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Textiles for protection against Electromagnetic Radiations: A review

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ABSTRACT
Increased use of electronic devices creates a need to protect a present generation from the harmful effects of electromagnetic radiations. This review paper discuss about different textile materials that have been explored for shielding applications in place of conventional rigid metal shields. There are different techniques of producing such textiles and their mechanisms have been discussed here. Developments in this area are also taken into account with the help of recent studies. A brief review of the various test methods available for analyzing the performance of such fabrics is also reported.
Keywords- Attenuation, EM, Intrinsically Conductive Polymers (ICP's), Shielding effectiveness (SE)

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I. INTRODUCTION

With the advancement of wireless technology, people are becoming adaptable to more and more electronic devices which become indispensable parts of our daily lives. These devices raise different radiations in different frequency bands. As per the definition is given in Oxford dictionary, Radiation is the emission of bulk of high velocity energy as electromagnetic waves or as moving sub-atomic particles, especially high energy particles which cause ionization [1]. This ionization causes chemical reactions in body tissues which leads to serious health problems like cancer, nausea, genetic damage etc. [2]. So, protection against these radiations is gaining importance nowadays. Besides the protection against harmful effects to the human body, shielding against electromagnetic interference is a serious concern. Conventionally, metals, due to their high conductivity, are considered the best material to shield electromagnetic waves. But their use is very limited due to certain limitations like a heavyweight, poor dexterity, corrosion etc. The incorporation of conductivity in textiles has overcome these limitations [3]. Different ways to incorporate shielding properties in textiles and different test methods to check shielding effectiveness will be discussed later in this paper.

II. SOURCES OF RADIATION

Radiations can arise from many man-made sources such as microwave ovens, industrial electric furnaces, and wireless networks like Wi-Fi and Bluetooth or from main sources such as the magnetic field of the Earth and sunlight that contains visible, infrared and UV rays and many more harmful frequencies. Patients are exposed to nuclear radiations in diagnosis and cancer therapy etc. Depending on occupation, risks can be greater than average. People working in nuclear power plants, underground miners, radiologists, medical technologists are under different levels of radiation exposure [4]. Electromagnetic shielding textiles protect the passage by blocking the penetrations of radiations to the levels at which the effect can be minimized.

2.1 Effects of Radiation

In recent times, many people have studied the effects of EM radiations on health. It is found from many studies that, all kinds of radiation can cause some sort of health effects, these may be short-term (headaches, dizziness etc.) or long-term (brain tumor, cancer, memory loss etc.). Although the effect depends on the type of radiations you are exposed to, like, ionizing radiations shows the severe effect as they can penetrate into the tissue [2]. So, the major effects of radiations on human life include Dizziness, Headache, Memory loss, Change in the crystalline lens of the eyeball, Change in blood pressure, Cancer, Brain tumor, Anxiety, Birth defect etc.

Secondly, sometimes certain electronic equipment like pacemakers also face some interference due to electromagnetic radiations, debit and credit cards fail in a transaction if kept near to cell phones for a long time, oscilloscopes also show deviated results due to stimulation by radiations in surroundings [4].

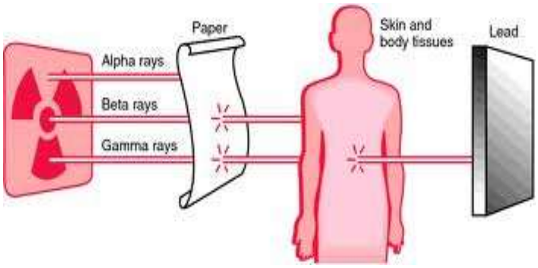

Fig.1. Passage of radiations through the human body **[4]**

III. MECHANISM OF SHIELDING

Based on the above-said effects, Radiation shielding textiles serve two purposes, first is to prevent the emissions of the electronics of the component from radiating outside the limits of the component, and secondly to prevent radiated emissions external to the component electronics, which may cause electromagnetic interfering in the component.

The electro-magnetic rays network with molecules of the medium or the body when they pass through them. The spectacle of interaction in figure 2 could be divided into three different mechanisms:

3.1. Attenuation due to Reflection

Reflection is the prime shielding mechanism. For this mechanism to occur, the shield must have free electrons or charge carriers [5]. As soon as the electromagnetic wave occurrence on the surface of the shield, the oscillation of free electrons takes place at the same rate of recurrence as the incident wave. This oscillation of charge will cause reflection. Reflection mechanism is generally shown by metals or metal coated fabrics [3-4].

