how often in an applied magnetic field a substance is magnetized. Mathematically, it is the magnetization M-ratio (magnetic moment per unit volume) to the magnetizing field strength H applied [12]. Common fibres are typically manufactured from polymer materials and is not conductive or nonmagnetic. Throughout the preparation process it is important to incorporate different methods for the functionalization of textile fabrics. Fibres, yarns, electromagnetic functionalisation, and the textiles can be made by spinning, weaving and finishing. Metal fibres are moderately elongated and weak toughness; therefore, they are not suitable for weaving alone. Metal fibres are mixed with fibre before spinning, or weave with normal fibre made yarn during weaving. It's also possible to spray the metal fibres on top of fabric surface. Fibres, yarns and materials are used for the coating. A surface region has been established for the fabric or thread that has no electromagnetic characteristics. It can be covered by an electrolysis board, electroplating, sprinkling magnetrons, or other techniques with metal or magnetic powder. Table 3 Typical fibre magnetic sensitivity.

Material	Magnetic susceptibility (χ)
Ethylene	-10.3 x 10^{-6}
Polypropylene	-10.1 x 10^{-6}
Fluorine	-47.8 x 10^{-6}
Polyester	-6.53 x 10^{-6}
Nylon	-9.55 x 10^{-6}

Table 3: The magnetic susceptibility of common fibre

[9]

3 Electromagnetically shielding use the textiles

3.1 Commercial Products

Commercial products are described here for application of electromagnetic radiation shielding fabric.

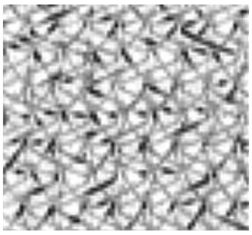
NaturaShield is a high performance, crisp-looking protecting texture with a delicate feel. Development innovation has made a fibre that has deep down the conductive components, with outward pure common cotton. The effect could be a skin-smooth fabric with an excellent feel and a 20-35 dB exposure of 100 MHz to 2.2 GHz with a performance frequency up to 10 GHz. Resistivity to the surface is 109 Ohm/sq. It’s perfect for bedding, clothing, wraps and most other applications requiring protecting without harsh metalized textures. It is a washable and dryable machine (cool), without losing protecting execution. It's cotton-like and customisable sews.

FlecTron X Is an extremely low surface resistivity, good quality nylon ripstop, plated copper fabric, with less than 0.1 ohm / sq. It is lightweight and adaptable. It is really tear-resistant and can be sliced and sewn much like traditional fabric. It has an enticing satin cover of copper. It can be used to shape secure walls in very effective areas or fabrics.

FlecTron®-N The air efficiency is as strong as FlecTron Copper, but the nickel tolerance is extremely prevalent. Nickel can induce sensitivities to the skin as it can be. Such tissue does not require skin touch to be organized. Defensive gloves are recommended for the handling of this fabric.

Ex-static™ Conducting texture is lightweight, rugged, conducting textures comprising 87% polyester, 13% gray BASF threads are specifically woven into the fabric in an elegant pattern, with a toughness of 105 ohms per square inch. This can be flexible and washable, like polyester fabric. Could be used as an e-field safety bedding, system coverings, clothing, covers, separators and everything else you 're going to design.

See-Through Conductive Fabric may be a stretchable transparent nylon work coated in silver. It will ensure that the microwaves and the radios with low strength (with power security with up to 67 dB at 1 Mhz and 33 dB at 1 GHz). < 5 Ohms / square Resistance.   This can be used as a bridge for bedsheet, a roofing panel, a broiler cover, a computer screen, a monitor, an amplification, a lighting device, a junction board, a vacuum cleaner, a headlight, a window cover, etc. It may also be used.



Phantom Fabric This conductive fabric is highly durable and sturdy and has excellent protection (~45 dB) and is almost transparent. This consists of copper-coated polyester job and has 90 cords per inch. It permits for glowing entrance and circulation of air. For protected dress, caps, bedding, or wraps it makes a culminate lining. Cover dividers, show screens and LED's for electric field protecting. This will be utilized over tablets, microwave stoves for tv, clock/radios, and most machines.

High-Quality Silver Work fabric can be utilized in a mesh fabric for ideal shielding efficiency. Resistivity to the surface is < 0.5 Ohm / sq. The viability of the protection from 30 MHz to 3 GHz is > 60dB. The electronics can be covered over a large range of temperatures from -30 ° to 90 ° C. making draperies, tents, closets, cell phone covers, and more. This will too be utilized in healthcare applications

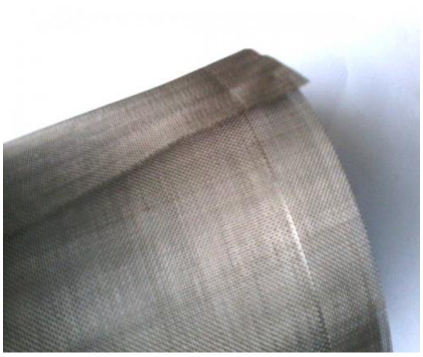
Shieldit ® Super is built on preferred grade raw nylon which is lined with exceptional protection, plates of tin and copper and is instead treated with conductive acrylic on one side, less than 0.1 Ohm / sq. Super is cantered on a low level erosion. Therefore, the polyethylene boundary cement is hot melted (203 ° -338 ° F) on the other side (for a wonderful intensity to moist, wash ability. This can be pressed or rolled onto cloth, wood, glass or paper and at this stage it can be dried by scrubbing the plume to dry. Like conventional texture, it can moreover be cut and sewn.

ZELT Texture is a plain-weaved tin / copper cloth nylon that offers the overall average fabric protection of 80 dB of 30 MHz to 1 GHz. Good care to cut and bind, as it doesn't seem distracting with the most secure textiles. It can be utilize in window ornamentation, bedding, wall cupboards, sheathing iron, etc.

Stretch Conductive Fabric Stretch Conductive Fabric is a 92 percent Nylon 8 percent Silver plated therapeutic revision Dorlastan fabric offers the rare ability to stretch in either heading. It is also an excellent product for interaction with wires, elastic hats, boots, gloves or other garments. This is an antibacterial woven material. It can be used to render wraps or allotments for line holders and divisors. May be irritated, co-ordinate touch with the skin [13].

Copper-Nickel coated polyester fabric the line has the potential to cover each fibre with a nickel-like coating that's safe against corrosion and contains solid protecting esteem. There are right now accessible metal-coated textures and cloth materials of diverse shapes. There are right now accessible metal coated textures and cloth materials of diverse shapes. The line permits for electrical conductivity values to be gotten from 100 milliohms squared and up. Tall erosion resistance, due to need of copper Stability of the significance of shallow resistance Conductivity resistance indeed beneath monotonous mechanical or rough movement and visit twisting. Good assurance from low frequencies of the attractive field and from those of up to 18 GHz Healthy mechanical steadiness and tear-resistance. The advancement of textures as structures and strands making up their electrical and mechanical effectiveness gives trust for item creation beyond those as of now established [14].

Silver fibre Non-woven fabric with a shielding range 10 MHz to 3Ghz. Surface conductivity lesser than 10hm/inch. Consist of 100% silver coated nylon. It can be used for RFID Blocking, anti-radiation, antibacterial applications. Machine washable with cold water lesser 30 cent-degree [15].



Copper-Nickel coated Nonwoven fabric Lightweight and long service life. Extremely electrically drivable. Very fast to cut and to stitch fabric. Not at all like conventional metalized fabrics, have the forms of coating, utilized to store metals into the fabrics, given an impenetrable bond that cannot be broken. In reality, restrictive metalizing innovation ties the metal to tissue at atomic level, basically melding the tissue to the metal. The coming about bond offers unequalled sturdiness indeed beneath ceaselessly flexing, twisting conditions, Extending or murmuring. No other metalized texture is stronger and our conductive textures offer tried, steady indeed within the most challenging situations due to the predominant holding innovation. The conductive non-woven texture is made of non-woven polyester as a substratum and is secured with a coating of nickel and copper. RFID / RF boundary. Remove protection against the EMF / EMI. Conductive fabric secures against flag / Wi-Fi radiation / HF. Preserves electronic frameworks working validity within the case of an EMP or a CME. Use of protecting gaskets for EMI / RFI, protected walled in areas, covers, etc. Can moreover be utilized for protecting rooms & stands. Viable cell tower protecting, remote switches, microwave signals, smart meters, security frameworks, radars etc. Convenient scanners for encryption are blocked. It can be utilized to form a pocket for the mobile phone, smart key or anything that acknowledges or transmits such signals, Establishing mats, components with protecting, pockets, handbag. Blocking EMI / EMF and securing hardware from EMP. High-shielding conductive texture to piece RF signals like cell phones, Bluetooth, Wi-Fi, GPS and others [16].

3.2 Composite yarn fabrics

The conductive yarn can be produced by mixing metallic fibres For example, staple fabrics, steel, copper, nickel, zinc, aluminium etc. Core covered or plied yarn can be manufactured by twisting metallic fibres with either staple fibre or filament. By hollow spindle twisting composite yarn can produced where the metallic wire will be the core material and the textile fibres will wrapping the metallic wire. Carbon, aramid and other elite fibres can also use. The composite yarns will have a lot of features other than EMI shielding. Core spun yarn with a metal wire as the sheath and textile fibres. By using Comingling and air covering we also can produce conductive yarn. Figure 4 shows the structure of core spun yarn.

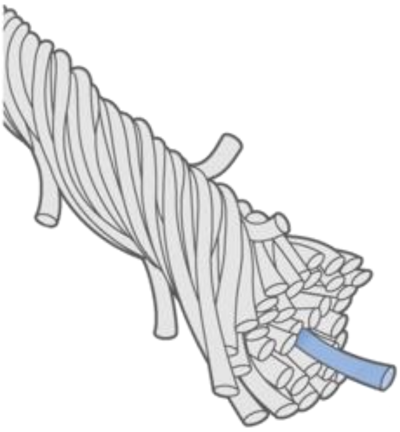


Figure 3: Core spun yarn [61]

Ply yarn can consisting of metallic, textile fibres can deliver under various twists, count. Various parameters during the manufacturing process, the helix or tightness of the twist can upgrade EMI shielding properties. Such as Core spun yarn show higher EMSE than plied yarn. With higher metallic content the EMSE increased. Core spun yarn can be produced by Ring, Rotor, Friction, Air jet spinning. It is also possible to Electrospun Conductive Nanofiber Yarn. With the conductive composite yarn, various types of fabrics with different construction can be made according to the required function of the textiles. Woven fabric can be produced by jacquard, shuttleless handloom or by other modern handlooms. Both warp and weft knitting can be possible, it can give varying functional properties than woven fabrics. It is also possible to use coating polymer, though it will give less protection. But it can be applied for low-cost commercial products. Different properties of the fabrics such as warp density, gsm, loop length, abrasion resistance, etc. can change the performance of the end product. Such as fabric with 1/1 plain construction has better EMSE than 2/2 twill weave because of the better electrical arrangement. Tight mesh fabrics and high conductive electric yarns have high reflectance coefficients [17] [18] [6].

Below will describe some research articles about composite yarn fabric.

3.2.1 Copper/glass fibre knitted fabric reinforced polypropylene composites

The matrix material and glass fibres kneaded for reinforcement is thermoplastic polymers polypropylene. Copper wires or staple threads are used as fillers for having the desired EMSE properties for the composite content. Copper was chosen due to its superior electrical characteristics in comparison to other metals. This is why numerous steps have been taken to improve conductive knitted composites. The following parts also describe the impact of the knitted composites, the density of the seam and the yarn composition on the EMSE characteristics. Glass fibers were used as supporting cables and copper cables as a conductive step of the composite content. It is often challenging to thread the strong rigidity of both glass fibres and copper lines. The strong traction of these fabrics with the knitting needles also results in greater tension on skin, contributing to fractured nails and torn loops. The polypropylene membrane filters were used to cover glass fibre and copper wires to minimize frictions between the thread and the cutting surface so as to ensure the efficient spinning of fibres of glass and copper wire. This type of yarn is known as mixed yarn for development of core spun yarns, a hollow spindle spinning system was used. The unmingled fibre has three distinct components: the core thread, the fibre and the binding thread. As wrapping and manufactured fabric, the matrix of PP fibres is used. The main thread used is the copper conductive filler wires and/or glass fibre reinforcement. The manufacturing of uncommingled yarns has been found to be much simpler than production of glass or copper wires alone. Compared to the harm that happens alone, the glass of uncommingled yarn sustained comparatively low knitting injury. The lubrication of PP fibres wrapped around glass fibres and copper wires for unmixed yarns is essential. The adjustment in the knit shape, the steadiness of lines, and the longitudinal duration of yarns for spinning and filling will create a big difference in the amount of copper in the composite content. Promising knitted composite design for electromagnetic safety [19].

3.2.2 Conducting structures constructed from nanotube-coated polyester yarns of polypropylene / multiwall fibre

The use of conducting yarns does not make production complicated by multi-wall carbon nanotube conducting textiles and knitted fabrics, because weft threads are woven with Ped yarn. Polypropylene / Multi-Wall Carbon PET conductive yarn, highly torsional and flexible for the manufacture of conductive fabrics by means of a circular knitting machine, is required for optimum applications. Therefore, the conductive yarn becomes more delicate with an increasing speed of coiling. Consequently, the resulting conductive fabrics have less fabric density and greater pores. The application of composite polymer fillers or polymer composite yarns is considered to adversely affect the consistency and ductility of the material. Multi-wall polypropylene carbon nanotube runs over the surface of PET yarns with an extrusion method for manufacturing conductive yarns. This method ensures that a large number of core yarn can be loaded into a PP / Multi-Wall Carbon Nanotube Layer by single wall carbon nanotube. The core yarn picked is a PET fibre, with excellent mechanical properties and a great degree of softness for the conductive thread. Leading yarns may be turned into knitted or woven fabric or Woven fabric. The usage of conductive threads strengthens these conductive materials with durable mechanisms and its mechanical properties, electrical resistivity and EMI SE. The improvement of configuration and the amount of film layers of leading textiles significantly improves the efficiency of EMI protection [20].

3.2.3 Core spun yarn covering with polypropylene wire and polyamide Filaments.

The polypropylene filament was used as a matrix during the heat pressing process. The use of reinforcement material, copper and stainless steel wires as conductors in composite materials has led to the adoption of high-tensile polyamide filament. Since copper and stainless steel wires are extremely stiff, it is extremely difficult to weave or knit on conventional weaver or cutting machinery. The wrapping of PP filament, polyamide filament, and copper wire with steel wire minimized friction between yarn and eye-heddle surface and reed surface, which permit successful weaving in warp and wave direction of PP filament, copper, and creative steel wires. This research has been used to examine the characteristics of isotropic composites in flat-screen safety using a theoretical model. The protection efficiency of a single layer for general applications is barely satisfactory, and multi-layer fabrics provide adequate efficiency in flat wave protection [21].

3.2.4 Conductive Knitted- Fabric-Reinforced Thermoplastic Composites for Electromagnetic Shielding

Matrix type is polypropylene, and composite content is reinforced by glass fibres. Through inserting in conductive fillers stainless steel wire and staple thread, electromagnetic defensive properties of a composite substance are improved. Either glass fibres or stainless steel cables are blended very hard because of their extreme rigidity. Uncommingled yarns consisting of rubber wires, glass and polypropylene fibres are made using a hollow spindle spinning process to make knitting easier. Different types of knitted weave fabrics are made, and moulded using a compression moulding process into composite material. The yarn was made using a hollow spinning method to overcome rigidity of materials such as glass, stainless steel. The threads were developed into knitted woven fabric by means of a flat knitting machine. Depends on the volume of steel, the number of tines, its composition and the density of the knitted material, the electromagnet protection of the knitted material [22].

3.2.5 Copper core-woven fabrics

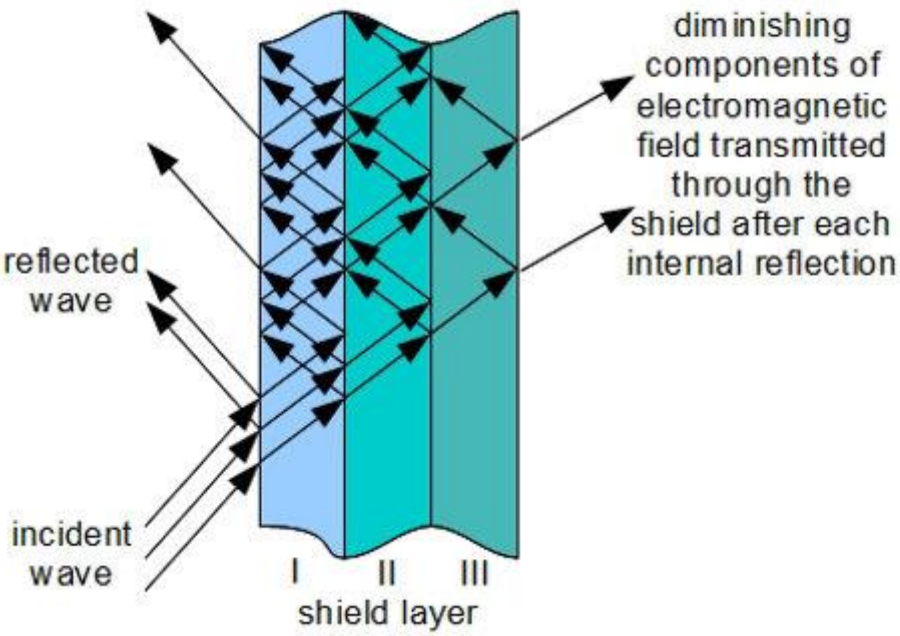
Copper wires are used to manufacture core yarn of copper and cotton fibre as sheath material as a conductive filler in this research. The multiple types were rendered by varying criteria of the fabric from the same central yarn of plain and twill fabric. The key characteristic of the leading textile is this attenuation. A particular material between the electromagnetic energy source and the receiver is responsible for the loss of reflectivity, absorption and multi reflection caused by an average of electromagnetic energy. Because copper is a robust material, it is bending resistant to polymeric textile content during weaving. The bending of the copper thread for an increase in diameter is harder, leading to open areas in the tissue, leading to reduced protection performance compared to other samples. These materials are suitable for the protection of domestic devices, FM / AM sets, wifi, mobile phones, laptops, sheltered buildings and other electronic devices [23].

3.2.6 Conductive fabrics made of polypropylene/multi-walled carbon nanotube coated polyester yarns

Polypropylene /multi-walled carbon nanotube coated polyethylene terephthalate (PET) yarns are made of conductive woven / strung materials. This work produces conductive fabric, whose electrical properties are stable, light weight and long life. In addition, the protection required by standard electronic devices is achieved in your EMI SE. As the base, PET yarns are used and fed into the coating yarn method. PET yarns are then treated by utilizing the polypropylene / multi-walls Carbon Nanotube Composite Pellets. Such research generates products with lasting electrical properties, and a lot of the multi-wall carbon nanotube is linked, a conducting network that permits carriers to move from one end to the other. This contributes to the power conductivity that absorbs electromagnetic wave energy and dissipates heat energy low weight and long life. However, the EMI SE meets the standard electronic devices for the level of protection needed. Founding and fed into the coating yarn method, PET yarns are used [24].

3.3 Nonwoven fabrics:

The nonwoven material has more functionality and usage differentiation than woven and knitted fabric. It can be developed by the use of conductive materials for spun bonded, hot-bonded or needle-stuck nonwovens during combat forming. Carbon and other conductive polymers have greater diffusion and poor optical qualities for metallic materials. It substance will create a finished product of EM safety sufficiency by adjusting the mixing ratio. Nonwoven clothing is conductive to be produced by coating metal objects with conductive materials. Non-woven fabrics with multiple layers also give a variety of shielding [17]. Figure 25 shows the multiple reflection scheme in a multi-layer shielding system. Figure 4 shows the multiple reflection scheme in a multi-layer shielding System.



[25]

Figure 4: Multiple reflection scheme in a multi-layer shielding System

3.3.1 Different studies on nonwoven fabric

In our research, we will work with nonwoven fabric. Below we will describe some research articles about nonwoven shielding fabric.

3.3.1.1 Needle-punched nonwoven fabrics from stainless steel

Staple fibre the electromagnetic protecting properties of needle-punched nonwoven fabrics made from stainless steel strands. The needle-punched nonwoven fabrics were fabricated utilizing staple stainless steel conductive strands, utilizing innovations and machines for carding and needle-punching. The coaxial transmission line gear was utilized to degree the retention, reflection, and EMSE values of the needle-punched nonwoven textures within the recurrence run of 15–3000 MHz It was found that pre-needled, twice-needled and thrice-needle-punched nonwoven textures made from staple stainless steel conductive strands in the test have the most noteworthy Electromagnetic shielding efficiency (EMSE) values of 22, 25, 27 dB separately within the 2100–2400 tall recurrence run. As the thickness of needle-punched nonwoven texture developed, the EMSE esteem of the needle-punched nonwoven texture too expanded. Thus the needle-punched nonwoven texture thickness was understood to be a very important parameter for EMSE. It was observed that EMSE values of pre-needed, twice-needled and thrice-needled nonwoven fabrics within the low-frequency range are 20, 17.5 and 13.5 dB respectively, especially for GSM 900 MHz cellular phone communication groups. The low recurrence EMSE values are determined as good grade shielding efficiency; the rate of electromagnetic protecting ranges from 99.0% to 90%. It is believed that since the distance travelled within the pre-needed bulky nonwoven fabric structure by an electromagnetic wave is further, the EMSE value of the pre-needled nonwoven fabric is also higher. In general, EMSE tests of woven and weaved fabric made from yarn with metal wire and calculated with coaxial transmission line equipment show that EMSE values show a diminishing drift as the frequency increments. On the other hand, the EMSE comes about from needle-punched nonwoven textures made from stainless steel conductive staple strands appear that, as the frequency increments, EMSE values appear a developing propensity beginning from a specific frequency. Whereas woven and sewn fabrics with centre yarns containing metal wire have higher EMSE values at the low frequency level, the EMSE values at the high frequency extend are higher for needle-punched nonwoven fabrics. The absorbance and reflectance behavior of pre-needed, twice-needled and thrice-needled nonwoven fabrics is indistinguishable. All nonwoven needle-punched textures have higher absorbance values and lower reflectance values at both low and high-frequency ranges. In middle-frequency ranges, on the other hand, all needle-punched nonwoven textures appeared a diminishing inclination for absorbance and expanded inclination for reflectance. It was in this manner caught on that the needle-punched nonwoven texture thickness was not a critical parameter for retention and reflection [26].

