

# Review and Analysis of Contemporary Polymer Coats based Electromagnetic Shielding Strategies

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## Abstract

**Objectives:** To understand the existing solutions in electromagnetic shielding strategies categorically on polymer coats based solutions to understand gaps and issues in existing solutions. **Methods/Statistical analysis:** The method adapted for the process is to conduct a detailed review of literature. Many studies were carried out earlier in the domain. Reviewing such studies, the solutions proposed in the earlier contributions and focusing on the research reports that discuss the directions for future course of research in the domain are the priorities. On the basis of inputs gathered from various studies, the information is collated to derive the requisite information. **Findings:** It is imperative from the study that predominantly the electromagnetic shielding using the polymers was on lead based solutions. Lead based polymers are used for designing the special aprons and solutions that can support in improving the shielding effects. However, one of the key challenges with lead based protective gears are about the increased weight of the apparel and advanced solutions like CNT can be more resourceful for EM shielding. **Application/Improvements:** CNT is one of the contemporary solution that is explored in the shielding of electromagnetic radiation and if the CNT polymer composites with blended process can increase the efficiency of shielding electromagnetic radiation.

**Keywords:** Apparel Coating, Carbon Nano Tubes, Polymer, Electromagnetic Shielding, Lead based Coating, Radiation Impact

## 1. Introduction

Environmental impact is one of the pressing challenges envisaged by the nations across the world. Though the technological advancements are being supportive in improving the quality of life, engineering science and development, as a side effect to the conditions, environmental impacts in various forms are very high<sup>1</sup>. Right from climatic change, global warming, and impact of electromagnetic radiation levels rising high, there are numerous challenges that are impacting the eco system.

Among the varied elements that impact the environment and the quality of life, electro-magnetic radiation is one of the key issues that is raising high concerns. With the rampant developments of ICT (information and communication technology solutions) and wireless technology advancements, the impact of exposure to electro-magnetic radiation has grown

exponentially<sup>1</sup>.

Numerous researches are carried out in vivid dimensions towards addressing the issue of electromagnetic radiation. While few researches are focusing on reducing the stream of developing technologies and solutions towards reducing the radiation emission and control, few researches are also focusing upon prevention and shielding from radiation impact<sup>2</sup>. In this research paper, the focus is upon one such dimension – where the shielding from electromagnetic radiation is considered for the process.

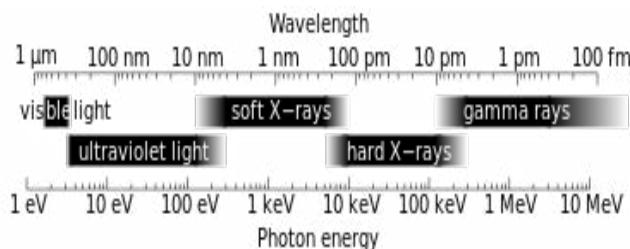
In the further sections of this report, the focus is upon reviewing the aspects of electro-magnetic radiation, how it impacts the individuals, the contemporary research that has taken place in the domain of shielding electromagnetic radiation and the scope for research towards futuristic solutions that can be resourceful in developing contemporary solutions for electromagnetic shielding.

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## 1.1 Brief Intro of Electromagnetic Radiation

Electromagnetic (EM) radiation is a kind of energy widespread and emits as Gamma rays, X-rays, Microwaves, and Radio-waves. In the recent past, with exponential growth of cellular network solutions, there is significant rise in the quantum of microwave radiation. For instance, the cell phone towers emit high frequency radio waves or microwaves that can travel as far to 45 miles over level terrain and it is imperative that with such high volumes, for individuals exposure to radiation is dynamically high. Even the sunlight is a form of EM energy, however, visible light is miniature portion of EM spectrum comprising broad range of electromagnetic wavelengths<sup>3</sup>.