3.2. Attenuation due to Absorption

The secondary mechanism of absorption depends on the thickness of shield. Absorption mechanism relates to the occurrence of electric and/or magnetic dipoles. Electric and magnetic dipoles can be provided by $BaTiO_3$ and Fe_3O_4 respectively [5]. The field is scattered due to the emission of the field in different directions, although the pattern of emission is related with a signal charge oscillating antenna. Energy is continuously lost in form of heat because the charge vibrates in the medium. This loss of signal is termed as attenuation due to absorption [4].

3.3. Attenuation due to successive internal reflections

In this mechanism introduces shielding is of multiple reflections. When the reflections occur at various surfaces or edges of the shield, then some part of the wave is replicated, and the rest part is spread and diminished on its passage through the medium. This mechanism requires the presence of large interface area in the shield, for example; Porous material or foam [5].

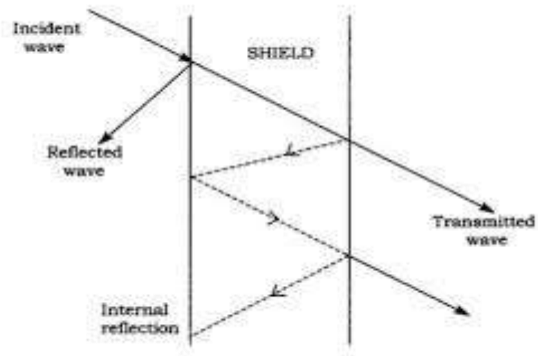

Fig.2. The phenomenon of Radiation Shielding **[5]**

IV. METHODS OF SHIELDING

Covering a body with any conducting media is the simplest approach to protect anything from electromagnetic radiations, as a conductive medium can generate and transport a lot of free charges. Based on this approach, the following are the different methods by which we can produce radiation shielding textiles;

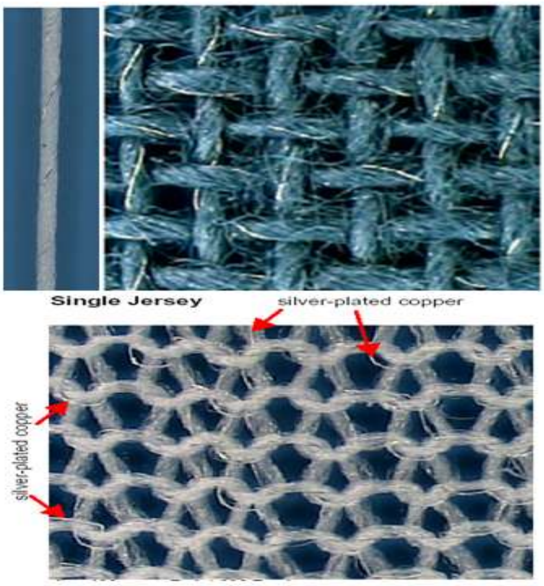

Fig.3. Method of Shielding **[1]**

4.1 EMI shielding by using Metalized fibres/yarns/fabrics

It is well known that synthetic fibres like polyamide, polyester etc. exhibits poor conductivity and the problem of static charge generation is associated with their use. However, natural fibers like silk and animal hairs comparatively exhibit good electric conductivity due to their high moisture content. But still these fibers do not serve the purpose of electromagnetic shielding [6]. The most effective way is to utilize the conductivity of metals along with fibers by different techniques like using metallic fibers, coating metals like copper, nickel, sliver etc. on fibers, using carbon black as conductive fillers and many more techniques comes along the way to achieve good shielding properties. Many techniques are used for the metallization of fibres and fabrics such as; laminating with aluminium foils, dying with copper sulfide or electroplating, using certain metals in electroless plating or vacuum deposition. Using DREF-III spinning to make hybrid yarns having metal wires in the core, is also another approach for achieving shielding effectiveness [7]. Copper wire and polyamide filaments used as core yarn were enveloped with polypropylene filaments for shielding fabrics as reported in a study by H.C. Chen et.al. [8]. Such conductive yarns and fabrics are capable enough to shield humans, home appliances and other electronic devices from electric fields. Similarly, the shielding effectiveness of stainless steel conductive yarns used in acrylic knitted fabrics was also reported in a study by [9]. Similarly, Woven fabrics made of amalgam yarn containing stainless steel wire shows a shielding effectiveness of 25-65 dB. Although shielding characteristics depends on several factors like, type of metal, direction, density, structure, humidity of the hybrid yarn [10-11]. The shielding efficiency of metallized textile fabrics is based mainly on reflection phenomenon which is not so good. So, materials that work on absorption phenomenon are gaining importance for electromagnetic shielding applications. One example of this kind of research was reported in a study in which a multi-layer fabric was designed with different layers coated with different materials and having different textile structures. This multilayer structure works on simultaneous absorption and reflection. Top layer works on absorption phenomenon and an internal (bottom) layer reflects residual incident radiation. By using such composite structures, it is possible to optimize the protective effect [12].