3.3.1.2 Nonwoven isolating panels of copper and recycled textiles.

In this study, the recycled nonwoven fabrics used in buildings and cars were generally applied as noise insulation material. Sample fabric under 2 kPa is 9.15 mm thick. The felt is a waste material consisting of different materials. The felt material. Two layers of recycled nonwoven textiles and a sheet of copper wires have been used to build insulation sheets with the electromagnetic shielding. Copper wires have been randomly positioned over a nonwoven fabric and another fabric has then been added to these layers. Model panels are about 20 mm thick in final thickness and 30x30 cm panels in dimensions. Four numerous insulation panels have been developed to examine magnetic shielding variations by adjusting the length and strength of the copper wires. For an expanded duration and/or strength of copper wires, the contact points of the cables often increase. Therefore, this may contribute to increased conductivity and alter the magnetic defence effect. Spatial frequency calculation is used for calculating the frequency of security of the nonwoven plate. Throughout the far-reaching regions of transmitters and receivers from the signal source, the primary tool is used to measure the signal attenuation on each side of nonwoven frames. A reflector, absorber, and an event attenuator is the conductive layer for non-woven plates. The strength we get lets us determine the defensive properties of the stand. It is known that cable length and volume differences affect the EM safety property through the analysis of the results. The optimum cable duration and volume will be established for potential experiments. Electromagnetic protection products can be manufactured in certain areas by this process. Throughout the electromagnetic protection systems, a broad bandwidth of 1125 to 292 5 MHz often has a large capacity. It is often a considerable value in relation to the usage a conductive fibre with its not complex and economical properties in other weaving and knitting processes. Thanks to its entirely recycled technologies it guarantees ambient pollution and EM emission protection [27].

3.3.1.3 Polypyrrole-coated Nonwovens for Electromagnetic Shielding

In general, metals or metal-coated materials show high electromagnetic properties the quality of shielding. The opening in the traditional Wall of a sheet of nickel-coated Nylon rip stop fabric over silver. Metallized fabrics cannot be used for electromagnetic wave absorption because they are shielded by surface reflection due their high conductivity. Innovative materials such as ICPs, can absorb and reflect electromagnetic waves and have some advantages over metallic materials. This research finds an electromagnetic using dual-TEM measurements Defence efficacy 37 dB for new PPy-coated manufactures updated. Values for textiles are comparable with those of science literature PPy and polyaniline coated. These Tests of goods (twill and nonwovens) commercially available have a long stability of the thermal. This reveals an interesting outcome The PPy nonwoven fabrics show the high absorption coefficient, the metallized fabric contrasted. We found the absorption a substantial share, up to 20% and up to 16% of insertion losses Overall effect of shielding. The efficiency of the defence of metallized textiles is mainly focused on energy reflection, but such a phenomenon under some circumstances Unable to be considered healthy, because it is important to absorb electromagnetic energy. PPy manufacturers reported their expanded capability Electromagnetic radiation absorption. We found an increase in addition of shielding effectiveness that can be precisely determined with the increased conductivity in the electrical shell. And we will conclude that, in electromagnetic interference applications Removal of, the value of the fairly PPy-coated fabrics Defence efficiency simple to monitor via surface changes Resistance to electricity [28].

3.3.1.4 Plasma Metallized textiles as Electromagnetic Fields Shields

Nonwovens, particularly nonwovens are polypropylene Used mainly because of professional applications they're cheap. Polypropylene metallisation cycle the textiles (nonwovens) were sputtered Zn metal goal (99.99%) mounted on metallic objectives WMK-100 TYPE magnetron weapon. The goals were Driven with a 12 kW capacity by the DPS. The power dissipated in the goal is in normal systems Checked by the current magnetron supply point. In Pulse and power were given in the case. The magnetron the pulse width of 10-0.2 has been modified. The reliability of reactive processes was under these conditions safely. The stability is achieved through the removal of Arch discharges unregulated. The sputtering cycle was achieved with an argon pressure range of 10-2 Pa do 10-1 Pa (5N). Complete 100 watts has been modified to 1 kW for the dissipated strength of the goal. The frequency of modulation is 5 KHz. The target distance – substratum was 10 cm. For the first time. Both deposited layers were power below 1 kW Characterized by strong adhesion, uniform to PP textiles Metallic colour and thickness. In the same way to compare the samples of nonwoven and conditions shall be sputtered Text. Pulse magnetron metallization of the PP material Sputtering enables the creation of metallic layers Unable to get by with very good adhesion Processes. Similar power rates have been suggested The DC-M mode, dispersed into the target, ensures higher Performance. Performance. It is linked to increased levels of deposition of the sheet of metal. The metal layers achieved were characterized by Effective PP adherence and quality defence (SE) About fifty db. 3D structure indicated the value of SE is influenced by textile surface. The value of the tested resistance has been confirmed the factor needed for obtaining but not conclusive Good attenuation. The second necessary condition the structure of a conducting net on the carrier is fulfilled Healthy contact surface at points of touch [29].

3.3.1.5 Needle punched nonwoven from conductive silver coated staple polyamide fibre

Nonwoven needle punched Structure of 1.7-dtex silver-coated staple has been developed Polyamide fibre punching line using Automatex Comprised of carding, lapper and punching with needles. Machine. Machine. EMSE, reflectance, surface absorption and the needle punched nonwoven resistivity property testing of fabric. The fineness of the silver coated staple polyamide fibre as raw material, 1.7 dtex is used. The fibres are originated from the French-based R-Stat SAS Firm. The key the Silver-coated staple polyamide properties of 1.7-dtex. The silver polyamide staple fibre was tested Used and held calorimetry differential scanning (DSC). Out of the TA Instruments research laboratory at DCS Q2000. For the first time. Tests, roughly 3.5 mg staple polyamide filled with silver Weighed fibre sample. The DSC check was performed 10 degrees C up to 300 degrees C per minute. Silver staple polyamide melting point 1.7-dtex. Fibre made of silver coated staple polyamide. Polyamide fibre particles. Gold will be stored Electrolyses plating of polyamide fibres. Fibre of polyamide is made very pure and conductive and antibacterial on the rubber, silver suffused. The metal layer allows synthetic fibres to maintain their primary original Apps. Apps. The fibres basic length is 40 mm. The 1.7-dtex silver-coated Polyamide staple fibre. Ground resistance of the punched needle nonwoven made of conducting Fine polyamide fibres silver-coated staple fabric. These low fabric area densities have been shown excellent EMSE value, in the high frequency range in particular. As the frequency rises, it was seen that Nonwoven needle-punched EMSE worth Silver-coated staple silk fabric the fibres of polyamide are continuously growing. The highest EMSE of the needle punched Nonwoven fabric made from 1.7-dtex staple polyamide fibres silver coated as 36.53 dB with 3000 MHz frequency. As frequency rises, it has been shown that Nonwoven needle-punched reflective qualities in the floating model are gradually declining, while floating absorption values increase wear. The highest importance of reflection has been established Low frequency range of 75.88% at 300 MHz the overall absorption amount was calculated as High frequency range: 71.84% in 2400 MHz [30].

3.3.1.6 Electromagnetic shielding fabrics obtained from carbon nanotube composite coatings

The use of conduction fillers or coatings in the making of films will also create conduction fabrics with conductive yarns. During their production processes, the fibre polymer is mixed with fillers, including melting or wet-dreaming; or a synthetic and a metallic yarn is twisting and wrapped with mechanical spinning. The yarn layer methods are mainly in situ polymerisation or sheeting. Through the application von conductive fillers or coating during yarn processing, small-diameter yarns can be created with highly versatile and lightweight materials these coating technologies are less frequently used due to their inherent complexity. Metals and carbon goods are the commonly common components for EM safety applications. Carbon Nano pipes were intensively studied in EM protective applications but were mainly used in the production, rather than for the production of EM safety products, of composite films for higher frequency applications. It is reported that nanoscale materials can fill the vacancy of the conducting network made up of conducting materials of various forms, thus creating a denser and more complete conducting network. In comparison, large measurable surface area and low density are identified in Nano-scale products. CNT’s have extraordinary technical, mechanical and electrical characteristics, as well as an incredibly high aspect ratio, often improve lead networking. This work reveals the possible sources of nanocomposite coating items for electronics and EM health applications [31].

3.3.1.7 Highly conductive copper-clad carbon fibre nonwoven fabrics

The shielding materials with desirable EMI protection efficiency and full shielding efficiency were lightweight, flexible pitch-based, pitch-based activated carbon fibres, which were produced as carbon frameworks with a high surface and matching thickness. Besides, an electrical plate containing a thin layer of copper uniformly clad in the fibre surface was mounted as a highly conductive functional component. The fabrics were also very resistant to pitting. Most practical and industrial applications can be incorporated with prepared protective materials [32].

3.3.1.8 Wave Shielding Textile by Electrolysis Ni-Based Alloy Plating

The authors developed a textile containing the metallic magnetic substance that was Ni-Fe coating. The fabric was lightweight, flexible, and breathable than the noise suppressor layer. The Ni-Fe is difficult to cover within the cloth and a higher electromagnetic wave shielding effect has then been hard to obtain. Thus, the metallic magnetic substance was coated within the textile using an electroless layer. This paper describes the development of an electro-free Ni-based platform electromagnetic wave safety textile. They used polyester as the raw material of the nonwoven fabric. In a measured frequency range, more than 99 percent of the SE of the electro-magnetic surface textile was sputtered by the electromagnetic wave shielding with a Ni-Based Alloy coating. The textile has the power to resist the electromagnetic wave. The properties are light, flexible and breathable. With this electromagnetic wave protection non-woven textile, materials for various electromagnetic wave protection applications are expected [33].

3.4 Conducting polymer composites:

For some application only EMI absorption may needed over reflection. That’s why the application that needed the reflection more especially military equipment’s for camouflage and stealth are favoured polymer composites. Polymers are ideal for absorption and reflection in the electrically conducted phase. It shows improved performance over metallic textiles and metal and carbon mixing. In situ polymerization of conduction polymers such as polyaniline and polypyrrole may be achieved for the conduction of polymer composites in textile substrates that can be woven, knitted or unwoven fabrics [17].

Following will describe some research article about conducting polymer composites

3.4.1 Conducting polymer composites reinforced E-glass fabric

There are large industries where fibrous materials are used as a substrate for polymers reinforcement. Polyaniline and polypyrrole as conduction polymers to have electronic conductivity in the e-glass structures, reinforced composites with varying composition and conductivity use poly-methyl methacrylate and polyvinyl chloride, which are industriously essential polymers, as a host matrix. EMI SE is being increased with improved conductivity and polymer conductivity thickness. The efficiency of the defence of metallic textiles derives mainly from the reflexion of energy, but under some circumstances, such an occurrence cannot be regarded as a successful one because it is important to absorb electromagnetic energy. The conducting polymer-coated fabrics benefit from a relative protective performance, which can be managed easily by adjusting electric resistance in surfaces. Therefore, the behaviour of materials based on polymers is much stronger than metallised surfaces as a protection for EMI [34].

3.4.2 Segregated polymer/carbon nanotube composite via selective microwave sintering

Separated structure design in leading composites is an important technique to achieve high conductivity at a relatively low filler load. But not all polymers will meet the requirements of the traditional hot compression process, and the inter-facial bonding between the polymer domains will still be weak. A clean and energy efficient approach was proposed based on selective microwave sintering to produce composites with a significantly enhanced electromagnetic interference blindness and mechanic performance, segregated polyethylene co-octane / carbon nanotube. Microwave selective sintering supplying the CPCs with the excellent EMI security properties, which could be suitable for the most polymers, is an optional technique for developing the superior segregated conductive network. Many researchers have recently successfully manufactured different EMI SE polymer composites of 60 dB. Integrating pores into POE phases may be an effective technique for further improving the EMI security efficiency of the separated polymer / CNT composite by inducing multiple reflections and dispersion [35].

3.4.3 Porous double-percolated structure in MWCNT/polymer-based composites

The most prospective alternatives to metal based materials in the fields of electromagnetic interference safety are expected to be porous conductive polymer composites, but they continue to face the need for poor results. A pore double percolated structure with a judicious mix of melting blends and Supercritical Carbon Dioxide foaming in the co-intensive polystypyl methacrylate / MWCNT method solves the problem. This research provides a new concept for the design of lightweight, high-performance EMI safety materials with enormous potential in electronics and aerospace applications. Supercritical carbon dioxide foaming was used to build an environmentally safe microcellular system. Therefore, composite foams that are light and highly leading are expected to be utilized as high-quality EMI defence materials and the easy and green method of production in the aviation and electronics industries in particular [36].

3.4.4 Carbon fibre-based polymer composite via creolization

This research consists of novel electro-conductive ceramic polymer composites that are produced by the incorporation into ethylene-vinyl acetate (EVA) of glass (GP), mica powder (MP), montmorillonite organic-modified (OMMT) and short carbon fibre (SCF). The EVA / GP / MP / OMMT / SCF had a high-temperature resistance capability and was fitted with an outstanding Electric Magnetic Interference shield before and after treatment at 1000 ° C. No research on the simultaneity achievement of excellent EMI safety efficiency and high temperature tolerance by ceramization for composite polymers can therefore be used as a guideline for the study of ceramic-based functional polymers. The high-temperature resistant characteristics of ceramic composites and their ceramics dependent on EMI safety [37].

3.4.5 In-situ, polymerized Nano fibre membrane, layer by layer assembly of Low-temperature

Layer-by - layer assembly is usually used for the accurate preparation of conductive material in step-by - step process. The basic idea is to construct a multi-layer system framework for effective EMI safety utilizing a layer auto assembly process. In this study, THIS proposed a simpler approach for designing and producing lightweight and lightweight composite films based on conductional polymer composites with a sandwich and core microstructure combined. The first move was to design PA films using traditional electrospinning methods PA films were fitted with PDA to improve their system usability. Finally, pyrroleum polymerization in situ was carried out at low temperatures. The PDA treatment and on-site polymers on pyrrols improved the PA nanofibers and the interfacial adhesion of PPy nanoparticles at low temperature and enabled more PPy nanoparticles to be deposited and decreased on PA nanofibers. A multi-layered system consisting of different conducting materials provides a modern mechanism to manufacture electromagnetic radiation mirrors, thereby increasing EMI safety performance [38].

3.4.6 Nanocomposites are preferentially dispersed in extremely stable polymers.

A highly robust ethylene-co-methyl acrylate /Ethylene octene copolymer/Multi-walled carbon nanotubes mixer with excellent EMI shielding performance combined by a simple solution mixing process, with good mechanical and heat properties. Non-uniform ethylene-co-methyl acrylate/ Ethylene-octene copolymer MWCNT delivery and pre-emptive ethylene-co-methyl acrylate and Multi-walled carbon nanotubes delivery. The ethylene-co-methyl acrylate/ Ethylene-octene copolymer blend system co-continuous morphology and preferential Multi-walled carbon nanotubes distribution has enabled a dual perccolated conducting system that increases power conductivity. This composite has a great potential for high-performance EMI shielding content due to its fast processing, high electric conductivity and superior EMI protective properties [39].

3.5 Metal coated fabrics and conductive fabrics:

The usage of own metallic materials as another method for rendering textiles more conductive. This has been achieved in several different forms. The techniques for the metal coating of textile layer include vacuum evaporation, chemical vapor deposition, electrolysis plating. The electrolysis technique can be a method for depositing metal layers on the surface of the feel which gives high conductivity. In fact, a finished method for the manufacture of EMI shielding packaging may require metal powder coating on plastics and textiles. Coated materials of clear metal particles have a strong surface on the cloth substrates. The finely metallic top layer chooses a high-frequency reflective nature, while the composite metal structure tends to affect low-frequency reflections. Metallic texture demonstrates effective wave assimilation by validly choosing the parameters of the material and leaving the pores of their form free, which may result in better EMI safety [17].

Following will describe some research article about metal coated fabric and conductive fabric.

3.5.1 Electroless plating of Cu–Ni–P alloy on PET fabrics

Electroless Cu – Ni – P alloy putting on fabrics made from polyethylene terephthalate (PET). The rate of deposition increased with increasing temperature, pH and concentration of nickel ions also increased. $K_4Fe(CN)_6$ may be applied to the solution to lower the deposition rate and compact the deposits. The application of $K_4Fe(CN)_6$ to the solution greatly decreased the surface resistance of alloy-coated fabrics considerably. Naturally, because of the high nickel content in the deposits, the Surface resistance of alloy coated fabrics has improved with increased levels of nickel ions in the solutions. $K_4Fe(CN)_6$ was applied to minimize the resistance of the surface substantially, due to the compacter and smoother deposits compared with absent $K_4Fe(CN)_6$. Leading materials with a high shielding quality [40].

3.5.2 Ultrasonic-assisted electroless deposition of Ag on PET fabric with low silver content

Electroless Ag plate for the development of conductive PET fabrics for low Silver EMI safety has been ultrasonically assisted. As a result of its specific deposition method, electroless coating may be a successful method of making metal coating materials in comparison with other silver coating techniques in textiles such as sputter coating, electron beams evaporations and chemical vapour deposition. The benefits of this approach include efficient metal deposition, outstanding conductivity, robust protection and application to diverse materials or non-components on almost any fabric. It can be manufactured at any stage of textiles' development, including yarn, stock, fabric or cloth. The ultrasonic assistant creates a particular agitation that results in a high-quality metallic coating resulting from the cavitation process on both substratum surfaces and air. The lightweight and continuous silver covering was manufactured successfully using the ultrasonic electroless positioning technique on a 3-mercaptopropiltriethoxysilane modified PET fabric. The silver coated materials have a protection efficiency in ranges from 0.01 MHz to 18 GHz of over 32 dB [41].

3.5.3 Hybrid PA6, 6 composite containing multiwall carbon nanotube and carbon black

Mono-filament yarn made of electromagnetic composite polymer conductive to the the drawbacks of previous electromagnetic fabrics. The monofilament produced is lightweight, corrosion resistant. Compared with metal filaments, the manufacturing process is different. This makes it an option for the development of personal electromagnetic protection clothes. This creates an electromagnetic shield for a manufactured monofilament. The synergy impact of Carbon Black and Multi-Wall Carbon Nanotubes on the compost distribution of Nano-fillers was created. The electrical conductivity was increased while the viscosity of the extrusion was appropriate. The electromagnetic shielding of the woven fabric sample with the conductive monofilament developed as the stuffer weft in the centre of the structure was also promising for personal protective clothing [42].

3.5.4 Electroless Cu-plated PET fabrics

Electric metal plating is a non-electrolytic solution deposition method that can be explained by a mixed theory of potential, a combination of oxidation and reduction processes. Such reactions are powered by the theoretical gap between the metal solution interface and the balance electrode theoretical for such half-reactions. In a traditional electro-less deposition system, copper reduction and formaldehyde oxidation are both a cathode and anodizing reaction. This deposition will proceed until a positive motor for all these reactions is available and the rate of reaction reduces by which these two reactions. A variety of literatures have taken the kinetics of electroless deposition on the different substrates into account in deciding the placement efficiency depending on certain materials and conditions of the solution. However, on the catalyzed surface, plating is initiated and the plating reaction is maintained by the catalytic nature of the plated metal surface itself, so that its properties depend very much on the pre-treatment method. The physical properties of the untreated PET include the tensile extension and the copper-plated tissue flag steadiness, but the tensile strength was slightly reduced. Due to various pre-treatment conditions, there are no major changes in physical properties. Due to the ductility and fragility of the copper coating on the PET surface, copper-coated PET frustration activity is achieved. Thicker Cu-coated fabrics are expected to exhibit higher EMISE. However, the results of this research have shown that the higher EMISE has been given by the fabrics with rather thinner Cu film. These findings demonstrate that the association between copper thickness and EMISE will not always be linear, and other important factors do exist [43].

3.5.5 Copper/modal fabric composites through electroless plating process

Modal fabric (MF) is a sort of regenerated cloth made from the beech trees' pulp. For clothing and household textiles like bedding, upholstery and towels it is very soft and common. MF is light and solid, it has excellent wicking properties and can inhibit bacterial growth within a given range. Electroless deposition of copper was developed on chemically grafted modal fabric (MF). The process relies on a simple coupling reaction to 3-aminopropyltrimethoxysilane grafting to MF. When comparison with the other two activation samples, the copper coating by silver activation has a smoother surface, higher electrical conductivity, and greater electromagnetic interference shielding efficacy. The Cu / MF composites are strong enough to be useful in applications where conductive materials are needed. The Cu / MF composites obtained can pass a Scotch-tape test for peel adhesion. Silver activation is ideal for producing conductive fabrics with higher electrical conductivity and better effectiveness in EMI shielding [44].

3.5.6 Cuprammonium fabric/polypyrrole/copper (CF/PPy/Cu) composite

Typical EMI materials are sheet metal, metal frame and metal foam. Often heavy and difficult to handle these materials. The metal materials do have their key shielding shape, which prevents their development at SE. Leading textiles were widely studied, as durable and lightweight protective materials were produced. The resulting composite CF / PPy / Cu is a sort of conductive textile. PPy and Cu had outstanding EM wave absorption and EM wave reflectivity properties as conductive materials. The CF substrates comprises of sustainable agriculture and forestry feed materials and, owing to their mechanical toughness, the integral resilience, biodegradability, low cost and environmental efficacy, constitute a fitting substitute for petroleum polymers. Each of these tests showed that the CF-based composite introduced for EMI safety is suitable. The study found that there could be higher SE (30.3–50.4 dB) as part of PPy films within CF / PPy / Cu. Coating methods could enhance the layer while having minimal effects on tensile elongation [45].