Electromagnetic waves comprising electromagnetic radiation can be perceived as self-propagating transverse oscillation wave of electric and also the magnetic fields. Figure 1 depicted above reflects a plane linearly polarized EMR wave propagating from left to Right (denoted in X-axis) and the electric field is represented in vertical plane (denoted in Z axis) and the horizontal axis (denoted in Y-axis) depicts the magnetic field. Electric and magnetic fields in EMR waves constitute as a phase and at 90 degrees to each other.



**Figure 1.** Electro Magnetic Wave Composition<sup>3</sup>.

### 1.1.1 The EM Spectrum

EM radiation spans to significant range of frequencies and wavelength, known as electromagnetic spectrum. Profoundly, the EM spectrum is categorized in to seven regions for decreasing wavelength and also towards increasing energy and frequency. Some of the common spectrum ranges that are defined are Radio waves, IR (infrared), UV (Ultra Violet), visible light, X-rays and Gamma rays. Lower energy radiations like the radio waves are defined as frequency. Spectrum like microwaves, infrared, visible and UV light are categorized as wavelength and higher-energy radiation like X-rays and gamma rays are defined in terms of energy per photon<sup>3</sup>.

## 1.2 Electromagnetic Pollution

ICT (information and communication technologies), emerging environmental changes are drastically impacting the environment and quality of living. When compared to the yesteryears, currently there is manifold rise in the quantum of radiation emission and exposure to varied kinds of radiation. For instance, with rising temperature levels year on year, the level of exposure to UV radiation is growing very high. In the other dimension, with cellular network towers being erected at varied locations, the radiation emitting from waves are also high. Increasing radiation from sources like power lines, electrical appliances, and other microwave emissions are compounding the problem, thus resulting in conditions of electromagnetic pollution, and there is inherent need for the people to ensure that they are protected from high levels of exposure to electro-magnetic radiation<sup>4</sup>.

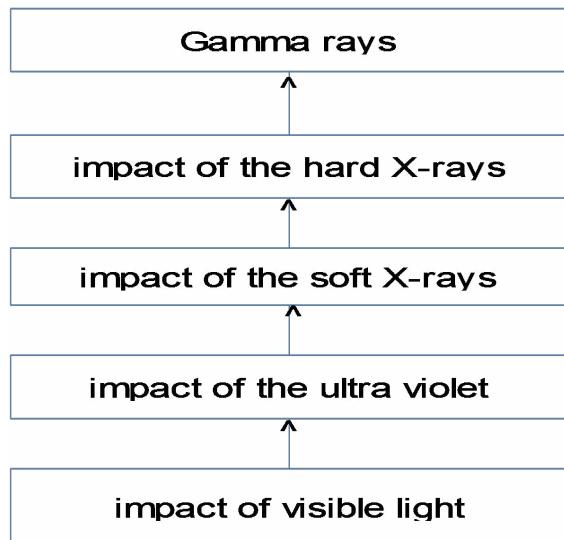
Also, the contemporary solutions and technologies that are adapted are also fuelling the rise of electromagnetic pollution. In many instances, the electromagnetic pollution is higher than other sources of electromagnetic fields or radiation.

The impact of such electromagnetic pollution leads to many implications. There are extremely low frequency electromagnetic fields that are categorized as potentially carcinogenic. And many researches are carried out to understand and develop shielding mechanisms and reduce the impact of electromagnetic radiation in the environment<sup>5</sup>.

## 1.3 Impacts of Electromagnetic Radiation

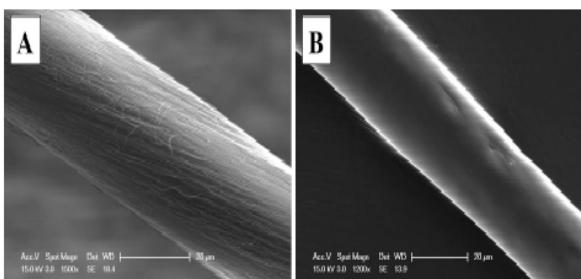
The impact of electromagnetic radiation can lead to significant damages to living bodies, and predominantly the impact and effect varied based on the frequencies. In every EM radiation, there are photons which are small particles which influence the effects. The energy of a photon is profoundly determined using Planck's law. With the rising frequencies, even the photon energy increases and the impact of radiation could grow exponentially<sup>6</sup>.