4.2. EMI shielding by using ferromagnetic substances

Ferromagnetic textile fabrics can be used to impart good shielding characteristics. These fabrics can be produced by introducing suitable substances into dope while extruding fibers or by spreading on surfaces. Ferromagnetic substances include metals; iron, cobalt, nickel, iron oxides, compounds with the general formula $MexFe^{+3}yO_2$, where Me is a mono-, bi- or trivalent metal, ferrites of the type $BaO \cdot Fe_2O_3$ and 9 $BaO \cdot Fe_2O_3$ [4,20]. However, 2-D metal carbides and nitrides (also known as MXenes) with general formula $M_{n+1}X_nT_x$ (where M is an early Transition Metal, X is carbon and T refers to functional groups such as –OH, =O etc) have capability to shield surfaces from electric fields. Sometimes graphites also show good conductive properties [13, 20].

4.3. EMI shielding by using ICP's

Polymers possessing the electric, magnetic and optical properties of a metal as well as retain the basic properties like, mechanical properties, processability etc, associated with a polymer, are termed as Intrinsically Conducting Polymers (ICP's) [14]. These are conjugated polymers having single and double bonds at alternate positions in the polymer chain, due to this charge carriers move freely along the chain once a dopant is added. They offer certain advantages as compared to conventional ways for EMI shielding applications such as low density, corrosion resistance, ease of processing, and moderate conductivity. In recent years, Polyaniline and Polypyrrole have a major focus for shielding application of textile while other ICP's, such as Polythiophene, poly-p-phenylene-benzobisthiazole (PBT), and/or their derivatives, is also studied [14-15,17-18]. Polypyrrole (PPy) can be sequentially polymerized chemically and electrochemically on a polyester is a woven fabric having high electrical conductivity [19]. It was reported that Polypyrole coated polyester fabric shows enhanced conductivity as it shields the EMI by absorption as well as reflection [15]. The reflection contribution to electromagnetic shielding can be increased by adding dopants. The same was reported in a study by using different concentrations of para-toulene-2-sulfonic acid as a dopant and ferric chloride as an oxidant, on polypyrole coated polyester fabrics. It was shown in figure 4 that reflection upsurges with increase in the concentration of dopant pTSA and polymerization time [16].

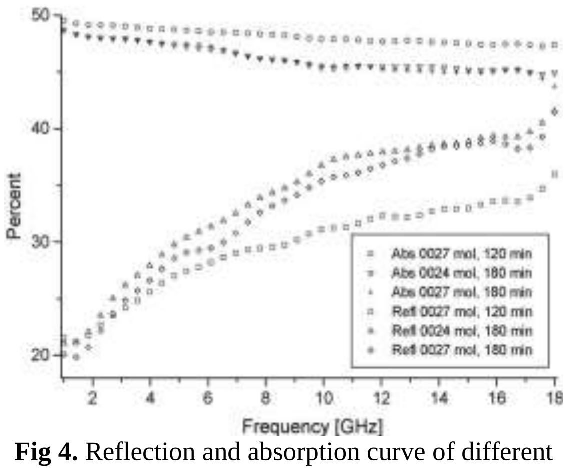

Fig 4. Reflection and absorption curve of different samples with different concentration of dopant and polymerization time **[16]**

Similarly, Polyaniline based conductive polymers are used for absorbing microwaves, by insitu polymerisation method using Ta_2O_5 as a dispersion media [17]. Double conducting polymer layer can be achieved by polymerising Polyaniline electrochemically on polyester substrate coated with Polypyrole [18].

4.4. Measurement of shielding

4.4.1. Shielding efficiency

Shielding Efficiency (SE) is distinct as the ratio of the strength of electromagnetic field restrained before and after the installation of protective shielding material [20]. The value of SE determines the level of prevention. It can also be defined as the ratio of power acknowledged with and without shielding sample present for the same incident power [4].