4 Methodology

4.1 Preparation of raw material

As a standard we followed Nonwoven polyester (PET) fabric. After copper coating it had a resistance of 70dB. Nonwoven polyester (PET) fibres are commonly used due to their flexibility, their strong mechanical characteristics and their ease of adjustment. PET is the thickness of 0.05–0.17 mm and 20-300 N per 5 cm wide in planar weight of 5–60 gm^{-2}. The fabric of 30gm^{-2}. The special structure enables it to be easily modified by various value-added methods, including surface metallization and other material lamination [62].

For this research work, we gathered different melt blown nonwoven fabric which was prepared. For raw material we choose polypropylene. Composites packed with particles electrically performed become ever more important for a variety of scientific applications for its special electric and dielectric characteristics. They can be used as smart and mechanical and chemical stability. Materials for constructing different electronic components. A number of their applications provide security against radiation, such as electromagnetic microwave absorbers Defence of interference from various devices to that end, Electro-free polymer matrix composites completed of composites of Particulate anisotropic like metal or carbon fibre. In the past, was implied. Polymers treated as polypyrrene (PPy) or, the latest substance class was Polyaniline (PANI). The material benefit is the versatility and beauty of technology the capacity to cover that can be used in the microwave system absorbers [46]. We compared the gsm and thickness of the fabric with standard sample 1 (s1) made from polyester. And select a nonwoven fabric with the optimized porosity. For testing we took 200x200 mm for each type of samples.

Sample number	Average Weight [g]	Average thickness [mm]	GSM [g/m2]	Density [kg/$m^{3]}$	Packing ratio [%]
S2	0.34	0.24	8.63	21.47	2.26
S3	0.40	0.19	10.17	25.31	2.66
S4	0.41	0.20	10.44	25.97	2.73
S1	0.44	0.07	11.24	27.96	2.94
S5	0.49	0.27	12.25	30.47	3.21
S6	0.64	0.66	16.19	40.27	4.24
S7	0.66	0.29	16.63	41.37	4.35
S8	0.79	0.36	19.75	49.13	5.17
S9	0.79	0.40	19.82	49.30	5.19
S10	0.85	0.40	21.29	52.96	5.57
S11	1.57	0.67	39.25	97.64	10.28
S12	2.31	0.96	57.84	143.89	15.15
S13	3.02	1.35	75.70	188.31	19.82
S14	3.08	1.33	77.13	191.87	20.20

Table 4: Sample fabric details

The sample S5 nonwoven fabric were selected by observing the density per meter square with the standard sample S1. The details of all fabrics described on the table 4.

4.2 Pressing

The right thickness secures the desired porosity of polyester made standard sample 1. To maintain the thickness of the s5 fabric with the s1 sample fabric, we used a pressing method. Used pressing machine of TUL laboratory has been shown in figure 5. The electromagnetic shield of the textile is increased with the GSM of the base material used for the production of conductive textiles. These fabric parameters are thus necessary as a shielding fabric for application. The pressing was done in 50 degree Celsius with an rpm of 2 meter per minute and 20 Kilo-Pascal pressure. By pressing we gained a thickness of 0.08mm similar to the s1 sample which has a thickness of 0.079mm.

Figure 5: Pressing machine

4.3 Stress strain measurement

We took 3 portion of the fabric and measured stress and strain. The relationship between stress and stress can be represented by a material stress-strain curve. The load is gradually applied to a test coupon and deformation is measured to determine stress and strain. Taking into account a bar of the original sectional cross-section, F-pulling forces are equal to the opposite in order to stress the bar. The material has a stress defined as the force ratio and axial elongation of the transversal area of the bar.

$$\sigma = F / A_0 \tag{1}$$

$$\epsilon = \frac{\Delta L}{L_0} \tag{2}$$

For ductile materials there will be a lot of tension required to start movement. As long as the distortion escapes the pinning, the stress is less. Normally the curve decreases marginally after the yield point. The first phase is the elastic linear region. The stress is proportional to the strain, it is the general rule of Hooke, and the slope obeys Young modulus. The material is only subjected to elastic deformation in this area. At the end of the point, the plastic deformation starts. This point is known as high yield point. The second step is the hardening field of strain. This region starts from the moment that the pressure exceeds the yield point to the maximum at the final force point. The necking area is the third level. In addition to the strength of the friction, a neck develops when the local intersection is much smaller than the average. The fracture ends in this region. The elongation of percent can be measured after fracture [47].

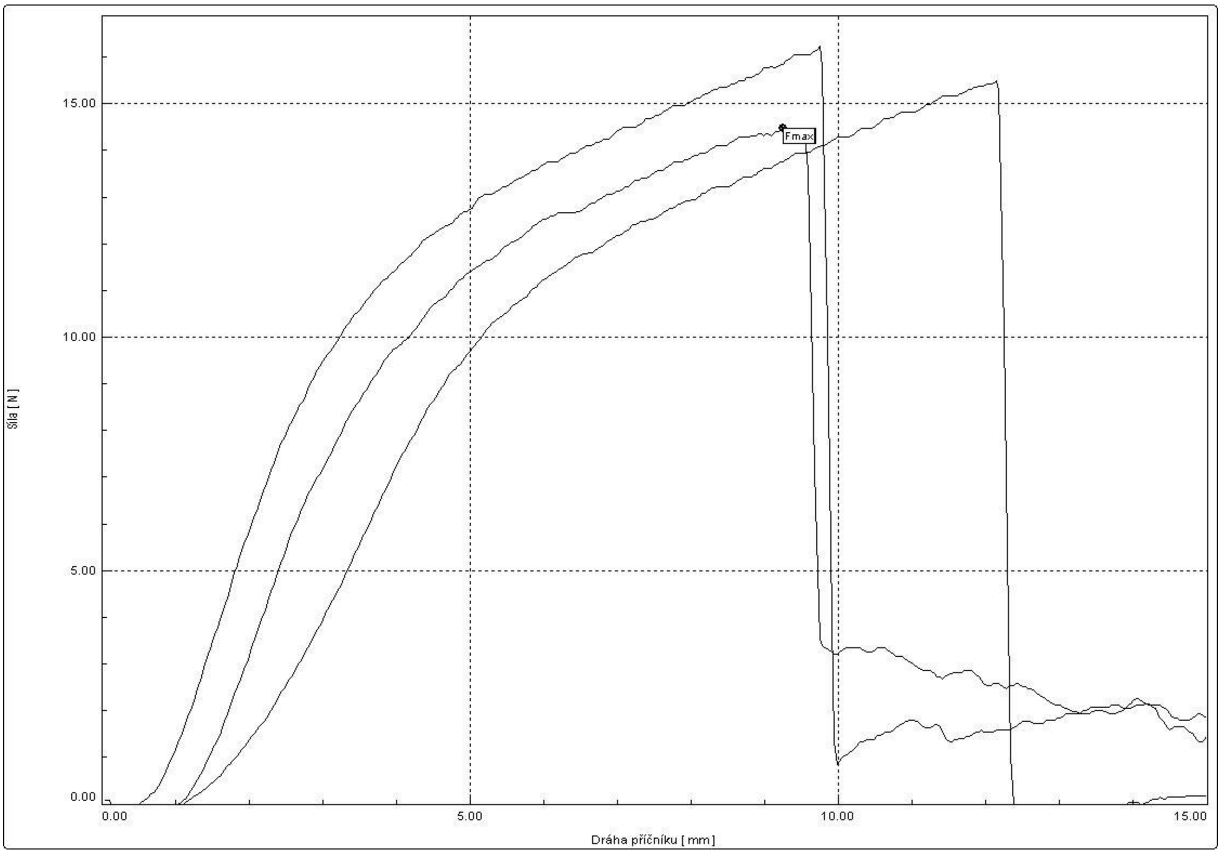


Figure 6: Sample S1 Cross Direction reading

Number of tests: 3

Sample S1 Cross Direction reading	Elongation max [%]	Force max [N]
Mean value of test	10.38	15.39
Standard deviation	1.55	0.89
Coefficient of variation	14.90	5.75
Minimum value	9.25	14.46
Maximum value	12.14	16.23

Table 5: sample S1 Cross Direction (CD) reading

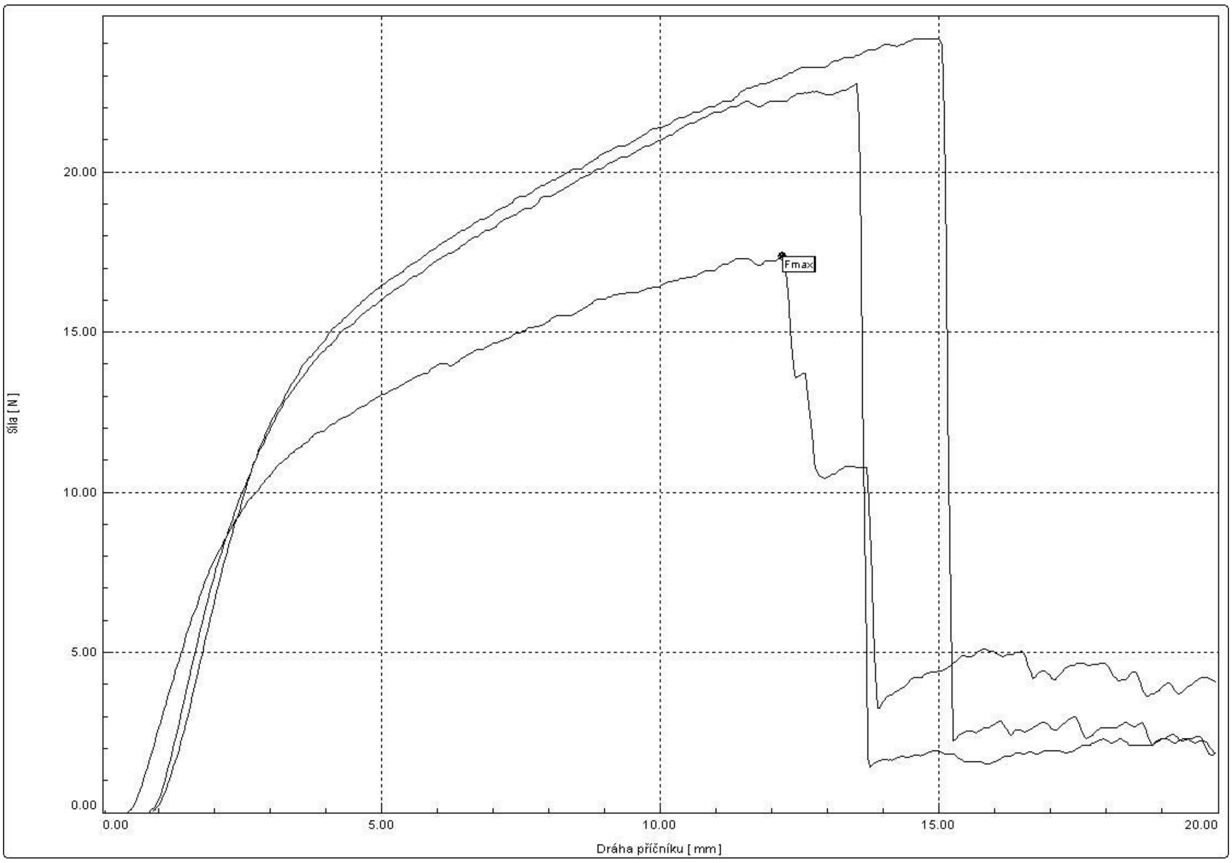


Figure 7: Sample S1 Length direction reading

Number of tests: 3

Sample S1 length Direction reading	Elongation max [%]	Force max [N]
Mean value of test	13.43	21.42
Standard deviation	1.18	3.59

Coefficient of variation	8.80	16.77
Minimum value	12.20	17.35
Maximum value	14.56	24.16

Table 7: sample S1 Length direction (LD) reading

Table 6: Sample S1 Length direction reading

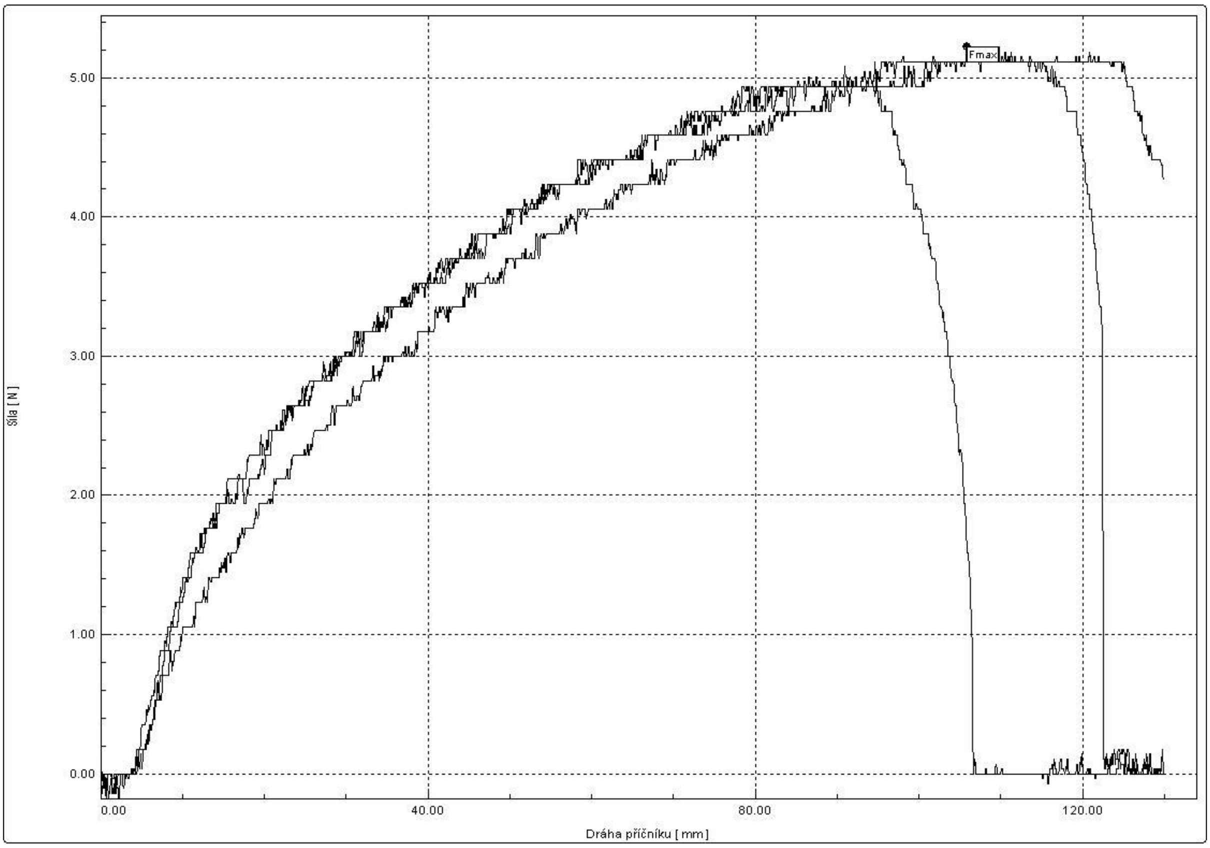


Figure 8: Sample S5 cross direction reading

Number of tests: 3

Sample S5 cross Direction reading	Elongation max [%]	Force max [N]
Mean value of test	102.67	5.16
Standard deviation	10.55	0.07
Coefficient of variation	10.27	1.42

Minimum value	90.91	5.08
Maximum value	111.28	5.22

Table 8: Sample S5 cross direction reading

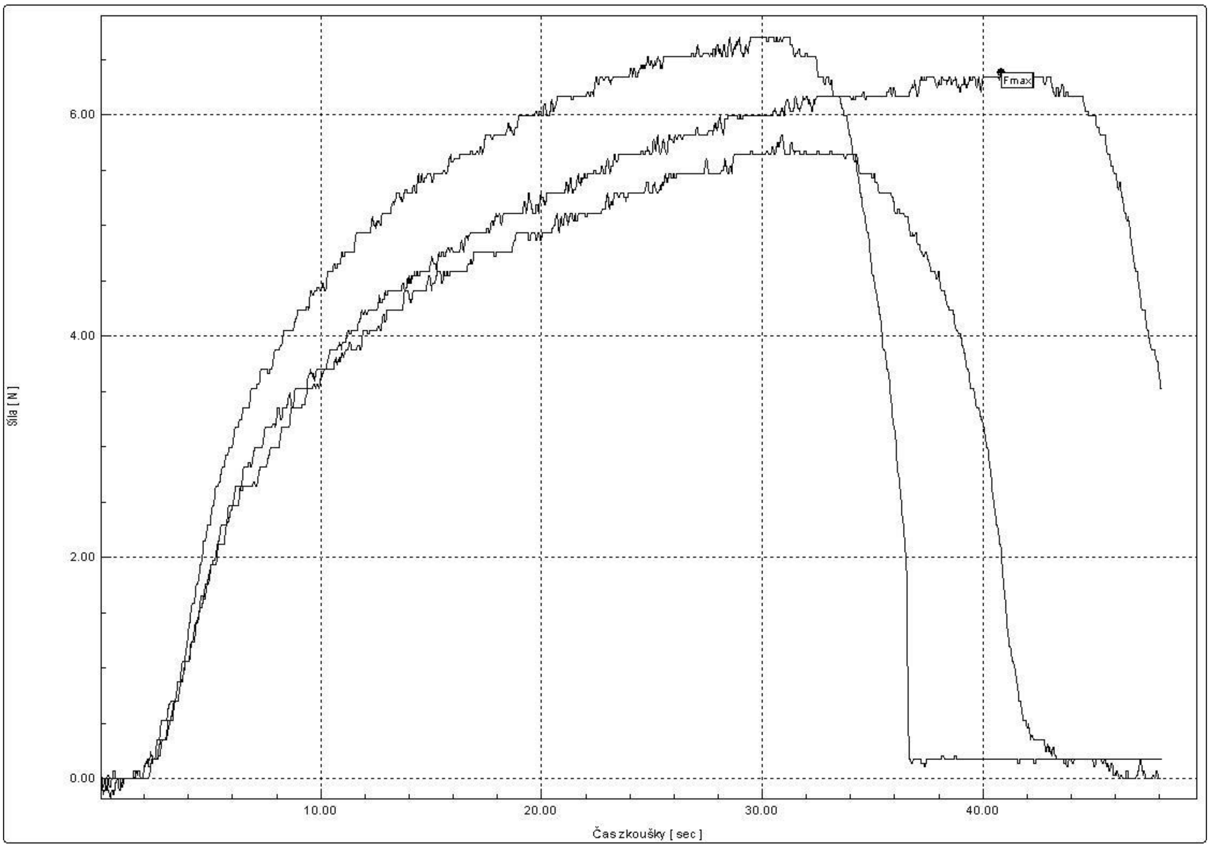


Figure 9: Sample S5 length direction reading

Number of tests: 3

Sample S5 length Direction reading	Elongation max [%]	Force max [N]
Mean value of test	55.46	6.30
Standard deviation	10.84	0.45
Coefficient of variation	19.55	7.09
Minimum value	47.36	5.82
Maximum value	67.78	6.70

Table 9: Sample S5 length direction reading

In table 9 below you can see the comparison between the mean values of samples.

Sample reading	Elongation max [%]	Force max [N]

S1 CD	10.38	15.39
S1 LD	13.43	21.42
S5 CD	102.67	5.16
S5 LD	55.46	6.30

Table 10: Comparison between the samples

From table 10 it's clearly seen that the S5 spun bond nonwoven fabric has more elasticity but lesser withstand of force than the polyester S1 sample, that we have followed as standard.

4.4 Choice of metal spray over fabric

A very active field is the synthesis of new materials and a lot of advanced materials were used in EMI protections. For examples, steel, copper and aluminium are the leading candidates for protecting due to their high electrical conductivity, but they have significant weight deficiencies. Multiple types of carbon, metal fibre or filament have been added to the matrices, and the shielding performance has been significantly improved, especially at high frequencies. In addition, there has been evidence of effective enhanced electromagnetic wave absorption by the use of filaments or fibres in multiple matrices. Leading paints or coatings are the growing technologies for EMI blindness applications. The consistency of the colour is quickly adjustable, and it has better value for time and weight. Metal foams are also used in the area of protection to ensure good protective properties and lightweight. Nevertheless, most composites, coatings or foams are badly performing in SE relative to metals and weakly stable for structural use. Nevertheless, the design of a new material incorporating improved mechanical strength, low weight and excellent shielding capacity remains a major challenge. [48]. When have to build a safe enclosure for electromagnetic interference, it is important to consider the cost-performance balance. During the design process, there is a range of important decision points that should always be made clear, for example: component price and tooling costs, galvanic strength, conductivity, application environment and corrosion problems, material thickness, configuration of the shield. In particular the shield height and formability, application speeds, short-term production quantity. One of the most critical and fundamental decisions for considering the material from which purpose or equipment the shielding is built for. In view of electromagnetic compatibility, the material option would directly impact project costs and application efficiency [49].

Copper

Copper (Cu) is the most effective metal in EMI safety as it is very useful in magnetic and electric waves attenuating. The use of copper in RFI security is successful, ranging from hospital MRI facilities to basic computer equipment. It can be conveniently produced with brass alloys, phosphorous bronze and beryllium copper, because of the durability of this metal. In general, these metals cost more than pre-tined steel or copper alloys 770, which are also alternative to safety, but provide a greater conductivity, on the other hand. In contact applications for batteries or springs, phosphorus bronze and beryllium copper are most frequently used due to their elasticity [49].

Aluminium

While aluminium (Al) does pose a few production challenges, its non-ferrous properties, its strength to weight ratio and its high conductivity are still an excellent choice for a variety of applications. Nevertheless, the use of this metal needs careful attention to its galvanizing and oxidation properties compared to copper. Aluminium has a conductivity of about 60%. Over time, the material is oxide and has low solder ability alone [49].

Zinc

Zinc (Zn) strength to weight ratio and its high conductivity are an excellent choice for a variety of application

4.5 Spraying and analysing metal spray

After gaining the thickness of .079mm we took 9 pieces in A4 size paper. We used hand spraying of copper, aluminium and zinc on the surface of the paper to find out the evaporation material parts after spraying. The table 11 depict the evaporation of metal particles in air after being sprayed.