It is imperative from the Figure 2, that with rising levels of photon frequency, the photon energy also raised and there is need for shielding from high energetic photon<sup>6</sup>. Impact of radiation over the human body increases with EM radiation energy as detailed below.



**Figure 2.** Photon Energy Levels-Frequency<sup>6</sup>.

The sequence in which the frequency levels are classified in the chart in Figure 3. The impact of EM radiation levels are depicted.



**Figure 3.** Electromagnetic radiation levels<sup>6</sup>.

### 1.3.1 Ionizing Radiation: Gamma Radiation, X-rays and Ultraviolet Light

With the high EM radiation, photons will have adequate energy for ionizing atoms. In the case of X-rays, similar to radio waves, they pass through most of the materials without interaction and it's safe for using the X-rays over patients in a restricted zone. Despite that the process of screening x-rays are safe, still because of rare interactions, there are significant chances that the cells might get affected (however, in the case of radio waves with lesser frequency, such issues do not creep up) and to reduce constant exposure, screens are used during X-ray process<sup>6</sup>.

Usually, among the vivid range of exposure in routine life, UV radiation is a cause of concern. UV based

radiation is marginally higher frequency (with higher levels of energy per photon) than the light and is absorbed by majority of substances. Even the skin absorbs high levels of UV radiation, thus leading to implications like cancer and skin related problems<sup>6</sup>.

### 1.3.2 Health Related Impacts of Radiation

DNA is the double helix chemical strand that handles the process of protein generation in the cells, which is a complex process. Chemical bonds play a vital role in holding the DNA together, similar to the other molecules. High energy photons usually have the ability to impact the electrons out of their orbits or even can interact to the nucleus of an atom. With higher frequency of radiation, such damage to DNA is feasible, and leads to implications like turning the cell into cancer cells or as genetically damaged cells are either destroyed or self-destructed<sup>6</sup>.

It is imperative from the review of studies carried out on varied kinds of radiation and its related impacts that, exposure to UV light from the sun is the pivotal challenge than many of the human technologies based radiation emission. Also, the frequencies that are used in telecommunications equipment do not comprise high enough frequencies for ionizing, irrespective of the strength of signals. But with the emerging set of researches, there are many other studies too that emphasize on some kind of impact that is envisaged by human life with the radiation emission from the mobile and wireless communication system networks<sup>6</sup>.

## 1.4 Need for Shielding from Electromagnetic Radiation

Electromagnetic radiation in one or the other form has significant impact over the living bodies. The impact and effect might vary based on the frequency ranges and also how often an individual is exposed to such radiation. Considering the evolving life style and the kind of developments that are taking place, it is very essential that the preventive action of shielding from electromagnetic radiation is also offered significant importance.

For instance, bioelectrical signals support in regulating many processes of the human body. The studies suggest that every cell in the body possess its own electromagnetic frequencies. But the strong EM frequencies penetrate in to the body and interfere with natural phenomenon of the body, thus impacting the complete cycle right from the sleep cycles to stress levels and immunity levels etc<sup>7</sup>.

Globally, there are many researches that have taken place in terms of solutions for electromagnetic shielding mechanisms. Some of the significant models of electromagnetic radiation shielding mechanisms are<sup>8</sup>.

## 2. EMR Shielding

EMR shielding as a subject has gained significant interest in the recent past and there are many researches that has suggested big leap of solutions towards addressing the EMR impact. Predominantly, the key solution that has come up from the researches are to ensure protection from the radiation, using varied range of chemical coating and polymer combination that can lead to better protections.

In<sup>9</sup> materials for electromagnetic interference (EMI) shielding of electronics and the other such radiation sources are reviewed. Emphasis has been more on composite materials and the resilient EMI gasket materials that handles the process of shielding by enforcing the reflection of radiation at high frequency levels.