SE= 10 log P_1/P_2 (Decibels, dB)

P_1= power received with the sample present

P_2= power received without the sample

4.4.2. Insertion loss

Insertion loss is a measure of the losses or diminution, of a transmitted signal caused by the insertion of shielding sample into the measuring channel [4, 20]

$$\text{Insertion loss (dB)} = 20 \log (U_0/U_1)$$

U_0 - output voltage without the sample,

U_1 - the same voltage as the sample.

Various test methods and techniques like ASTM D-4395-10, complex permittivity approach, Transverse Electromagnetic Cell (TEM), Dual TEM cell etc. are available to measure the shielding characteristics of textiles in different frequency ranges as mentioned in Table .1 [21-22].

Table 1. Various test methods and their operating frequencies **[21]**

Test method	**Operating Frequency Range**
ASTM D-4395-10	30MHz-1.5GHz
complex permittivity approach	100MHz-3.5GHz
TEM	1MHz-1GHz (E-field) 1MHz-400MHz (H-field)
Dual TEM cell	100MHz-2GHz
Time Domain	200MHz-3.5GHz

As reported in a study, an innovative tester is developed for depiction of electromagnetic shielding effectiveness of conductive textiles in low to high operating frequencies (500 MHz-12GHz). It was also reported in the study that this modified tester gives good results as compared to standard analyzer even in the high-frequency range of 8-12 GHz [23].

4.4.3. Commercial Products

A wide range of products is available commercially for protection against electromagnetic radiations depending on the level of protection required. Few of them are listed below.

4.4.4. ArgenMesh

ArgenMesh is silver mesh fabric composed of 55% Silver and 45% Nylon, having good conductivity and shielding properties of pure silver threads and strength of nylon. It provides a shield of 50 dB from 100 MHz to 3 GHz. This offers a surface conductivity of <1 ohm per square and fabric weight of around 3.6 oz/yd^2. This fabric is safe for contact with skin and can be used for garments and bedding, and also for curtains and wall coverings [24].

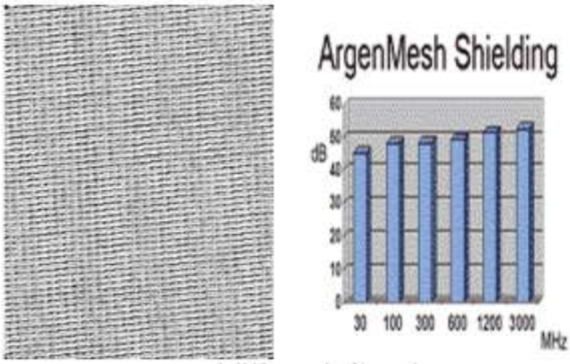

Fig.5. Argenmesh Shielding properties of Argenmesh **[24]**

4.4.5. Ex-Static™ Conductive Fabric

This light weight conductive woven fabric is composed of 87% polyester, 13% gray BASF Resistant (carbon) fibers, offers a surface resistivity of 105 Ohms per square. This fabric is extremely comfortable due to its light weight of only 3 oz/square yard and extremely durable that its conductivity holds up to 50 or more low heat washes. It can be used to make ground covers, appliance covers, clothing, drapes, room dividers and many more [24].

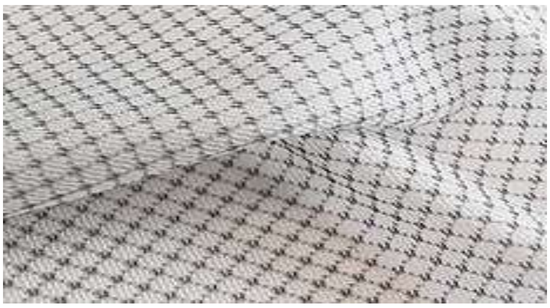

Fig. 6. Ex-Static™ Conductive Fabric **[25]**

Shieldex also provides a range of conductive yarns and fabrics (woven, nonwoven, knitted) for different shielding applications [25]. The market for these type of products is huge and expanding day by day.

V. CONCLUSION

Increasing use of electronic devices in this technological era, give rise to the use of EM shielding textiles. So that the harmful effects of these radiations on human beings as well as interference with electronic equipment can be avoided. The easiest way to impart EM shielding ability is by making the textiles conductive. In the recent past, various techniques are developed for achieving this level of conductivity, either it by metalizing the textiles, by using ferromagnetic substances or by use of ICPs like polyaniline and polypyrole etc.

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