Sample		Paper weight [g]	Total weight after metal spray [g]	Total weight after stabilized [g]	Metal weight after spray [g]	Left Metal weight after evaporation [g]	Left metal %
Copper	1	1.51	2.11	1.92	0.60	0.42	69.22
	2	1.73	2.80	2.49	1.06	0.76	71.44
	3	1.62	2.28	2.13	0.66	0.52	77.74
aluminium	1	1.61	2.04	1.70	0.43	0.09	21.86
	2	1.70	1.89	1.73	0.18	0.03	14.89
	3	1.70	1.95	1.73	0.25	0.03	13.60
Zinc	1	1.71	2.75	2.40	1.03	0.68	66.31
	2	1.68	2.72	2.32	1.03	0.64	61.90
	3	1.68	3.22	2.57	1.53	0.88	57.54

Table 11: metal spray evaporation

4.6 Microstructures

To test the dispersion SEM images were observed. Surface morphology of the metal-coated spun bond fabric was observed at different magnifications SEM images were taken of the longitudinal portion of the metal-coated spun bond fabric. Figure 10 shows the microscopic view of the spun bond nonwoven fabric. Figure 11, 12, 13 consecutively depict the microscopic view of aluminium, copper and zinc dispersion on the surface. Particulate matter makes the surface appreciably conductive. It’s clearly visible that the material spread all over the surface. Thus the coated fabric becomes suitable for shielding application with electromagnetic interference.

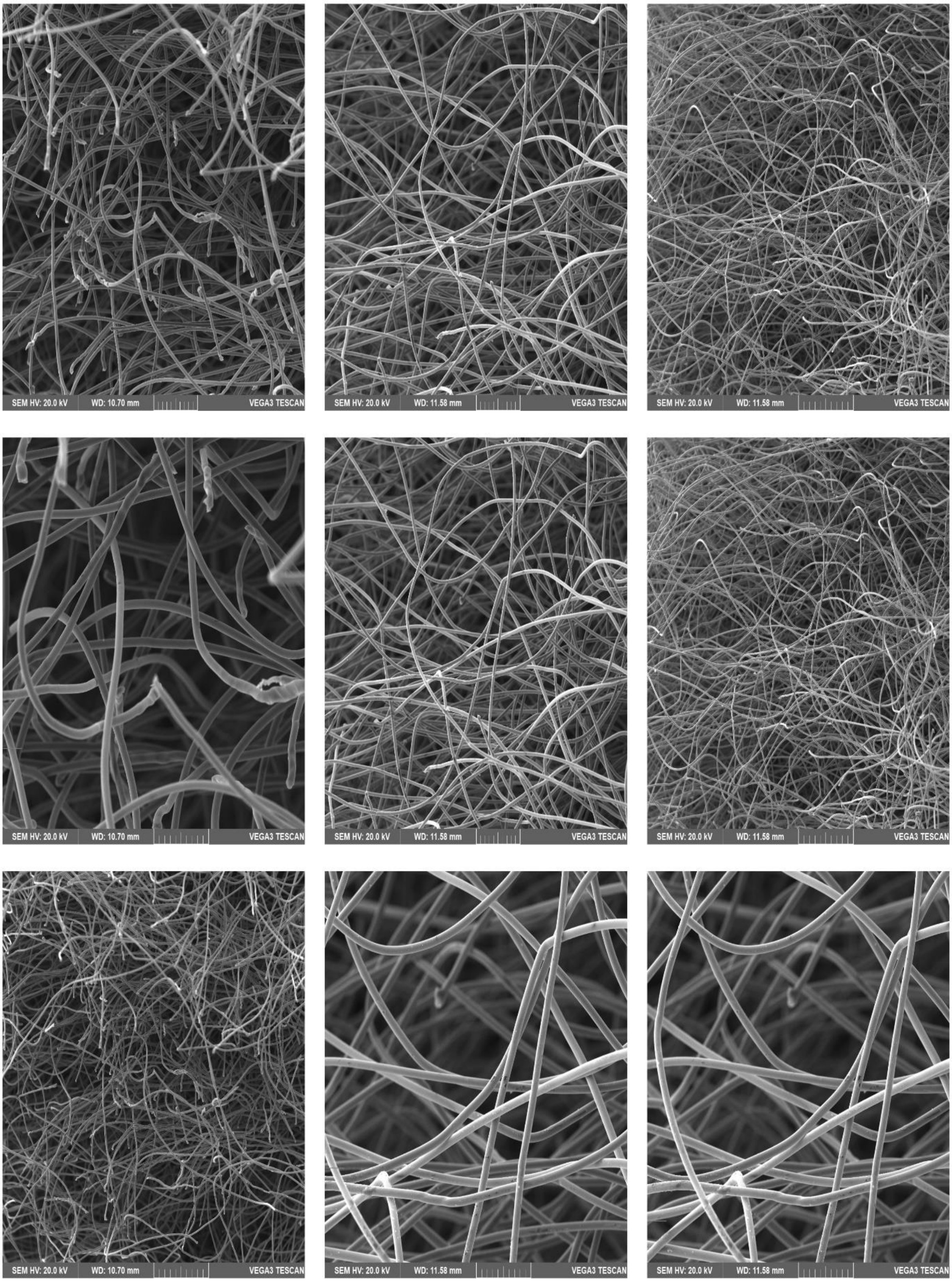


Figure 10: Microscopic image of the nonwoven fabric

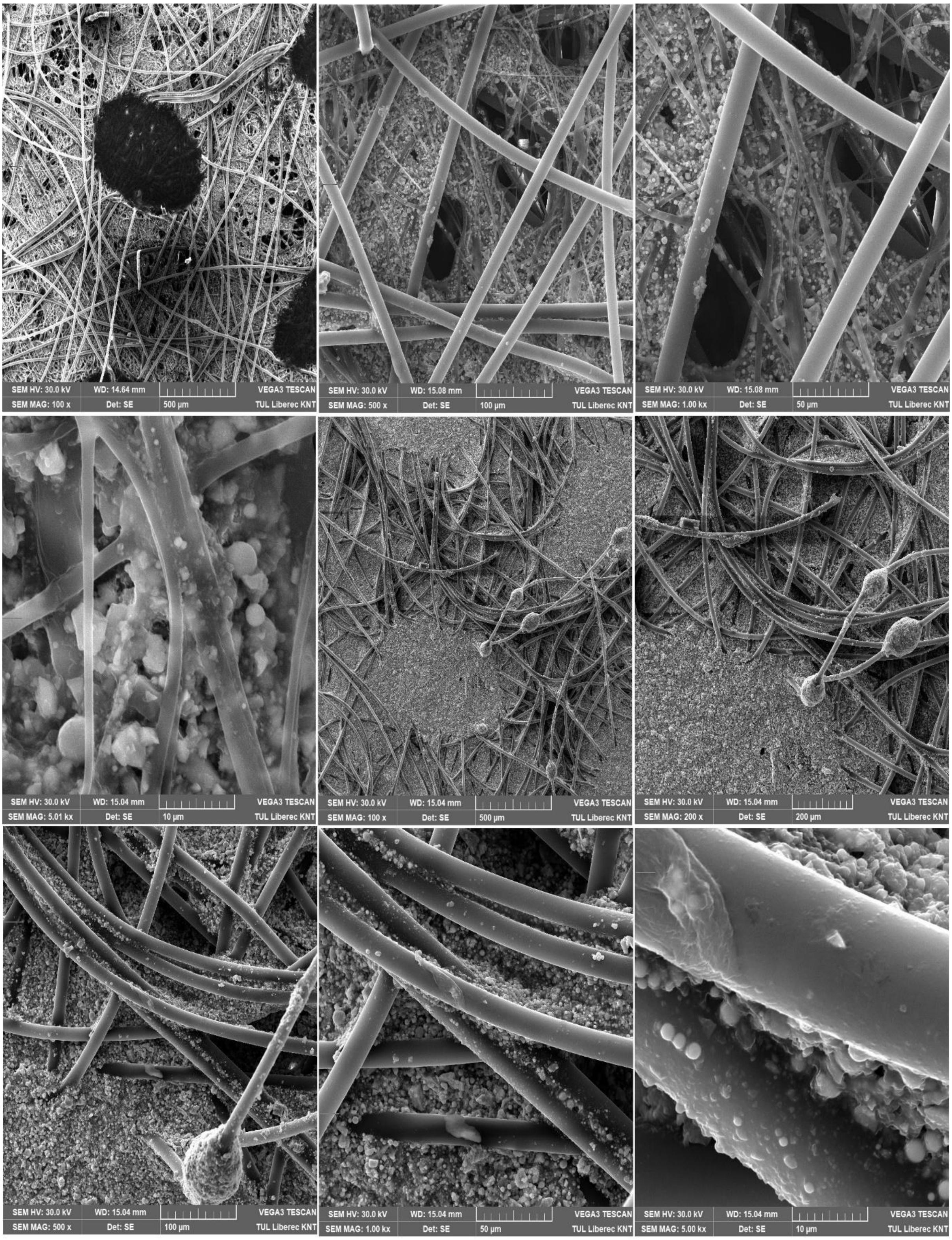


Figure 11: Microscopic image of the nonwoven fabric after Aluminium spray

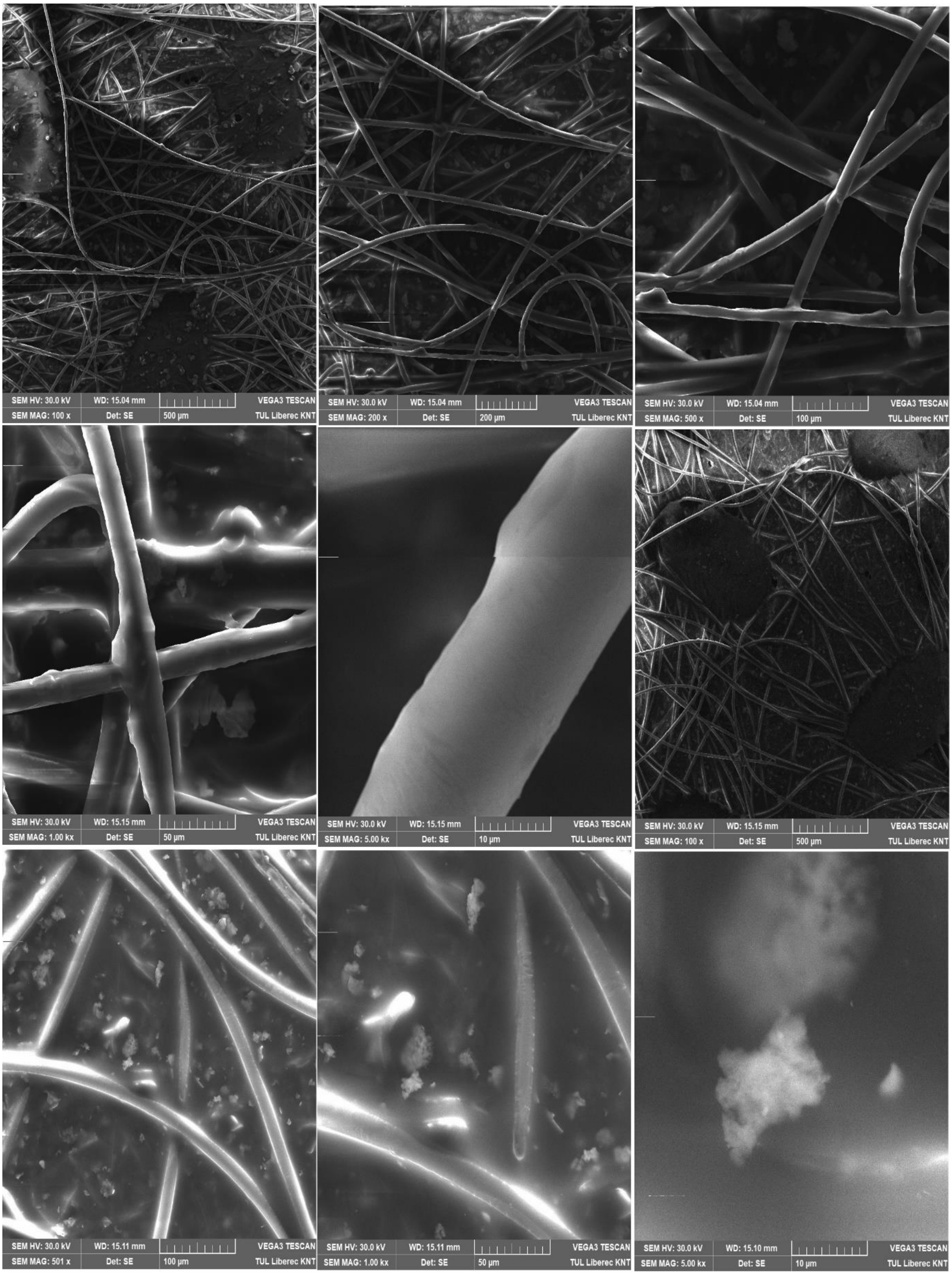


Figure 12: Microscopic image of the nonwoven fabric after Copper spray

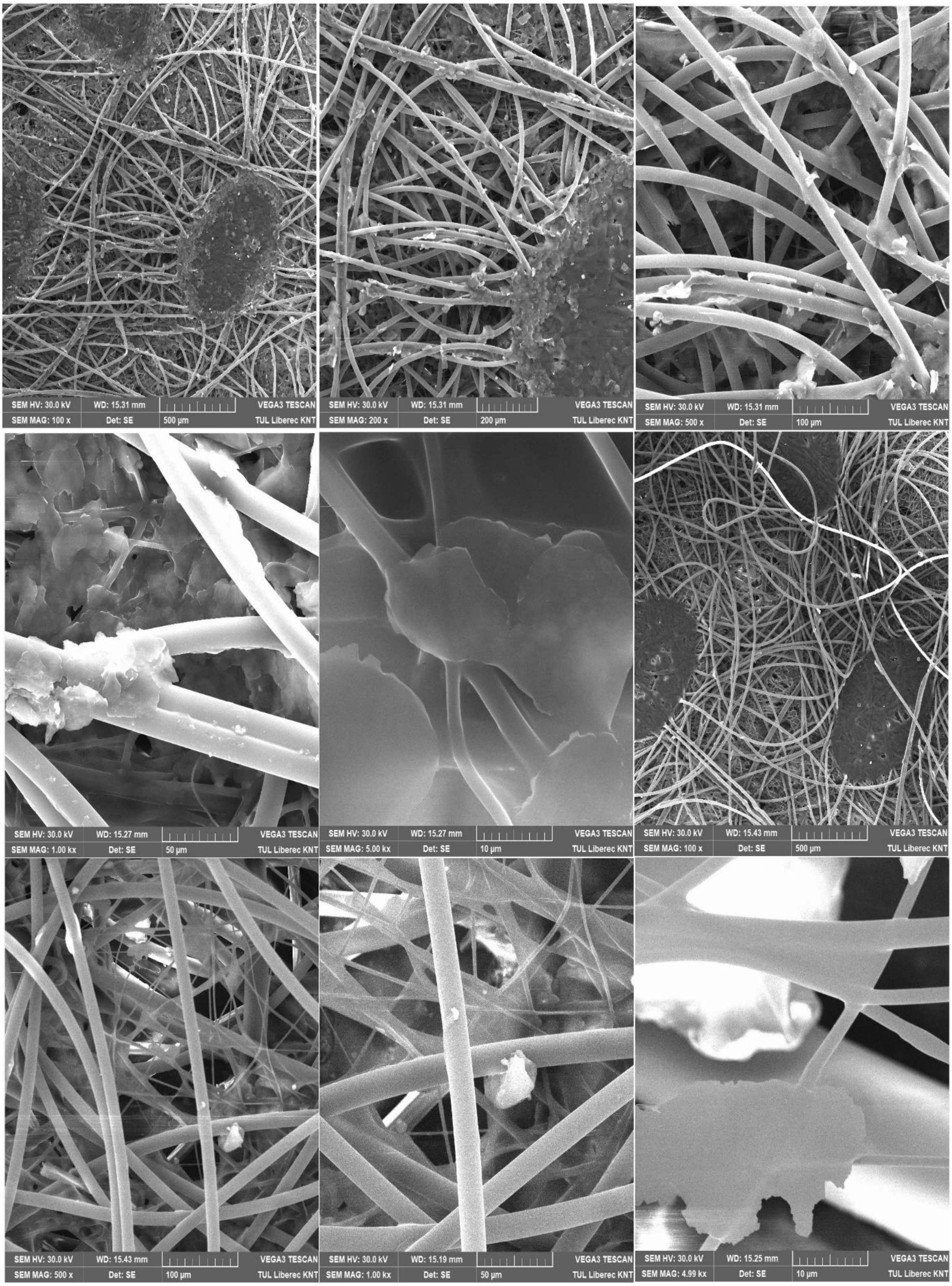


Figure 13: Microscopic image of the nonwoven fabric after zinc spray

4.7 Plasma treatment on fabric

In technical applications nonwovens, especially polypropylene nonwovens, are frequently used mainly because of their low cost. Metallization of polypropylene fabrics is done by sputtering metallic targets, which were mounted on magnetron weapons. In standard systems, the amount of current supplying magnetron influences the power dissipated in aim. Stability of reactive processes needs to be assured in such conditions. The reliability of the unregulated arch releases is accomplished. PP cloth metallization by sputtering of the pulse magnetron offers a way to create metallic layers with very strong adhesion, which can not be accomplished by any process. DC-M mode has been documented to ensure improved performance at comparable dissipated power levels. It's related to increased metallic layer deposition levels [50]. for the thesis we have inspect EM Shielding effictiveness of four samples copper silver (CuAg) and silver(Ag) coated which were plasma treated on one side, and two samples which were copper(Cu) on both sides by plasma treatment. the samples were collected from Turnex spol. s r.o. the samples details are below in Table 12.

Sample	details
1	Plasma treated on one side, CuAg coated
2	Plasma treated on one side, CuAg coated
3	Plasma treated on one side, Ag coated
4	Plasma treated on one side, Ag coated
9	Plasma treated on both side, 150nm Cu coated on nonwoven fabric.
10	Plasma treated on one side, 150nm Cu coated on nonwoven fabric.

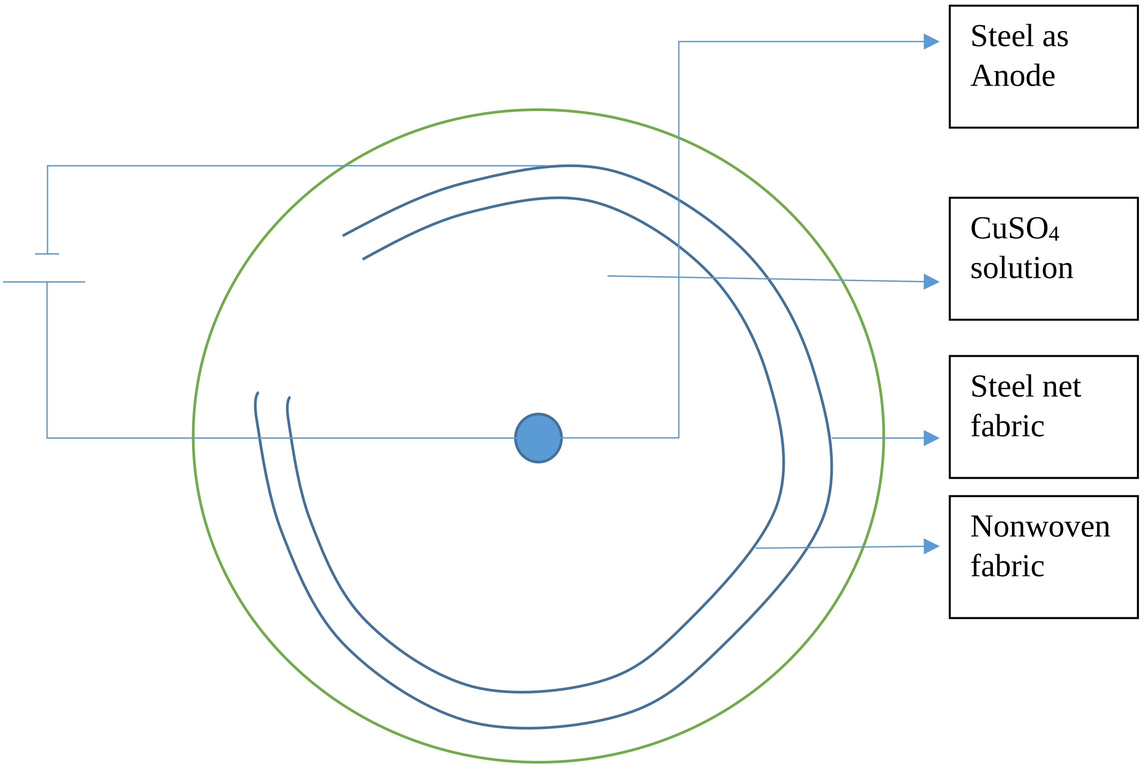
Table 12: Plasma treated sample fabrics.

4.8 Galvanization treatment on fabric

Electrically conductive textile fabrics, which are referred to as electro-deposition, are electrified by the electrical current to cover the layer with metal parts. The textiles are made of a dense, strong and heavy metal fabric. On the fabric surfaces with this technology can be mounted metals such as steel, cadmium, Chroma, copper, gold, iron, nickel, silver, zinc. The method of electroplating consists of one electrolytic cell containing two electrodes and an electrolyte. Anode (positive electrolyte) is metal covering and cathode (negative electrolyte) is the coating component. In the electrolyte approach to the cathode and the deposit ions occurred with low-voltage current. [51] The electroless or electrolytic surface treatment method, i.e. the separation and treatment cycle for each phase separately after reprocessing, does not shorten the method period, has little quality competitiveness and cannot reduce the production facility. A CVD process or sputtering process has been used previously to improve the bonding force between the carbon fibre and the metal, which has many issues because it is not economical due to the high cost of production. Since electro-less electrolyses and electrolyses are carried out continuously in one production facility, competitive products with easy cost and easy control can be made. The present creators have solicited a method for producing an extremely physical, conductive metal-plated fibrous nonwoven fabric. This results in the continued use of electrical and electrolytic surface treatment methods, which has more benefit than conventional electroless and electrolytic surface treatment processes, such as shorter cycle times, competitive price and simplifying production facilities, and reinforces the fact that not only conductivity, but also product quality is an excellent example [52].