### 2.1 Radiation Shielding Materials

Radiation is a key concern at all levels. Right from social life exposure to radiation like telecommunication based exposure, to the industrial level exposure. Contemporary literature has supported with considerable insights over various radiation shielding materials and its performance over the period. Shielding the industrial properties, devices, and mainly the humans, from the impacts of radiation is a significant issue and the earlier researches have focused upon many sensitive shielding materials, combinations that could ensure protection from EM radiation<sup>10</sup>.

Process of regulating the effects and quantum of penetration of radioactive rays might vary based on type of radiation exposed too. The process of indirect ionization of radiation (comprising neutrons, x-rays and gamma rays) is a different classification when compared to directly ionizing radiation, comprising charged particles. Varied range of materials is best suited for specific kinds of radiations, and can yield better results to certain issues. However, to large extent, such results depend on the interaction of specific particles and structural characteristics of the shielding material used<sup>10</sup>.

Some of the commonly used radiations shielding materials that are used in the process are:

- Traditional Lead (Pb) shielding
- Lead (Pb) composite shielding
- Non-Lead (Pb) and Lead (Pb) free shielding<sup>11</sup>.

### 2.2 The Three Types of Radiation Shielding Materials

Lead has been one of the significant components that is adapted in radiation shielding process. Some of the key reasons why lead has been chosen for the process is that, material is cheaper, easy to process, and also offers shielding that is durable. However, concerns pertaining to health, safety, and other environmental factors (mining, handling the lead, disposal of lead etc.) has lead the researchers to focus on alternatives for lead as the key component towards electromagnetic shielding. In many countries, usage of lead in certain product ranges, and solutions for varied applications has been regulated<sup>12</sup>.

#### 2.2.1 Traditional Lead Shielding

Lead as a chemical element possess the characteristics like its soft, malleable, and resistant to corrosion, and such factors make it a very ideal material for usage towards long-term protection. In its pure form, lead is brittle and is not a fit solution to be worn as apparel, but when mixed as a polymer coating, certainly the solutions are more effective and produce the requisite outcome. For instance, upon blending the lead with vinyl and other kind of binders, it is turned to flexible and durable material. Traditional lead-based materials are currently considered as toxic and disposal issues lead to consideration of alternatives for developing alternative solution<sup>12</sup>.

#### 2.2.2 Lead Composite Shielding

Lead composite shielding as a structure comprise mixing of lead with much lighter materials to ensure quality shielding materials are generated. Lead based composite blends are a proprietary mixture of lead and other such heavy metals that results in attenuate radiation. Compared to traditional lead based solutions, composite radiation shielding materials are lighter and are offer similar levels of protection (with same levels of lead equivalency)<sup>12</sup>.

#### 2.2.3 Lead-Free Shielding

Non-toxic and polymer based composite materials offer an efficient and effective solution for eliminating the

hazards that are usually associated with lead materials. It is usually available with lower costs compared to the other alternative materials, thus offering robust defence to the increasing consumption of lead.

The materials are produced using the techniques of composite engineering, but without using the lead. Composite modelling has supported experts in creating materials, that when combined, shall offer similar quantum of protection to the lead composite shielding. Lead-free composites are usually customizable, with wide range of densities, flexibilities and impact strengths, alongside heat-deflection temperatures. Such eco-friendly and durable materials can be resourceful as lead replacement for radiation shielding or weighing applications<sup>12</sup>.

### **2.3 Restriction of Exposure - Hazard Control**

To minimize the exposure to ionising radiations, there is integral need to consider the properties of ionising radiations and the key impacts that could be envisaged from them.

Two significant ways in which the radiation could impact human system is by external hazard and internal hazard. All the hazards from ionising radiations could be minimized using the lowest activity source or the energy of X-rays that are consistent to experimental needs<sup>13</sup>.

#### *2.3.1 External Hazard*

Penetrating radiation are the key reasons for external hazards. In<sup>13</sup>, the authors discuss more about scope of hazards and the need for addressing the impacts. For instance radiation emission from X-rays, Gamma emission, hard beta emittance and neutron sources are intrinsic external hazards. The impact of hazards rises proportionately with the rising levels of penetration and the frequency. Unless there is significant shielding performed it may not be feasible for thwarting the impact of radiation<sup>13</sup>.

#### *2.3.2 Internal Hazard*

Working with open or unsealed sources of radioactive material, there is significant scope that the material might get penetrated in to the human system, thus leading to internal radiation hazard<sup>13</sup>. As discussed in<sup>13</sup> there is integral need for preventing impact of radiation in every possible manner.

In the process of shielding from EM radiation, there are many practices that are adapted. From the review of literature<sup>14-16, 8,7</sup> some of the significant methods that are currently practiced are:

- Limiting the scope of exposure to radiation
- Ensuring that the devices and systems that are produced are eco sustaining with lower levels of emissions
- Shielding measures like polymer and textile coating solutions that could protect the resources from the effects of radiation.

Predominantly many researches in the recent past have focused upon the system of polymer coating in varied combinations that could help in shielding from radiation. Experimental studies and comparative analysis of various studies reflect the efficacy of the varied solutions that were proposed.

### **2.4 Textile Coating for EM Radiation Shielding**

In<sup>17</sup> researchers recommended that to a minimum value of 0.25mm of lead equivalent shielding is very essential to shield a person in an environment having scattered radiation. And 0.50 mm of lead equivalent shielding is very essential for ensuring protection from direct radiation beam like the x-ray tubes etc.

As discussed in<sup>18</sup>, protective gears like specially designed clothing has significant impact in terms of securing the people from the impact of radiation. Lead-shielding products like the aprons play a key role in the protection of people working in radiation environment<sup>19-22</sup>. But the toxicity of lead being a key concern<sup>23</sup>, many studies have considered application of other alternatives than lead. In<sup>18</sup>, the researchers advocate that, as lead aprons are composed of very thin layer application on aprons and bedsheets, certain intrinsic challenges like cracking problems in the polymer could take place due to extensive usage, bending and incorrect hanging etc.

In<sup>24</sup>, BaSO<sub>4</sub> (Barium Sulphate) is used an environmentally friendly shielding material which could be used for protection from radiation. Barium Sulfate is incorporated in to polymer with weight ratio of 60% at high loading levels. The experimental results depict that apart from not much of loss to the physical properties of polymer, there is good resistance from the solution. Also, the proposed solution is resistant to acids and alkalis<sup>25</sup>.

In<sup>26</sup> has focused on the societal and ground level radiation issues like workplace environment, radiation emission from mobile network towers, Wi-Fi solutions and Radio Frequency related challenges. The study has suggested silver-lined clothing made of 90% rayon and 10% silver, which could result in protection up to 90% for RF emissions, between range of 20Mhz and 8Ghz (cell towers emit 900 MHz is emitted by mobile network towers and LTE cell phones emit 2.4 GHz). It is imperative from the discussions that the output from the high conductivity materials offers antistatic properties and with the blend of silver, there is significant cut down of odour by inhibiting the growth of bacteria.

In<sup>26</sup> the solution of Swiss Sled Wear Fabric has been discussed wherein, cotton-based fabric woven with silver-copper thread and cotton fibre has been proposed. The study emphasize that the solution can be more resourceful for clothing and bedding, as the fabric shall be light, flexible and soft. The literature emphasize that even after tough usage of the fabric, Swiss shield fabric can be 99% effective in term of protection against RF based radiations up to 1000 MHz.

The other existing range of Apparel product in the market is from Holland Shielding systems BV, wherein the apparels fabric are made with Anti-EMI/RF solution, and delivers protection from radiation to significant extent. The fabric is made of materials used for Faraday tents, and it is easier for regular usage. Test results of the materials depict that protection from RF field's emission is feasible to the level of 90% with frequency range of 800 MHz to 18 GHz<sup>27</sup>.