4.8.1 Experiment 1

In our experiment we prepared copper sulphate solution by mixing 30 gram with 1litre of water. First we used a stainless steel made net fabric as a cathode and wound it around with a nonwoven fabric. A steel rod has been used as anode. The figure 14 depicts the setup.



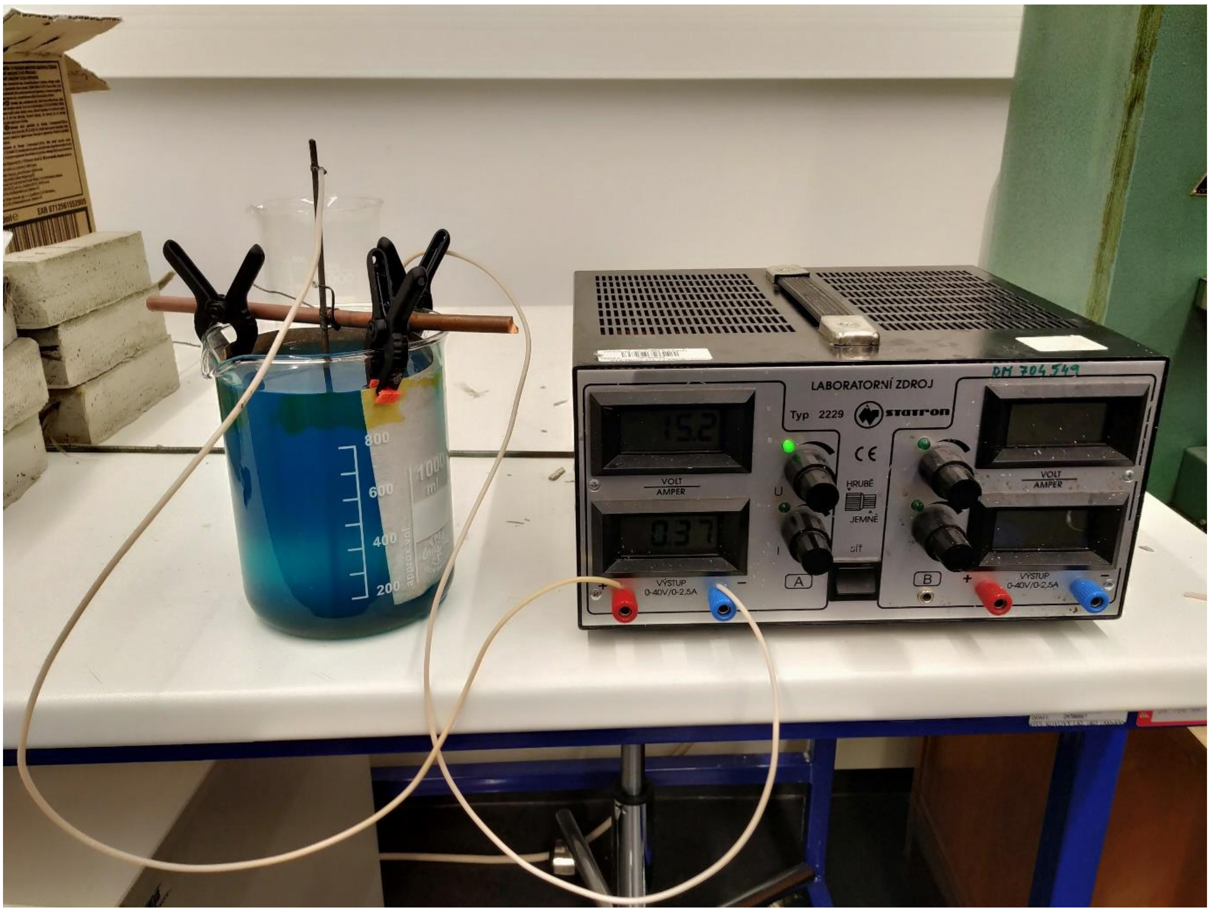


Figure 14: Galvanisation setup

As there are no metal particle mixed with the raw material of nonwoven fabric. The experiment failed without any deposition of metal on top of the fabric. On figure 15 the end result has been shown.

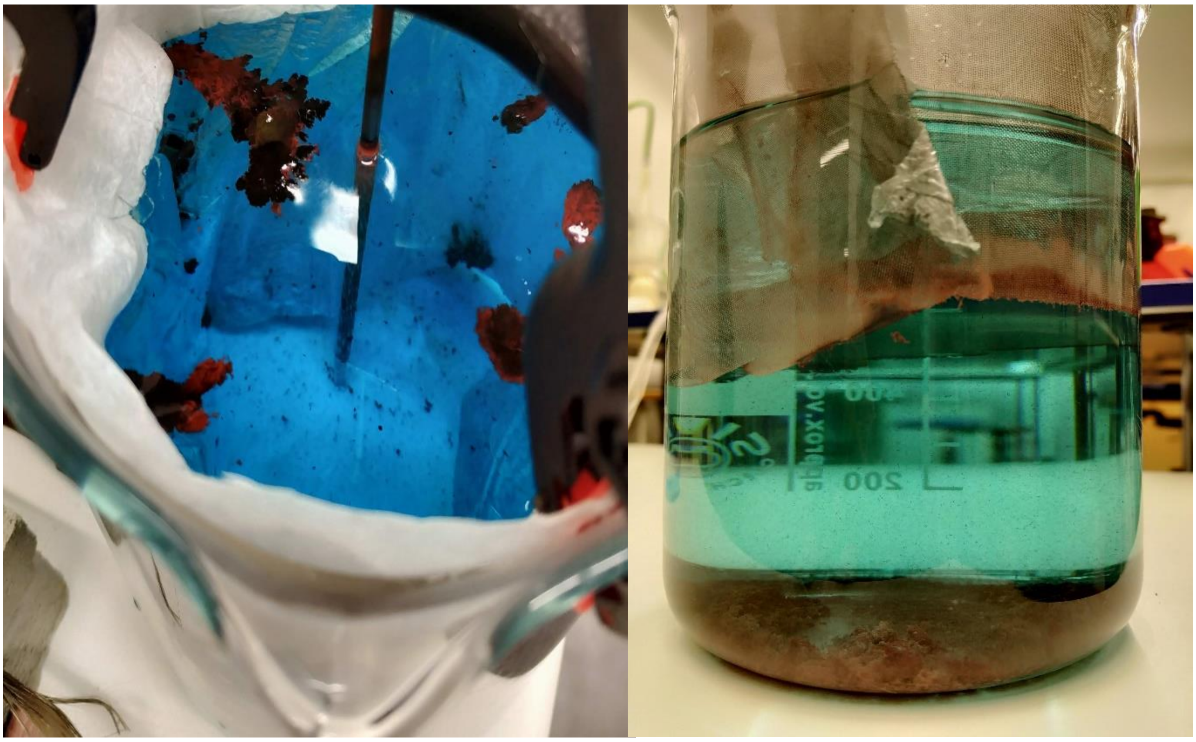


Figure 15: Galvinasation end result (experiment 1)

4.8.2 Experiment 2

As the 1st approach failed. In our second trial we used a CuAg coated by plasma treatment nonwoven fabric (sample 2) as cathode. This experiment also failed because of very thin layer of metal particles on the top of the fabric. The copper metal gathered together instead of making layer on top of the fabric.

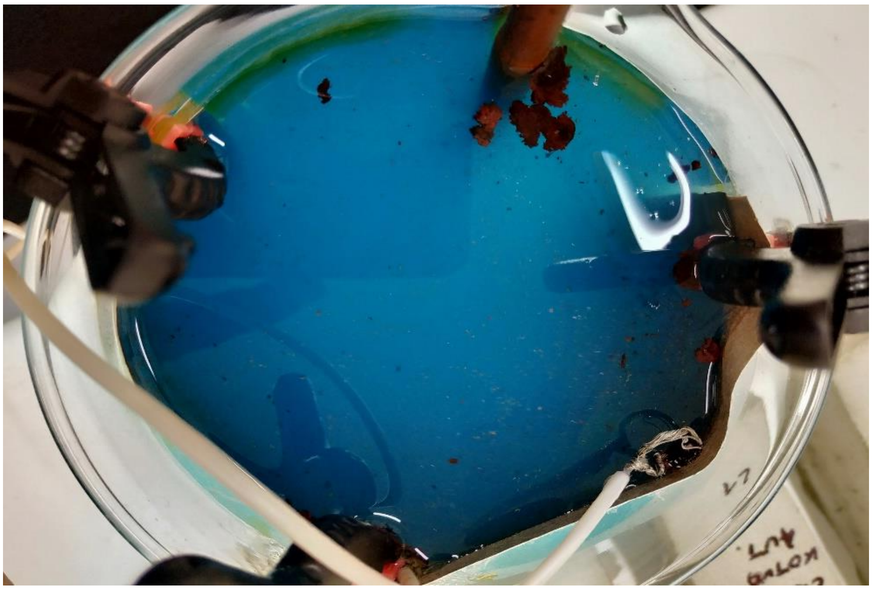


Figure 16: experiment 2 end result:

Figure 16 shows the end result of the experiment 2.

4.8.3 Experiment 3

On our third trial, we used a fabric as cathode which were 150nm copper coated on both sides by plasma treatment. We used a copper rod as anode. The method was unsuccessful because of choosing wrong solution. $CuSO_4$ reacted with the Copper coat of fabric by intriguing copper corrosion from the surface of fabric.

4.9 Measurement of resistivity method

Systems are capable of reducing the effect of surface currents that affect the resistance to volume. During volume current calculation. We can on the other hand minimize the influence of the volume part of the current, which affects the resistance of the surface when measuring surface current. It seems, that measurements of the volume and the surface resistances should be associated in textile materials with a very rich structure and highly established top. The presumption that a characteristic conduction current is a foundation for such a connection can be [53]. To measure the resistance we have used 4339B High-Resistance Meter. The table below shows the resistivity of the measured samples. Because of overloading of charges we had to change the voltages over samples. Figure 17 depicts the machine setup.

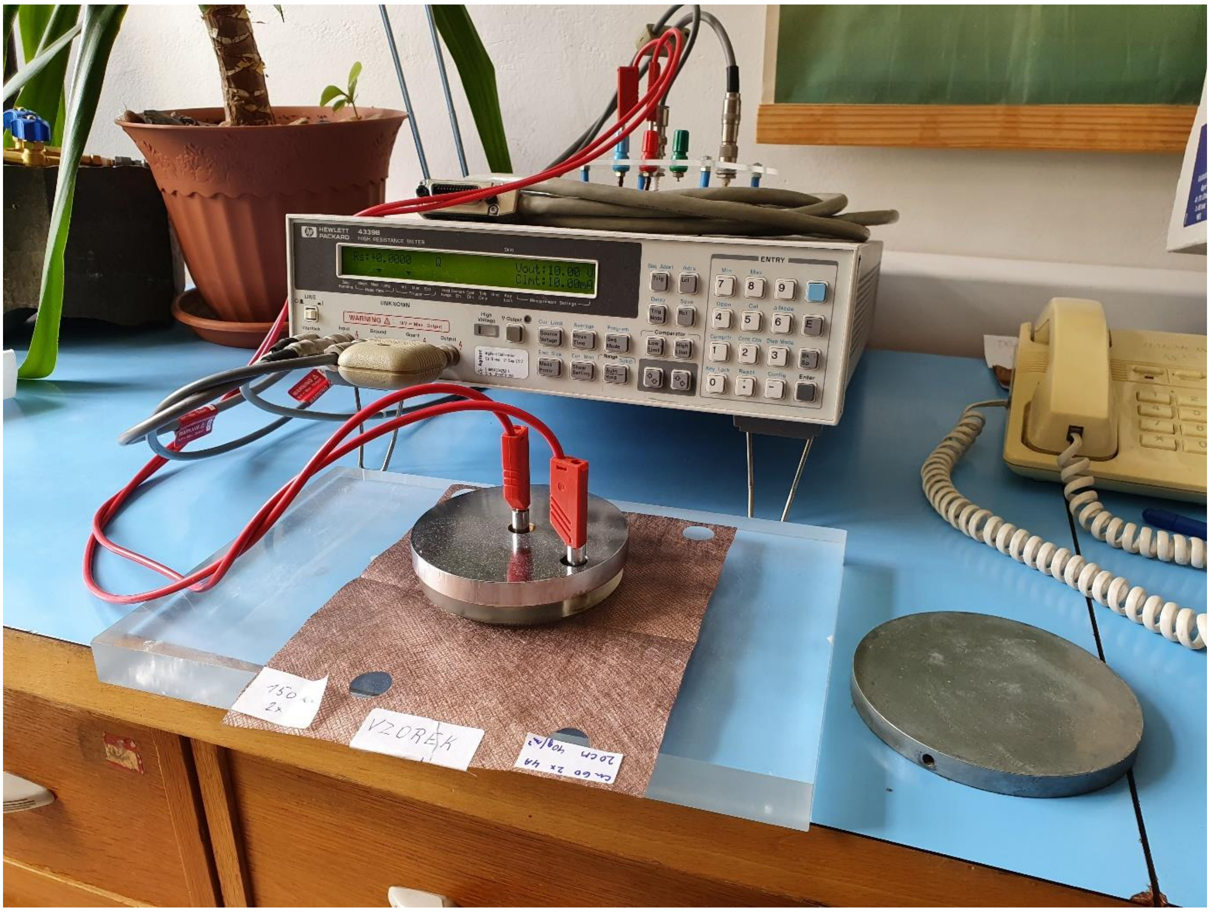


Figure 17: 4339B High-Resistance Meter

4.10 Electromagnetic shield measurement method

We did two types of measurement, one with a frequency range of 30 MHz – 1.5 GHz (EM 2107A) and other with a frequency range of 1.5 GHz to 3 GHz (EM 2108).

4.10.1 EM-2107A

The em-2107A is a standard test device for evaluating planar material's electromagnetic shielding efficacy. The system is a broader portion of the coaxial transmitter and follows the ASTM check method D4935-1 specifications in complete. The calculated results apply to the strength of the shielding owing to a plane wave and can be derived past field values for magnetic and electrical fields. A dynamic range model is provided for the EM-2107A as standard reference test sample.

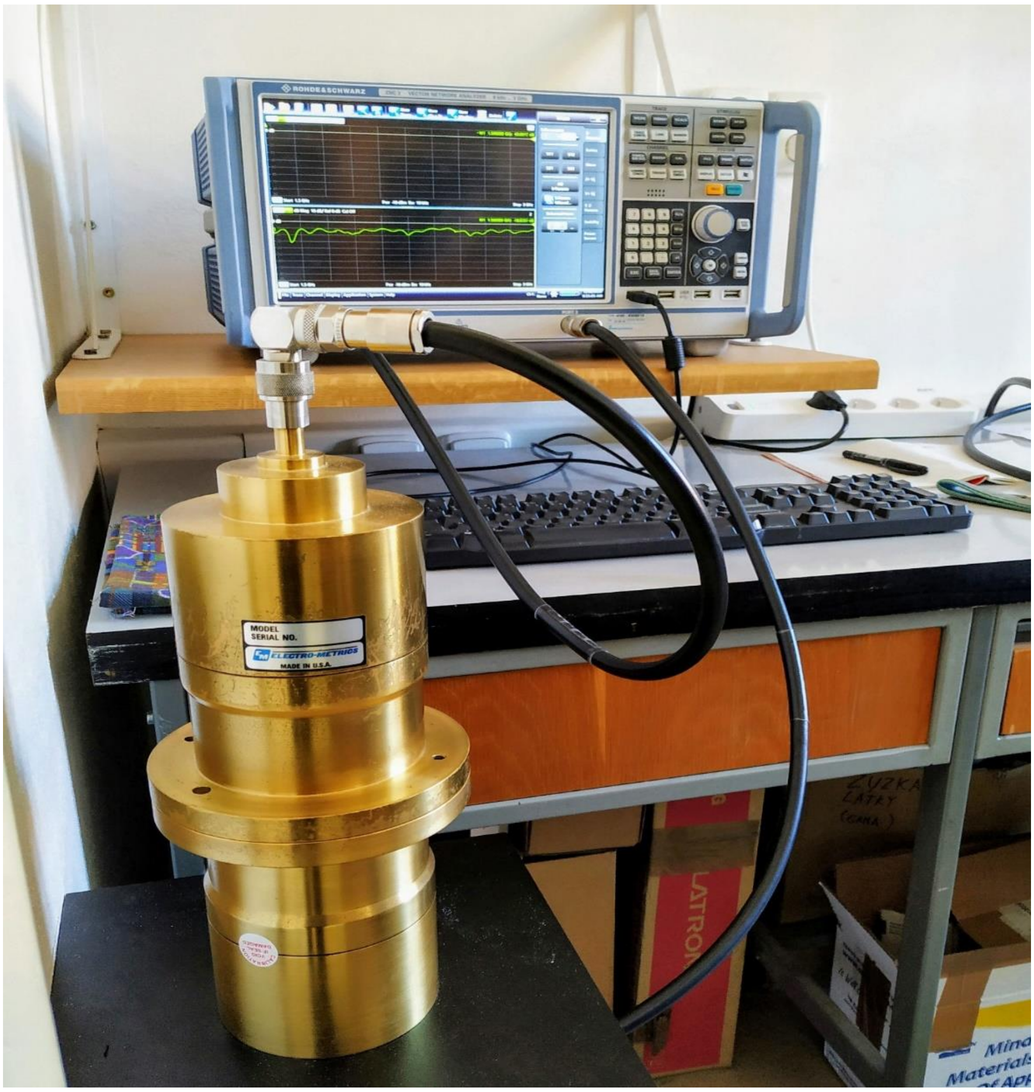


Figure 18: EM-2107A.

Dynamic range of more than 80dB can be reached, but usually the cables and other research system components have limitations. [54]. Figure 18 shows EM-2107A set up.

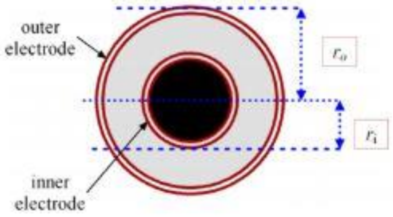


Figure 37: Principle of concentric electrodes [62].

The outer circular electrode radius here, r_0 = 31.46 mm and the internal circular electrode's radius is ri =14.98 mm. And for a certain Geometry R_S = 8.4679 R [62].

4.10.2 EM-2108

The EM-2108 is an electromagnetic shielding (SE) standard test set-up for the evaluation of planar material. The connection is a coaxial line component which is broken so that flat test materials can be inserted. The EM-2108 complies with and fully fulfils both the impedance and SE requirements as laid down in ASTM test method D4935-10 for up to 10 GHz while the ASTM D4935,010 is limited to an above-frequency of 1.5 GHz.

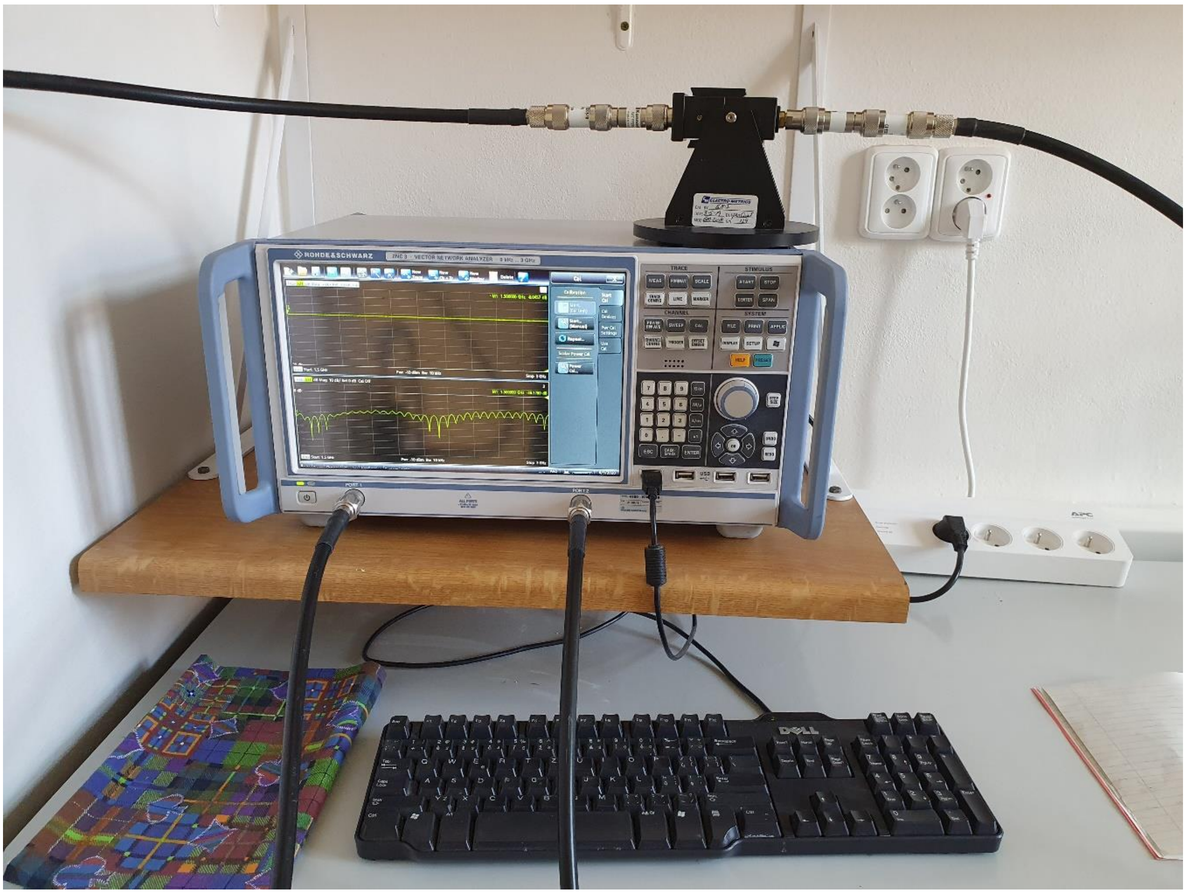


Figure 19: EM-2108

The data calculated are the protective efficiency of a plane wave (extreme). EM wave field) from which close to field values can be inferred for magnetic and electric fields [55].The measured charts are as following.