Many studies have focused upon vivid range of polymer coating solutions that could support in better levels of protection from the radiation emission. Some of the common phenomenon that was observed in the case of polymer coating based solutions proposed in the earlier studies are:

- To ensure that the proposed coat and polymers yield quality protection from varied range of emissions
- Secondarily, the process of coating should not be a costly affair impacting the mass production and regular usage

Despite the fact that many polymer coat solutions were proposed, there were certain kind of limitations that were envisaged in the process and solutions. In the contemporary literature one of the key areas that has

been focused upon and numerous solutions that were discussed are with CNT (Carbon Nano Tubes) oriented polymer coating for reducing the impact of reduction on the human body.

Preliminary review of various solutions that were offered with CNT solutions emphasize that application of CNT is one of the effective solutions that could lead to more effective apparel coating that could lead to shielding the radiation emission.

### 3. CNT Oriented Apparel Coating

CNT (Carbon Nano Tubes) has been a prominent solution because of its effective outcome in terms of exhibiting unique physical properties which could impact wider range of solutions in science and technology. Right from robust and strong composites to Nan electronics there are wider aspects in which the CNT solutions are implemented<sup>28,29</sup>. Many experimental studies that were carried out over CNTs reflect that they are among the stiffest range of materials<sup>30,31</sup> and are flexible (buckle elastically rather than fractured segment) even in wide range of bending and compressive strains<sup>31,32</sup>. The mechanical properties inherited in CNT allow it to be an effective reinforcement in composite materials. Such intrinsic properties ensure that CNTs tighten the matrix even in high temperatures, and increase the toughness of composites by absorbing energy.

Also, in the case of CNT, the benefit of low density in CNT-based polymer composites when compared to carbon fibre with reinforced composites is high. While the high surface area of CNT structures and the dimensions with polymer chains could support in composites acquired with new properties can be more resourceful for radiation controls. An electronic property of CNT<sup>33,34</sup> has been more resourceful in improving the efficacy of many applications.

In<sup>35</sup> it has been observed that usage of CNT materials comprising longer CNTs and little impurities could support in fabrication of CNT yarns constituting mechanical and electrical properties, representing properties of individual CNTs.

In<sup>36</sup> and<sup>35</sup>, the study affirms that among the commonly used approaches for CNT fiber, mass manufacturing process depends on gas fiber spinning as it generates CNT fibres without any interruption. However, the levels of fiber purity, structural disruption and lowered

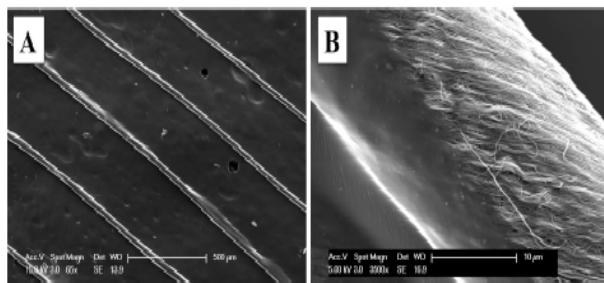
levels of tensile properties of the spun material could drop because of contaminant resulting from catalysis of nanoparticles<sup>35, 37</sup>.

Wet spinning CNT fibre is produced using conventional process that is similar to the ones that are used in polymer fiber. CNTs are dispersed in solvents and even some kind of additives might even be adapted. CNTs that are dispersed in strong acids can be used for spinning highly conductive CNT fiber<sup>38-41</sup>. Dry spinning using VA (vertically aligned) solutions is also popular because of its simplistic approach of fiber spinning<sup>42-45</sup>. Dry spinning are discussed in<sup>42</sup> which results in metal nanoparticle contaminants in the yarn.