5 Result and Discussion

5.1 Measurement of resistivity

After preparing all the samples, we renamed the samples as followings

Sample 1: Plasma treated on one side, 5s CuAg coated fabric.

Sample 2: Plasma treated on one side, 10s CuAg coated fabric.

Sample 3: Plasma treated on one side, 5s Ag coated fabric.

Sample 4: Plasma treated on one side, 10s Ag coated fabric.

Sample 5: Al coated by spraying on spun bonded fabric.

Sample 6: Zn coated by spraying on spun bonded fabric.

Sample 7: Cu coated by spraying on spun bonded fabric.

Sample 8: without any coating spun bonded fabric.

Sample 9: Plasma treated on both side, Cu coated on nonwoven fabric.

Sample 10: Plasma treated on one side, Cu coated on nonwoven fabric.

Table 13 below shows result of the test. Figure 19 shown the setup of hp 4339B high-Resistance Meter and table 13 shows the result of resistivity test. Here because of the electric overloading on the surface of fabrics, sample 9 and 10 resistivity has been measured on different voltage.

Sample	Surface resistivity [Ω]	Volume resistivity [Ωm]	Against voltage [v]
1	4.02×10^{12}	1.88×10^{12}	10
2	3.39×10^{12}	1.54×10^{14}	10
3	3.97×10^{12}	7.24×10^{13}	10
4	5.18×10^{12}	4.73×10^{13}	10
5	5.11×10^{12}	3.51×10^{14}	10
6	2.75×10^{13}	4.65×10^{14}	10
9	2.11×10^{3}	5.6×10^{4}	0.1
10	2.17×10^{6}	2.57×10^{11}	0.1

Table 13: Results of resistivity test

5.2 Electromagnetic shield measurement

5.2.1 Measurement in a low frequency range by EM-2107A

The electromagnetic effectiveness are shown in graph. Figure 20-27 depicts the graph.

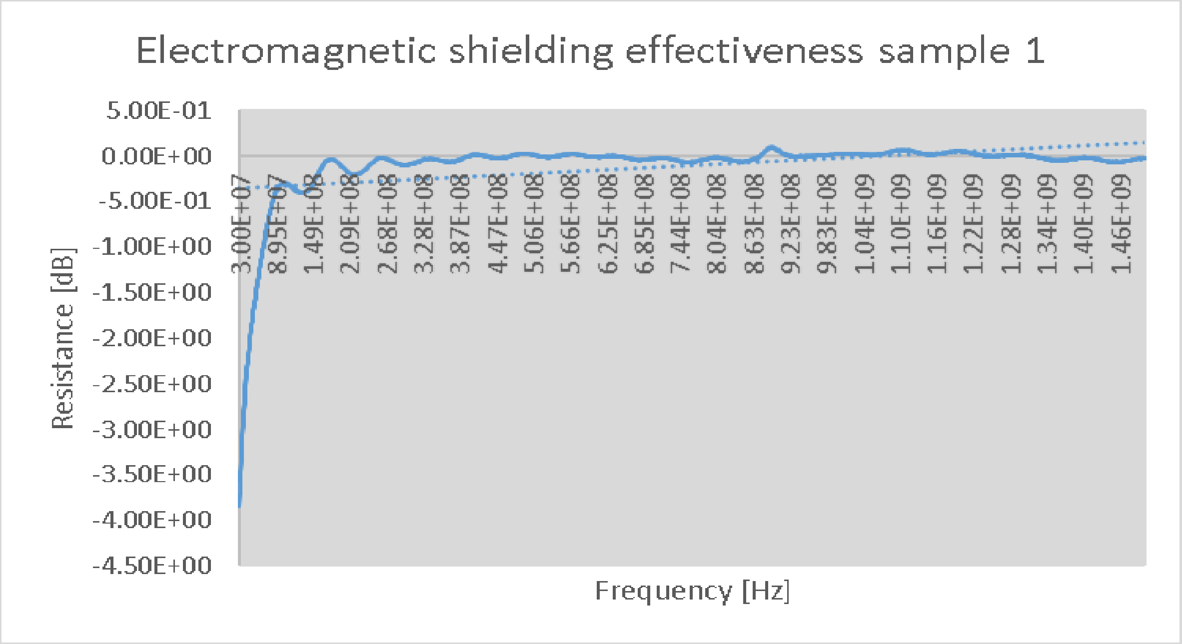


Figure 20: Electromagnetic shielding effectiveness of sample 1 on low-frequency range.

In figure 20 the graph shows 4dB resistance at its peak. Which is very low for the acceptable shielding property.

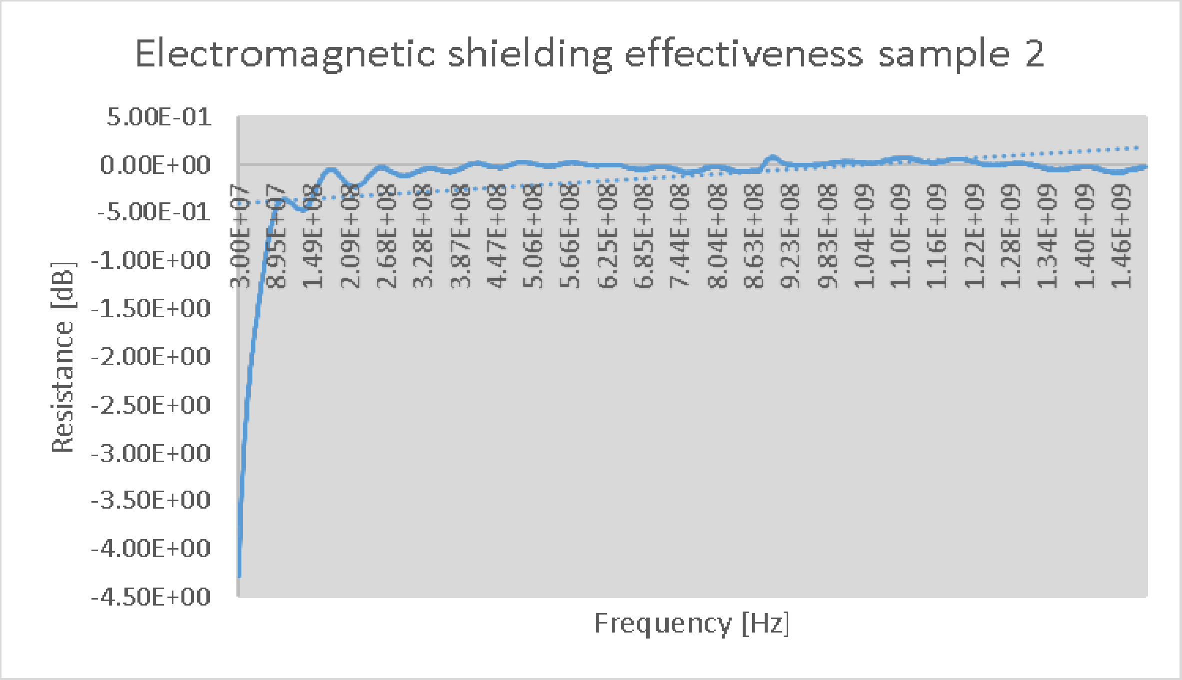


Figure 21: Electromagnetic shielding effectiveness of sample 2 on low-frequency range

In figure 21 the graph shows 4dB resistance at its peak. Which is very low for the acceptable shielding property.

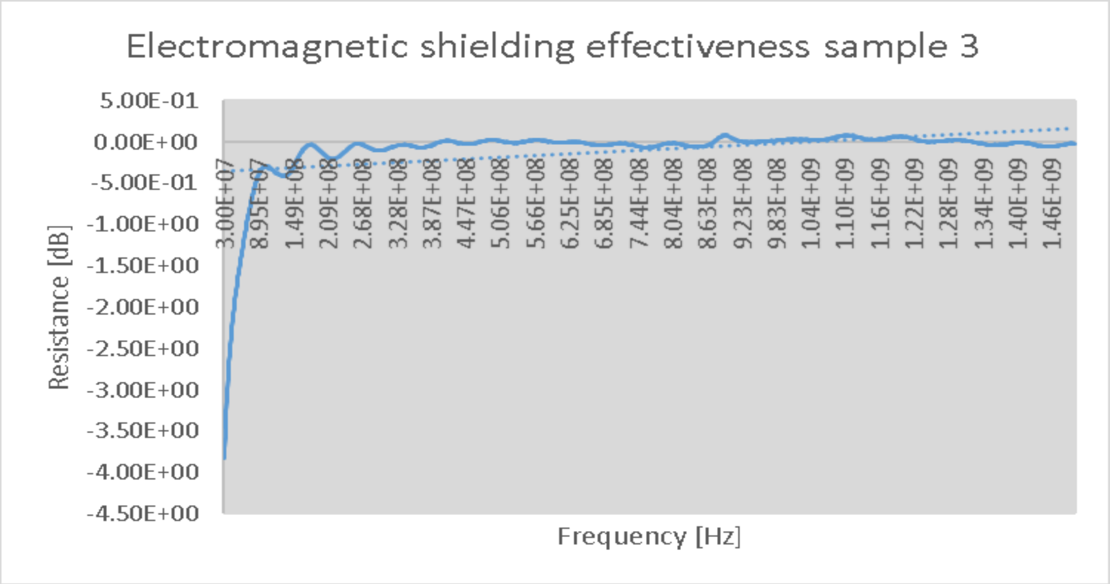


Figure 22: Electromagnetic shielding effectiveness of sample 3 on low-frequency range

In figure 22 the graph shows 4dB resistance at its peak. Which is very low for the acceptable shielding property.

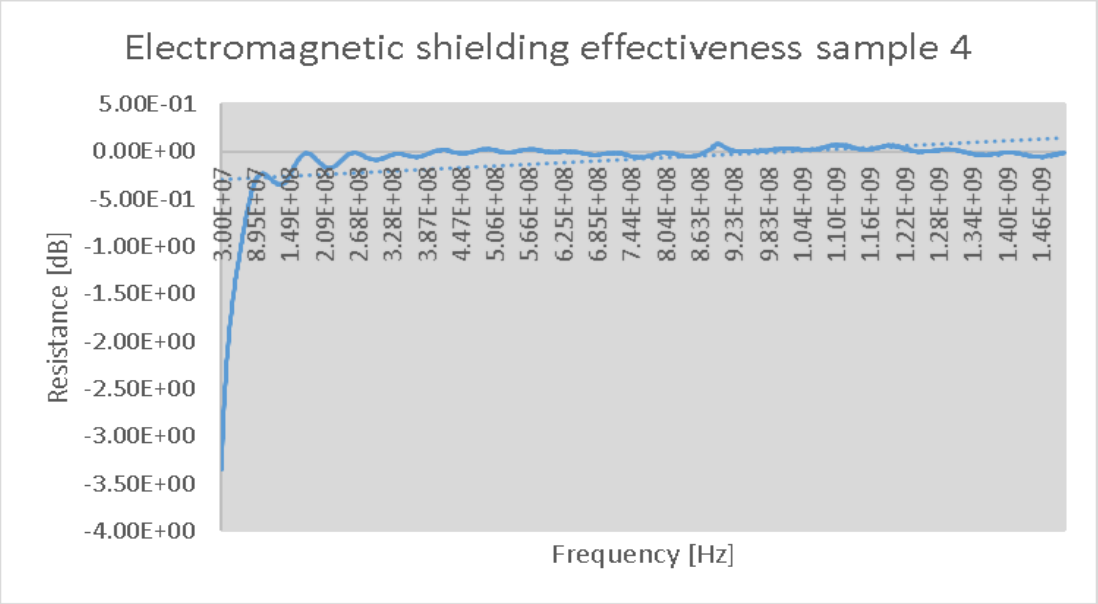


Figure 23: Electromagnetic shielding effectiveness of sample 4 on low-frequency range

In figure 23 the graph shows 3.5dB resistance at its peak. Which is very low for the acceptable shielding property.

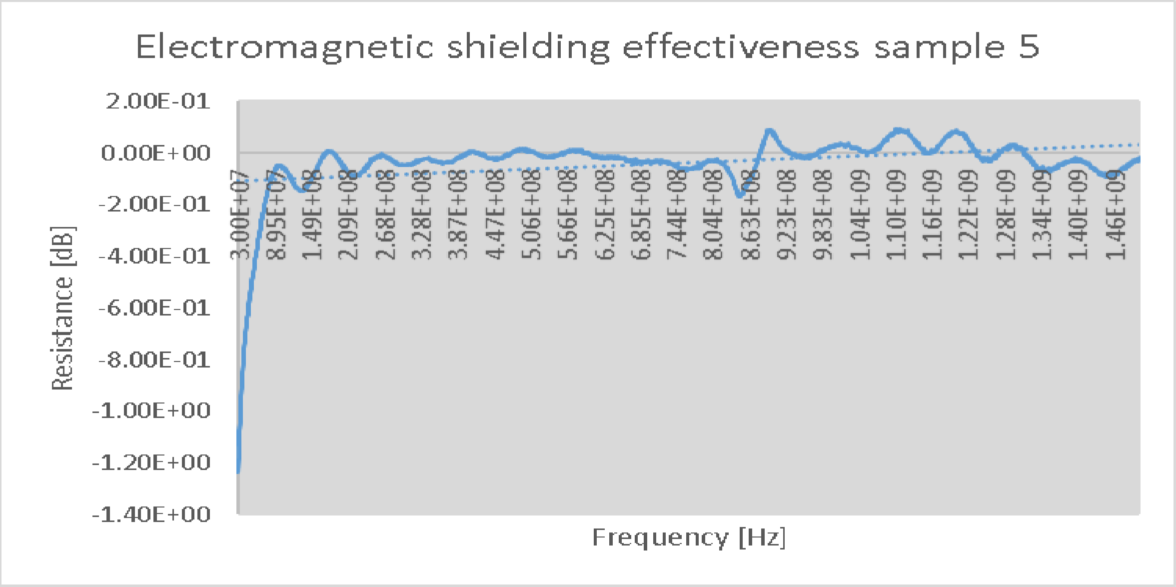


Figure 24: Electromagnetic shielding effectiveness of sample 5 on low-frequency range

In figure 24 the graph shows 1.2dB resistance at its peak. Which is very low for the acceptable shielding property.

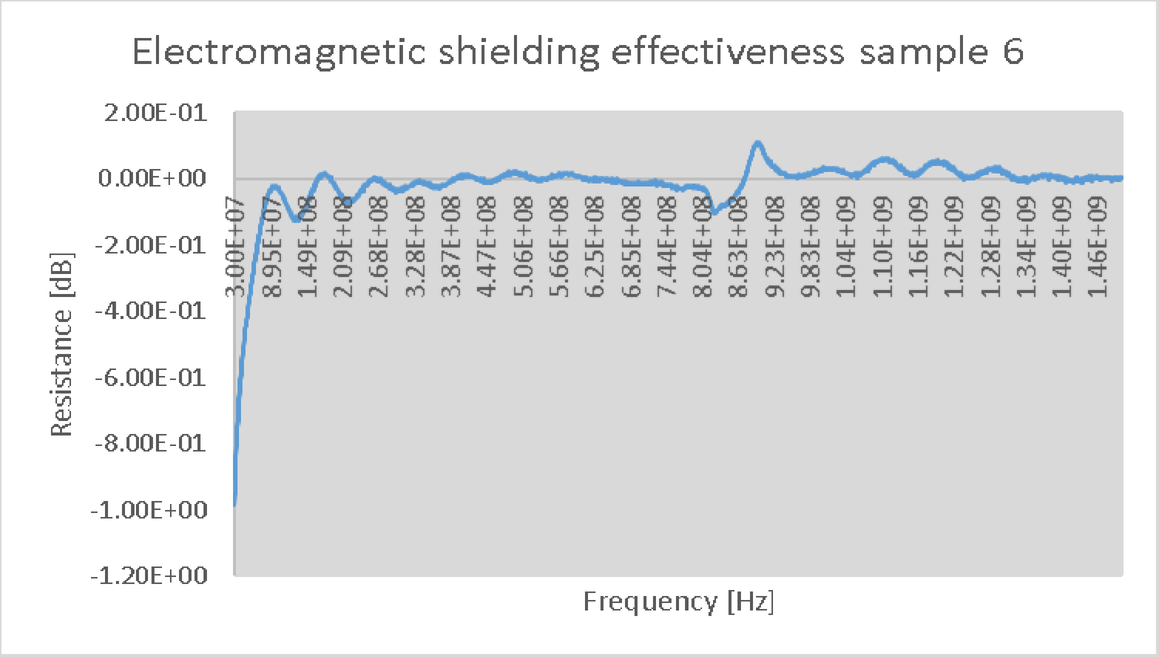


Figure 25: Electromagnetic shielding effectiveness of sample 6 on low-frequency range

In figure 25 the graph shows 4dB resistance at its peak. Which is very low for the acceptable shielding property.

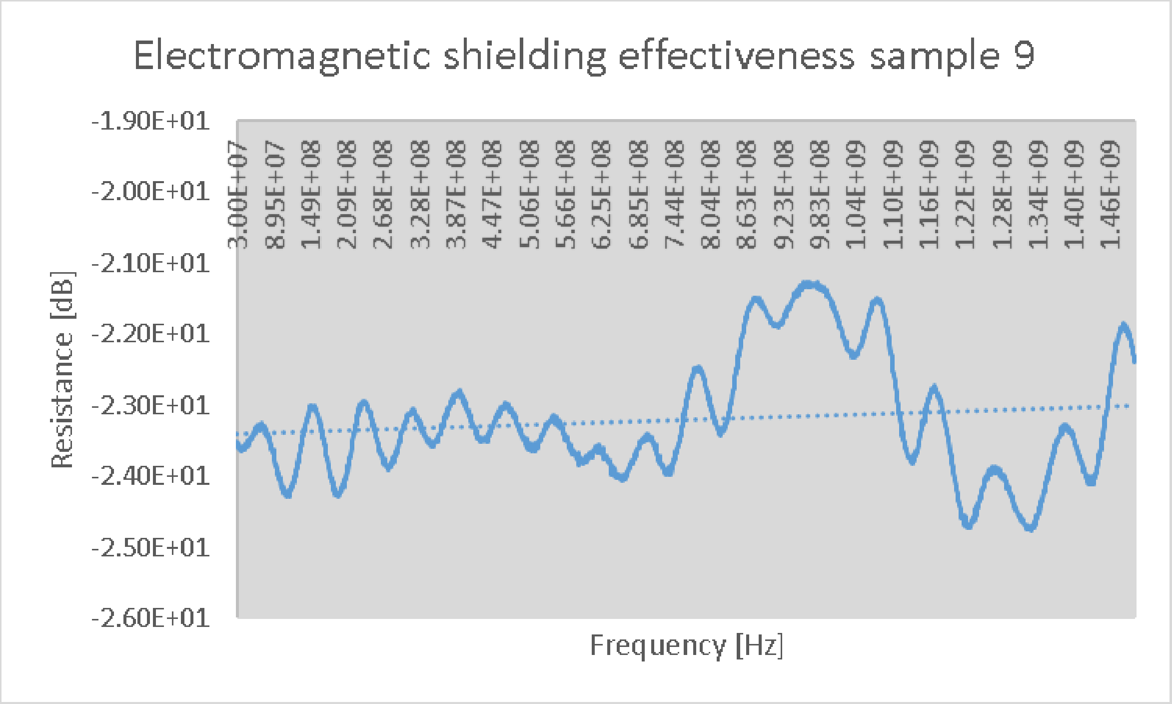


Figure 26: Electromagnetic shielding effectiveness of sample 9 on low-frequency range

In figure 26 the graph shows 25dB resistance at its peak. Which is quite good for use as a shielding material for lower radiation facilities. As an example for home textile.

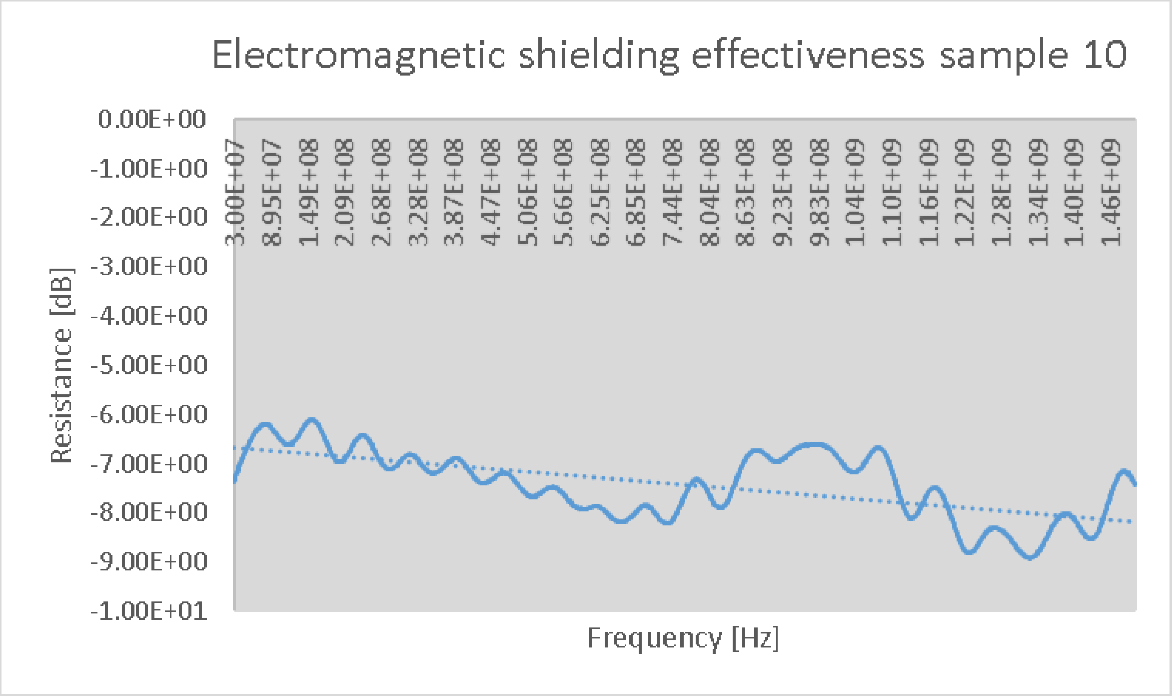


Figure 27: Electromagnetic shielding effectiveness of sample 10 on low-frequency range

In figure 27 the graph shows 10dB resistance at its peak. Which is very low for the acceptable shielding property.

Sample 1, 2, 3, 4, 5 and 6 all of them shows no prominent shielding effectiveness. Sample 9 with 150nm of copper coating on both sides shows an average 25dB resistance against a frequency range of 30 MHz to 1.5 GHz. Sample 10 with 150nm of copper coating on one sides shows a 9 dB resistance against a frequency range of 30 MHz to 1.5 GHz. On table 9 the highest resistance on the frequency against has been shown.

Sample	Frequency [Hz]	Highest resistance [dB]
1	3.00×10^7	4.0
2	3.00×10^7	4.0
3	3.00×10^7	4.0
4	3.00×10^7	3.5
5	3.00×10^7	1.2
6	3.00×10^7	1
9	1.34×10^9	25
10	1.34×10^9	9

Table 14: resistance on lower frequency range

5.2.2 Measurement in high frequency range by EM-2108

The electromagnetic effectiveness are shown in graph. Figure 28-34 depicts the graph.

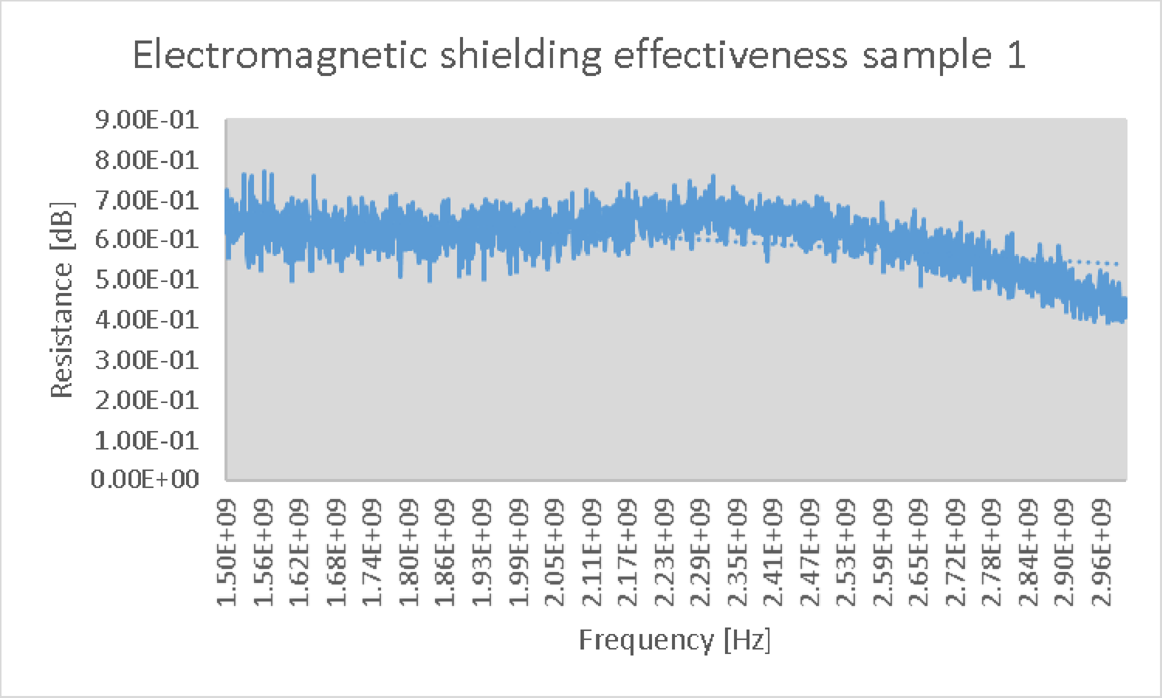


Figure 28: Electromagnetic shielding effectiveness of sample 1 on high-frequency range

In figure 28 the graph shows 0.4dB resistance at its peak. Which is very low for the acceptable shielding property.

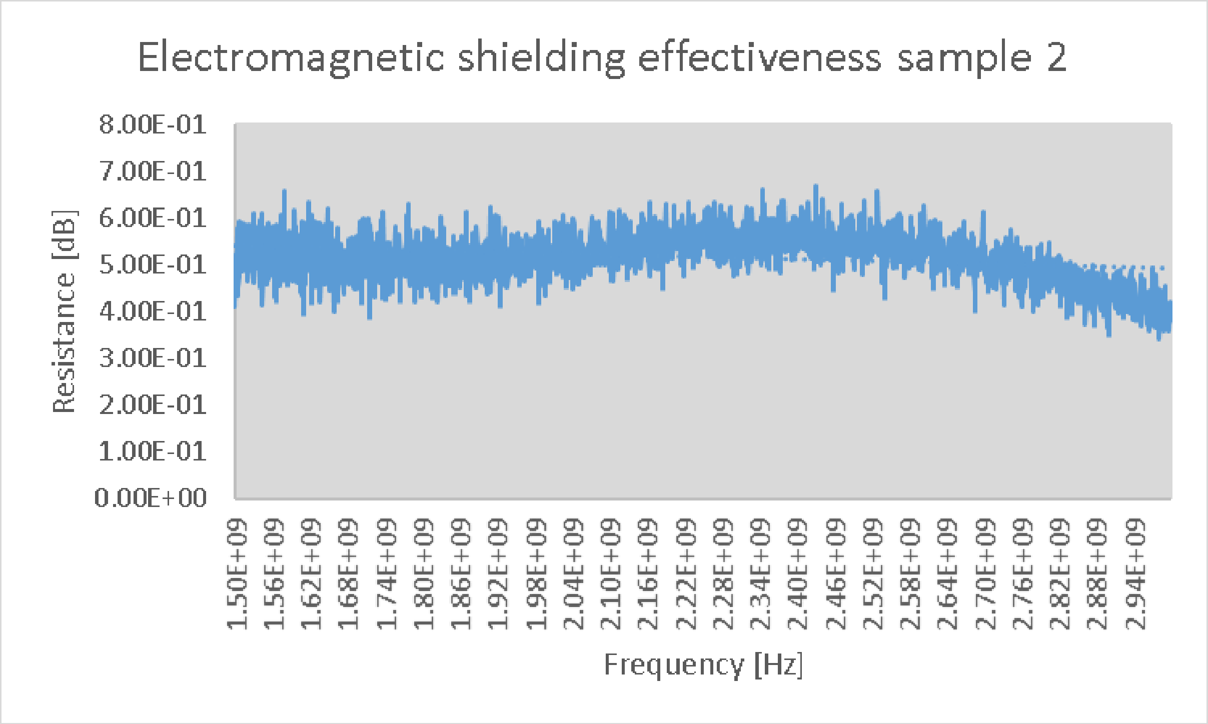


Figure 29: Electromagnetic shielding effectiveness of sample 2 on high-frequency range

In figure 29 the graph shows 0.4dB resistance at its peak. Which is very low for the acceptable shielding property.

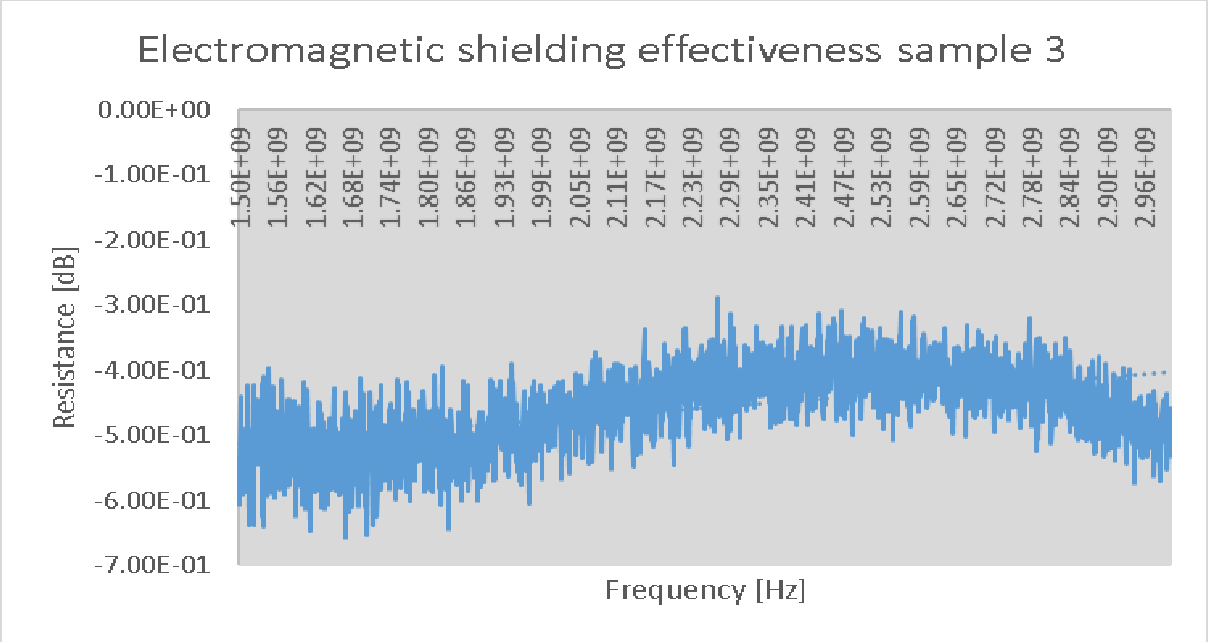


Figure 30: Electromagnetic shielding effectiveness of sample 3 on high-frequency range

In figure 30 the graph shows 0.6dB resistance at its peak. Which is very low for the acceptable shielding property.

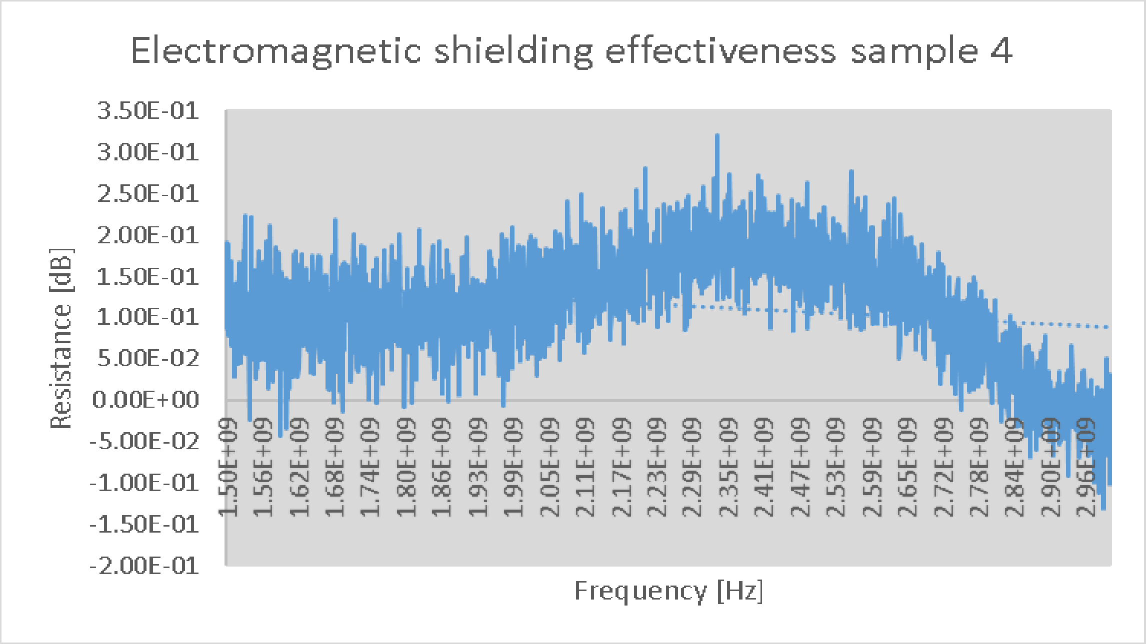


Figure 31: Electromagnetic shielding effectiveness of sample 4 on high-frequency range

In figure 31 the graph shows 0.15dB resistance at its peak. Which is very low for the acceptable shielding property.

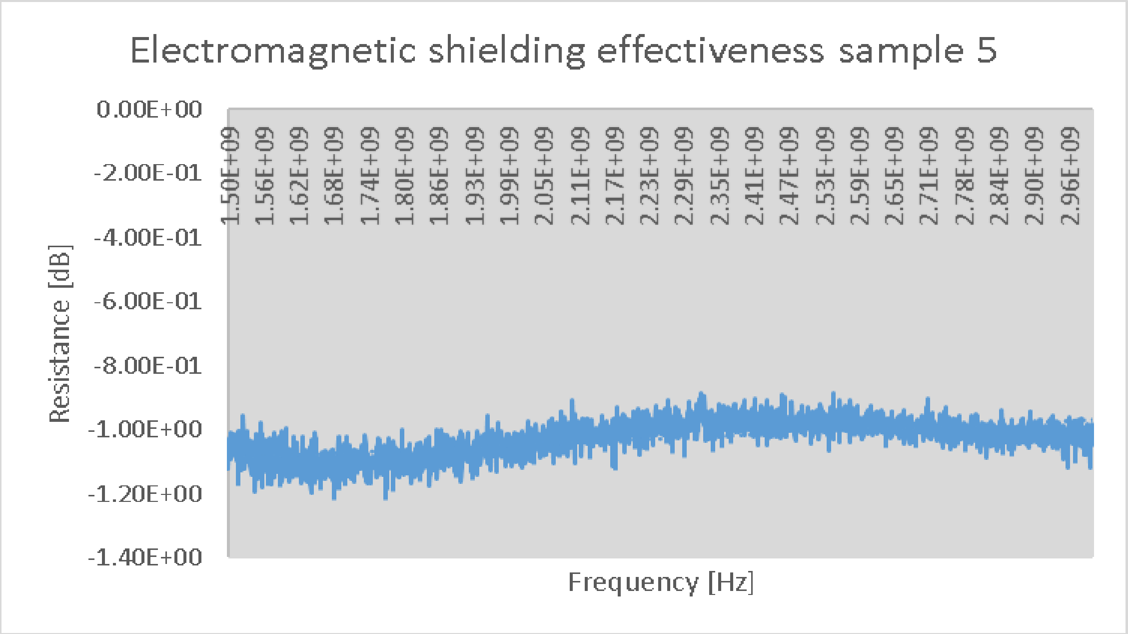


Figure 32: Electromagnetic shielding effectiveness of sample 5 on high-frequency range

In figure 32 the graph shows 1.2dB resistance at its peak. Which is very low for the acceptable shielding property.

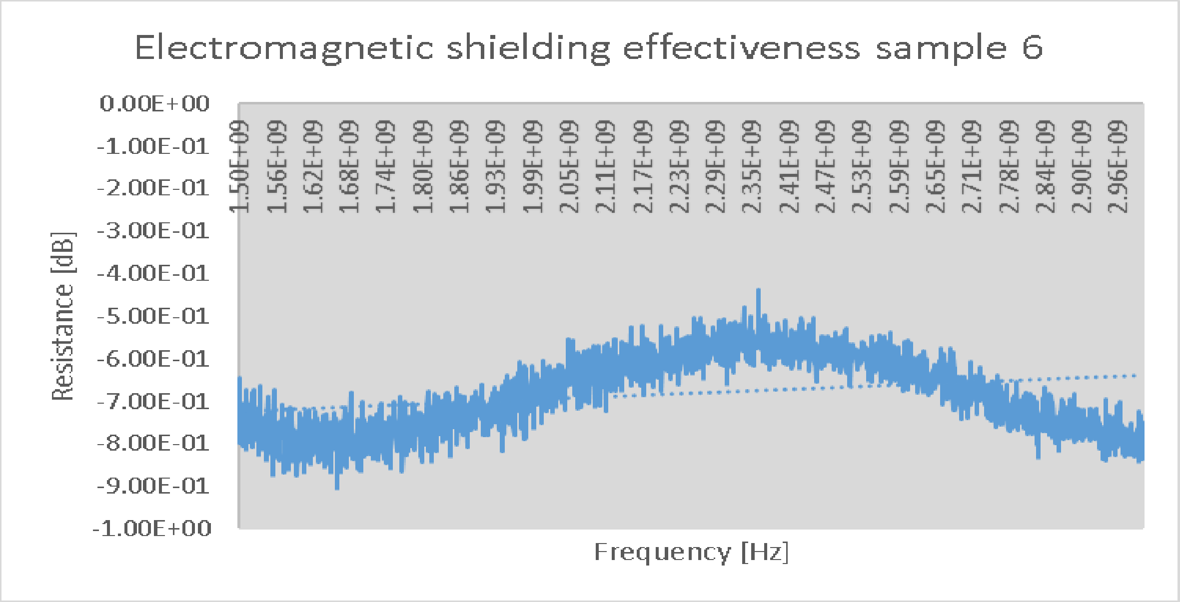


Figure 33: Electromagnetic shielding effectiveness of sample 6 on high-frequency range

In figure 33 the graph shows 0.9dB resistance at its peak. Which is very low for the acceptable shielding property.

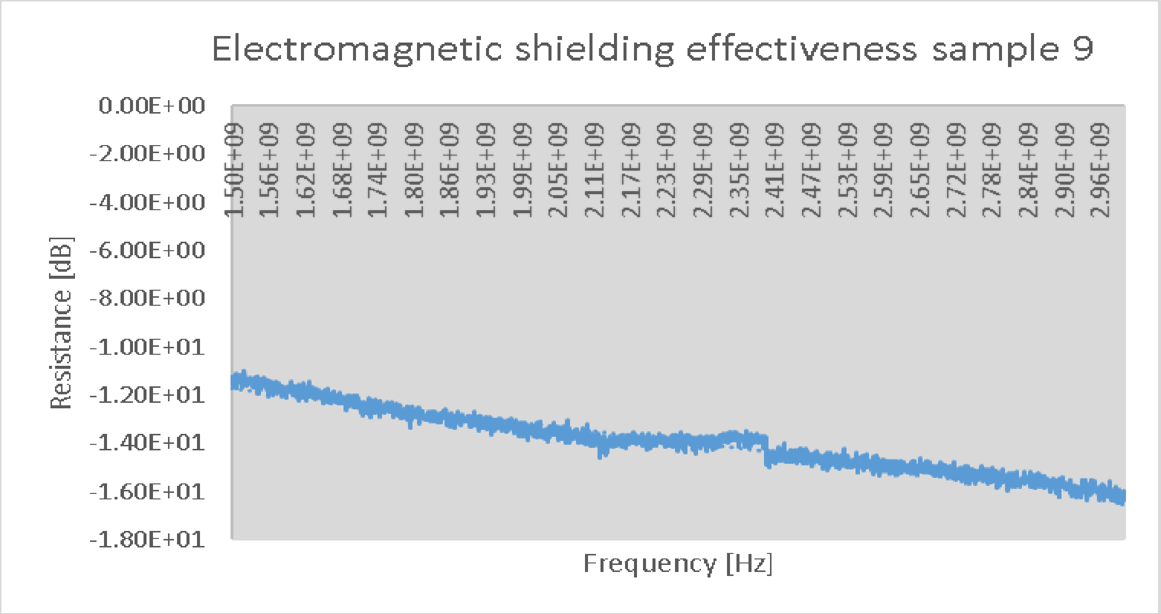


Figure 34: Electromagnetic shielding effectiveness of sample 9 on high-frequency range

In figure 34 the graph shows 16dB resistance at its peak. Which is acceptable for the facilities with lower radiation. Such as home textiles.

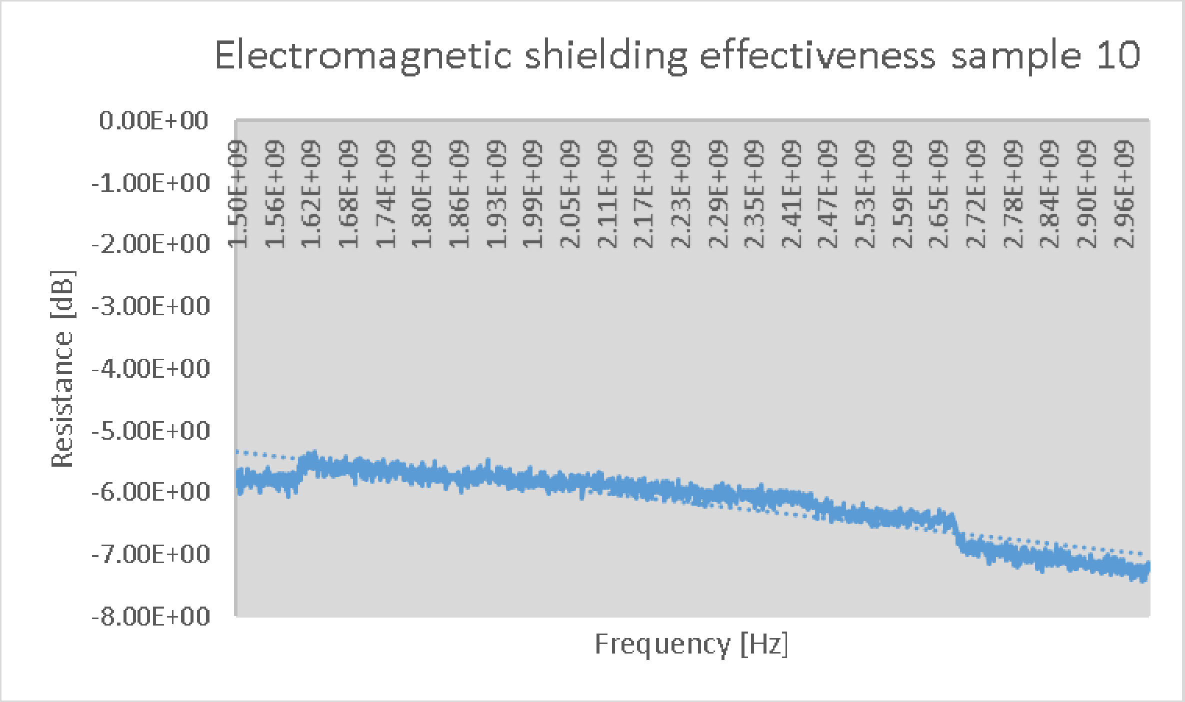


Figure 35: Electromagnetic shielding effectiveness of sample 10 on high-frequency range

In figure 35 the graph shows 7dB resistance at its peak. Which is very low for the acceptable shielding property.

From the Electromagnetic effective test, it’s clearly shown that sample 1,2,3,4 doesn’t have any prominent shielding effectiveness because of a very low amount of coating on one side. Sample 5.6.7 also doesn’t have any prominent shielding because of no uniformity of metal spraying all over the surface. Sample 9 with 150nm of copper coating on both sides shows an average of 16dB resistance with a frequency range from 1.5GHz to 3GHz (shows in figure 34). Sample 10 with 150nm of copper coating on one sides shows an average of 7 dB resistance with a frequency range from 1.5GHz to 3GHz (shows in figure 35). The difference between samples 9 and 10 is the copper coating on the fabric. Sample 9 copper was coated on both sides and sample 10 copper was coated on one side.

The shielding range of 10 to 30 dB is usually the lowest effective shielding level, while anything beyond that range is little to no shielding considered. The security from 60 to 90 dB is considered average, while from 90 to 120 dB is exceptional [56].

The table 12 shows the comparison between the resistances of sample on higher range.

Sample	Frequency [Hz]	Highest resistance [dB]
1	2.96×10^9	0.50
2	2.96×10^9	0.40
3	1.56×10^9	0.60
4	2.96×10^9	0.10
5	1.56×10^9	1.20
6	1.68×10^9	0.90
9	2.96×10^9	16
10	2.96×10^9	7

Table 15: Comparison between the resistances of sample on higher range.

6 Conclusion and plans

Light and lightweight protective materials such as textiles covered with metal layer can be use in EM shielding. With the huge increase of the use of Electromagnetic field sources, it is necessary to protect facilities. In this study, our main aim was developing an electromagnetic shielding fabric by the easiest technology and lightest way possible.

We use the method of treating spun bond nonwoven fabric as the cheapest and simple way possible. For that, we first compared different nonwoven fabric with a standard polyester made fabric. We compared the gsm of fabric and choose one nonwoven fabric on the basis of gsm. After we did pressing the fabric for better porosity. Also, with the same amount of metal coating the fabric with lesser thickness shows more resistance for electromagnetic frequency. Then we did experiment on metal-coated fabric. First we choose metal spraying on the surface of fabric. As metal spraying is one of the cheapest procedure available. For metal spraying the EM shielding was very low, because of the uniformity of metal on the surface of the fabric. For proper uniformity we tried galvanisation procedure. But it came out that for the lower conductive fabric these procedure is not applicable. That’s why we end up choosing plasma treatment method. Which is one of the cost effective method for industrial manufacturing. The end fabric also has better and uniform spreading of metal particles on the surface of fabric. The samples metal coated by spraying showed lesser than 1dB of resistance against the frequency of 30 MHz to 1.5GHz. One sided plasma treated samples with CuAg and Ag also showed lesser than 1dB of resistance against the frequency of 30 MHz to 1.5GHz. Fabrics which were plasma treated by Copper on one side, didn’t showed only around 9db of resistance lesser than 1dB of resistance against the frequency of 30 MHz to 1.5GHz. But the fabric with 150nm copper on both sides showed around 25 dB resistance against the frequency of 30 MHz to 1.5GHz. Which is suitable for use as home textile, clothing materials, curtains, interlinings. In plasma treatment process the metal layer on fabric is given by vacuum evaporation. Which is more eco-friendly than galvanisation process and more uniform then spraying method. The shift in plasma textiles saves a huge amount of chemicals and electrical energy, which is possible since a significant volume of waste or contamination is not produced by the plasma process. It increases the textile material's surface properties without altering its bulk properties. It is possible to modify the metal coating thickness at Nano meter range. This process also ensure more adhesion of the metals with the base fabric material. Plasma treatment on nonwoven fabrics has potential of large industrial production.

In future, it’s possible to produce metal coated fabric by plasma treatment with more resistance to electromagnetic frequency by only increase the thickness of metal coating.

7 References

[1] Dasaradan, B. S., & Perumalraj, R. (2010). Electromagnetic Shielding Effectiveness of Doubled Copper-Cotton Yarn Wovenmaterials. FIBRES & TEXTILES in Eastern Europe, 18(3), 74–80. https://www.infona.pl/resource/bwmeta1.element.baztech-91d71970-ed78-422a-965b-96edce7c6ee4

[2] kumar, R., & Thilagavathi, G. (2012). Electromagnetic shielding effectiveness of copper/PET composite yarn fabrics. Indian Journal of Fibre and Textile Research, 37(2), 133–137. https://www.researchgate.net/publication/287625723_Electromagnetic_shielding_effectiveness_of_copperPET_composite_yarn_fabrics

[3] Wikipedia contributors. (n.d.). Electromagnetic shielding. - Wikipedia. Wikipedia. https://en.wikipedia.org/wiki/Electromagnetic_shielding.

[4] P. (n.d.). The electromagnetic spectrum 129958274. Depositphotos. https://depositphotos.com/129958274/stock-illustration-the-electromagnetic-spectrum.html

[5] Sun Microsystems, Inc. (n.d.). Engineering Aspects of Electromagnetic Shielding. https://www.emcfastpass.com/wp-content/uploads/2017/04/Engineering-Aspects-of-Electromagnetic-Shielding.pdf

[6] Neruda, M., & Vojtech, L. (2018). Electromagnetic Shielding Effectiveness of Woven Fabrics with High Electrical Conductivity: Complete Derivation and Verification of Analytical Model. Materials, 11(9), 1657. https://doi.org/10.3390/ma11091657

[7] Tong, X. C. (2016). Advanced Materials and Design for Electromagnetic Interference Shielding. Amsterdam University Press.

[8] www.technicaltextile.net. (n.d.). Speakable Content. Technical Textile. https://www.technicaltextile.net/articles/electrical-properties-of-fibres-6699

[9] Xiao, H. (2019). Research Progress on Electromagnetic Textile Materials. Journal of Textile Science & Fashion Technology, 2(2), 1–4. https://doi.org/10.33552/jtsft.2019.02.000533

[10] Wikipedia contributors. (n.d.-a). Antistatic agent. - Wikipedia. Wikipedia. https://en.wikipedia.org/wiki/Antistatic_agent.

[11] Güneşoğlu, C., Güneşoğlu, S., Wei, S., & Guo, Z. (2016). The enhanced electrical conductivity of cotton fabrics via polymeric nanocomposites. Fibers and Polymers, 17(3), 402–407. https://doi.org/10.1007/s12221-016-5751-1

[12] Wikipedia contributors. (n.d.-c). Magnetic susceptibility. - Wikipedia. Wikipedia. https://en.wikipedia.org/wiki/Magnetic_susceptibility.

[13] Maity, S., Singha, M., Debnath, P., & Singha, K. (2013). Textiles in Electromagnetic Radiation Protection. Journal of Saf Ety Engineering, 2(2), 11–19. https://doi.org/10.5923/j.safety.20130202.01

[14] EMC/EMI Copper-Nickel coated polyester fabric. (n.d.). Soliani EMC. https://www.solianiemc.com/en/p/emc-emi-copper-nickel-coated-polyester-fabric/.

[15] 100% silver fiber Non woven EMF shielding fabric|Fabric| - AliExpress. (n.d.). Aliexpress.Com. https://www.aliexpress.com/item/32899814261.html?spm=2114.12057483.0.0.4b952213clKHPb

[16] Conductive Non-Woven Fabric -. (n.d.). Nano3dsystem. https://nano3dsystems.com/product/conductive-non-woven-fabric/

[17] Hulle, A., & A, P. (2018). Textiles as EMI Shields. Journal of Textile Science & Engineering, 08(02), 1–600. https://doi.org/10.4172/2165-8064.1000347

[18] Ueng, T. H., & Cheng, K. B. (2001). Friction core-spun yarns for electrical properties of woven fabrics. Composites Part A: Applied Science and Manufacturing, 32(10), 1491–1496. https://doi.org/10.1016/s1359-835x(01)00048-3

[19] Cheng, K. B., Ramakrishna, S., & Lee, K. C. (2000). Electromagnetic shielding effectiveness of copper/glass fiber knitted fabric reinforced polypropylene composites. Composites Part A: Applied Science and Manufacturing, 31(10), 1039–1045. https://doi.org/10.1016/s1359-835x(00)00071-3

[20] Lin, Z.-I., Lou, C.-W., Pan, Y.-J., Hsieh, C.-T., Huang, C.-H., Huang, C.-L., Chen, Y.-S., & Lin, J.-H. (2017). Conductive fabrics made of polypropylene/multi-walled carbon nanotube coated polyester yarns: Mechanical properties and electromagnetic interference shielding effectiveness. Composites Science and Technology, 141, 74–82. https://doi.org/10.1016/j.compscitech.2017.01.013

[21] Chen, H. C., Lee, K. C., Lin, J. H., & Koch, M. (2007). Fabrication of conductive woven fabric and analysis of electromagnetic shielding via measurement and empirical equation. Journal of Materials Processing Technology, 184(1–3), 124–130. https://doi.org/10.1016/j.jmatprotec.2006.11.030

[22] Cheng, K. B., Ramakrishna, S., & Lee, K. C. (2000a). Development of Conductive Knitted- Fabric-Reinforced Thermoplastic Composites for Electromagnetic Shielding Applications. Journal of Thermoplastic Composite Materials, 13(5), 378–399. https://doi.org/10.1106/mhkx-74a6-pkem-j7pl

[23] Perumalraj, R., Dasaradan, B. S., Anbarasu, R., Arokiaraj, P., & Harish, S. L. (2009). Electromagnetic shielding effectiveness of copper core-woven fabrics. Journal of the Textile Institute, 100(6), 512–524. https://doi.org/10.1080/00405000801997587

[24] Lin, Z.-I., Lou, C.-W., Pan, Y.-J., Hsieh, C.-T., Huang, C.-H., Huang, C.-L., Chen, Y.-S., & Lin, J.-H. (2017b). Conductive fabrics made of polypropylene/multi-walled carbon nanotube coated polyester yarns: Mechanical properties and electromagnetic interference shielding effectiveness. Composites Science and Technology, 141, 74–82. https://doi.org/10.1016/j.compscitech.2017.01.013

[25] Brzeziński, S., Rybicki, T., Karbownik, I., Malinowska, G., & Śledzińska, K. (2012). Textile materials for electromagnetic field shielding made with the use of nano- and micro-technology. Open Physics, 10(5), 1–600. https://doi.org/10.2478/s11534-012-0094-z

[26] Ozen, M. S., Sancak, E., & Akalin, M. (2014). The effect of needle-punched nonwoven fabric thickness on electromagnetic shielding effectiveness. Textile Research Journal, 85(8), 804–815. https://doi.org/10.1177/0040517514555794

[27] Çeken, F., Erdoğan, Ü. H., Kayacan, O., & Uğurlu, Ş. S. (2012). Electromagnetic shielding efficiency of nonwoven insulation panels designed with recycled textiles and copper wires. Journal of the Textile Institute, 103(6), 669–675. https://doi.org/10.1080/00405000.2011.598666

[28] Avloni, J., Lau, R., Ouyang, M., Florio, L., Henn, A. R., & Sparavigna, A. (2008). Polypyrrole-coated Nonwovens for Electromagnetic Shielding. Journal of Industrial Textiles, 38(1), 55–68. https://doi.org/10.1177/1528083707087834

[29] Ziaja, J. (n.d.). Using Plasma Metallisation for Manufacture of Textile Screens Against Electromagnetic Fields. Semanticscholar. Retrieved August 14, 2020, from https://www.semanticscholar.org/paper/Using-Plasma-Metallisation-for-Manufacture-of-Ziaja-Koprowska/e39c43438dcd9eb908f9e93df1498d6630f339ae

[30] Ozen, M. S., Sancak, E., & Akalin, M. (2014b). The effect of needle-punched nonwoven fabric thickness on electromagnetic shielding effectiveness. Textile Research Journal, 85(8), 804–815. https://doi.org/10.1177/0040517514555794

[31] Bonaldi, R. R., Siores, E., & Shah, T. (2014). Characterization of electromagnetic shielding fabrics obtained from carbon nanotube composite coatings. Synthetic Metals, 187, 1–8. https://doi.org/10.1016/j.synthmet.2013.10.003

[32] Lee, J., Liu, Y., Liu, Y., Park, S.-J., Park, M., & Kim, H. Y. (2017). Ultrahigh electromagnetic interference shielding performance of lightweight, flexible, and highly conductive copper-clad carbon fiber nonwoven fabrics. Journal of Materials Chemistry C, 5(31), 7853–7861. https://doi.org/10.1039/c7tc02074k

[33] Sonehara, M., Noguchi, S., Kurashina, T., Sato, T., Yamasawa, K., & Miura, Y. (2009). Development of an Electromagnetic Wave Shielding Textile by Electroless Ni-Based Alloy Plating. IEEE Transactions on Magnetics, 45(10), 4173–4175. https://doi.org/10.1109/tmag.2009.2021403

[34] Geetha, S., Kumar, K. K. S., Meenakshi, S., Vijayan, M. T., & Trivedi, D. C. (2010). Synergetic effect of conducting polymer composites reinforced E-glass fabric for the control of electromagnetic radiations. Composites Science and Technology, 70(6), 1017–1022. https://doi.org/10.1016/j.compscitech.2010.02.026

[35] Xu, D., Chen, W., & Liu, P. (2020). Enhanced electromagnetic interference shielding and mechanical properties of segregated polymer/carbon nanotube composite via selective microwave sintering. Composites Science and Technology, 199, 108355. https://doi.org/10.1016/j.compscitech.2020.108355

[36] Chen, J., Liao, X., Li, S., Wang, W., Guo, F., & Li, G. (2020). A promising strategy for efficient electromagnetic interference shielding by designing a porous double-percolated

structure in MWCNT/polymer-based composites. Composites Part A: Applied Science and Manufacturing, 138, 106059. https://doi.org/10.1016/j.compositesa.2020.106059

[37] Li, Y.-M., Deng, C., Zhao, Z.-Y., Han, L.-X., Lu, P., & Wang, Y.-Z. (2020). Carbon fiber-based polymer composite via ceramization toward excellent electromagnetic interference shielding performance and high temperature resistance. Composites Part A: Applied Science and Manufacturing, 131, 105769. https://doi.org/10.1016/j.compositesa.2020.105769

[38] Wang, Y., Peng, H.-K., Li, T.-T., Shiu, B.-C., Zhang, X., Lou, C.-W., & Lin, J.-H. (2020). Layer-by-layer assembly of low-temperature in-situ polymerized pyrrole coated nanofiber membrane for high-efficiency electromagnetic interference shielding. Progress in Organic Coatings, 147, 105861. https://doi.org/10.1016/j.porgcoat.2020.105861

[39] Ravindren, R., Mondal, S., Nath, K., & Das, N. C. (2019). Investigation of electrical conductivity and electromagnetic interference shielding effectiveness of preferentially distributed conductive filler in highly flexible polymer blends nanocomposites. Composites Part A: Applied Science and Manufacturing, 118, 75–89. https://doi.org/10.1016/j.compositesa.2018.12.012

[40] Gan, X., Wu, Y., Liu, L., Shen, B., & Hu, W. (2008). Electroless plating of Cu–Ni–P alloy on PET fabrics and effect of plating parameters on the properties of conductive fabrics. Journal of Alloys and Compounds, 455(1–2), 308–313. https://doi.org/10.1016/j.jallcom.2007.01.054

[41] Lu, Y., Jiang, S., & Huang, Y. (2010). Ultrasonic-assisted electroless deposition of Ag on PET fabric with low silver content for EMI shielding. Surface and Coatings Technology, 204(16–17), 2829–2833. https://doi.org/10.1016/j.surfcoat.2010.02.061

[42] Javadi Toghchi, M., Campagne, C., Cayla, A., Bruniaux, P., Loghin, C., Cristian, I., Burgnies, L., & Chen, Y. (2019). Electrical conductivity enhancement of hybrid PA6,6 composite containing multiwall carbon nanotube and carbon black for shielding effectiveness application in textiles. Synthetic Metals, 251, 75–84. https://doi.org/10.1016/j.synthmet.2019.03.026

[43] Han, E. G., Kim, E. A., & Oh, K. W. (2001). Electromagnetic interference shielding effectiveness of electroless Cu-plated PET fabrics. Synthetic Metals, 123(3), 469–476. https://doi.org/10.1016/s0379-6779(01)00332-0

[44] Lu, Y., Liang, Q., & Li, W. (2013). Fabrication of copper/modal fabric composites through electroless plating process for electromagnetic interference shielding. Materials Chemistry and Physics, 140(2–3), 553–558. https://doi.org/10.1016/j.matchemphys.2013.03.068

[45] Zhao, H., Hou, L., & Lu, Y. (2016). Electromagnetic shielding effectiveness and serviceability of the multilayer structured cuprammonium fabric/polypyrrole/copper (CF/PPy/Cu) composite. Chemical Engineering Journal, 297, 170–179. https://doi.org/10.1016/j.cej.2016.04.004

[46] Moučka, R., Mravčáková, M., Vilčáková, J., Omastová, M., & Sáha, P. (2011). Electromagnetic absorption efficiency of polypropylene/montmorillonite/polypyrrole nanocomposites. Materials & Design, 32(4), 2006–2011. https://doi.org/10.1016/j.matdes.2010.11.064

[47] Wikipedia contributors. (n.d.-d). Stress–strain curve. - Wikipedia. Wikipedia. https://en.wikipedia.org/wiki/Stress%E2%80%93strain_curve.

[48] Song, K., Pan, F., Chen, X., Tang, A., Pan, H., & Luo, S. (2014). Effect of Zn content on electromagnetic interference shielding effectiveness of Mg–Zn alloys. Materials Research Innovations, 18(sup4), S4-193. https://doi.org/10.1179/1432891714z.000000000676

[49] Electromagnetic Interference or EMI Shielding Material. (2020, January 16). Leadertechinc. https://leadertechinc.com/

[50] Ziaja, J. (n.d.). Using Plasma Metallisation for Manufacture of Textile Screens Against Electromagnetic Fields. Semanticscholar. Retrieved August 14, 2020, from https://www.semanticscholar.org/paper/Using-Plasma-Metallisation-for-Manufacture-of-Ziaja-Koprowska/e39c43438dcd9eb908f9e93df1498d6630f339ae

[51] Textile Metalization. (n.d.). Swicofil. https://www.swicofil.com/consult/innovations/conductivity/textile-metalization#:%7E:text=to%20vacuum%20deposition.-,ELECTROPLATING,coat%20of%20metal%20on%20textiles

[52] 곽. (2014, July 17). KR20160010700A - Method for Plating of Non-woven Fabric using Continuous Process of Electroless and Electrolysis Plating - Google Patents. Patent. https://patents.google.com/patent/KR20160010700A/en

[53] Kacprzyk, R. (2011). Measurements of the Volume and Surface Resistance of Textile Materials. Fibres and Textiles in Eastern Europe, 84(1), 47–49. https://www.researchgate.net/publication/298151296_Measurements_of_the_Volume_and_Surface_Resistance_of_Textile_Materials

[54] Kennisgeving voor omleiding. (n.d.). Google. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwi0i5qx06_qAhURsaQKHS5cDiQQFjAAegQIBBAB&url=https%3A%2F%2Ferris.gov.ro%2Fmain%2Fdownload.php%3Fid%3D5243%26wtok%3Da92bf41b5a0899f5617f4f9573cf1ee3ebd56a79%26wtkps%3DZY

[55] Index of /wp-content/uploads/2017/03/. (n.d.). Electro-Matrics. https://electro-metrics.com/wp-content/uploads/2017/03/ Product-Sheet-EM-2108.pdf.

[56] Measuring EMI Shielding Effectiveness. (n.d.). Thomasnet. https://www.thomasnet.com/articles/automation-electronics/effective-emi-shielding/#:%7E:text=In%20general%2C%20a%20shielding%20range,to%20120%20dB%20is%20exceptional.

[57] Safarova, V., & Militký, J. (2013). Electromagnetic Field Shielding Fabrics with Increased Comfort Properties. Advanced Materials Research, 677, 161–168. https://doi.org/10.4028/www.scientific.net/amr.677.161

[58] Products – By Property. (2019, June 4). Testex. https://www.testextextile.com/products/.

[59] S. D. R PerumalrajG. NalankilliG. NalankilliT R Balasaravanan, “Electromagnetic shielding tester has been modified to measure the electromagnetic shielding effectiveness (EMSE),” 2010.

[60] Harapad Root 2.0 EMF Laptop Computer Protector. (n.d.). Shop.Organiclivingaz.Com. https://shop.organiclivingaz.com/Harapad-Root-2-0-EMF-Laptop-Computer-Protector-p/root003.htm

[61] What is Core Spun yarn? Yarn produced at the ring frame by twisting staple fibers around a central filament core. In INVIYA® CSY, sp… | Spandex, Yarn, Cotton fiber. (n.d.). Pinterest. https://www.pinterest.com/pin/358951032794067907/.

[62] Militký, J., Křemenáková, D., Venkataraman, M., & Večerník, J. (2020). Exceptional Electromagnetic Shielding Properties of Lightweight and Porous Multifunctional Layers. ACS Applied Electronic Materials, 2(4), 1138–1144. https://doi.org/10.1021/acsaelm.0c00109