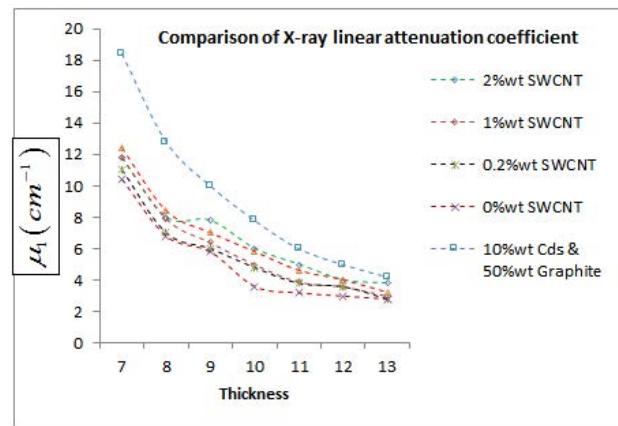
In<sup>42</sup> the spinable CNT yarns are seen as integral for developing new applications, as it supports in developing diverse range of commercial products<sup>46, 47</sup>. CNT has been successfully applied on EM shielding films, sensors and composites at varied range of applications<sup>46-50</sup>.

BY a simple dip-coating approach, CNT fiber can be formed in to a polymer solution and in a constant speed pulling out of the polymer coated yarn is also feasible. Dip-coating also supports in protecting CNT threads from any kind of mechanical tearing in the instance of contact.

HNBR concentration is proposed in<sup>51</sup>. In the proposed solution HNBR polymer concentration at levels of 5.5gms/100 ml shall offer a uniform and continuous film along the complete CNT fiber. Higher polymer concentrations results in higher polymer aggregates along the fiber, which impacts the uniformity of coating. Difference in diameter of fiber could be an outcome of CNT fiber classification post coating. For instance, distinctive CNT fiber upon organic solvent diffusion within the fiber results close to 24% diameter shrinkage in acetone<sup>52</sup> can be envisaged. Figure 4 and 5 indicates the pristine and polymer coated CNT fibres.



**Figure 4.** SEM images of (A) Pristine and (B) Polymer coated CNT fibres<sup>52</sup>.



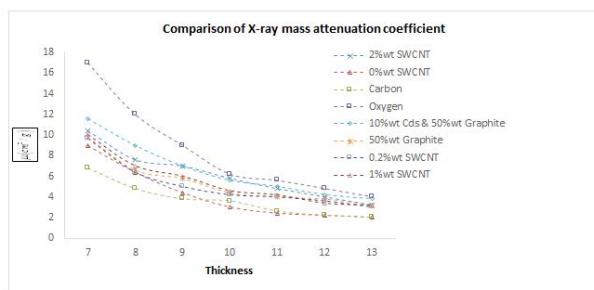
**Figure 5.** SEM images of several coated CNT fibres that (A) illustrate the uniform nature of the polymer coating.

### 3.1 Attenuation Properties for CNT

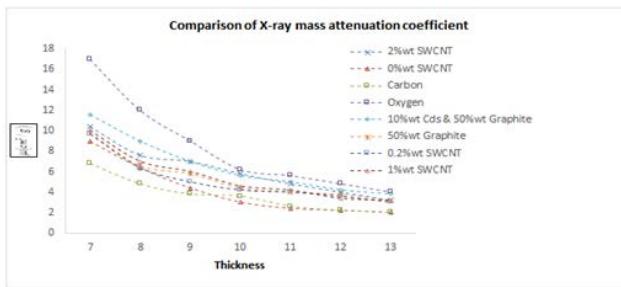
CNTs induce the X-ray attenuation in an outstanding phenomenon. In<sup>53</sup>, researchers have observed that mass attenuation coefficient of CNTs with higher significance value (>100%) than the ones that are observed with HOPG (Highly Oriented Pyrolytic Graphite) and Fullerenes (C60). In<sup>53</sup>, attenuation coefficient of CNTs was increased simple by reducing the thickness levels. For instance, the samples that are basically composed with EPOC 828(commercial epoxy resin) and hardener that is amine-based (1:4wt% vs. resin), along with single wall CNT SWCNT - Carbolex, diameter 1-2nm, length 5-30μm) and micro-sized graphite powder (Sigma Aldrich, granulometry<20μm) in different weight percentages). In<sup>54</sup>, focused on outlining the differences in behaviour emerging because of graphitic carbon organized in crystallinity size.

Figure 6 denotes X-ray linear attenuation coefficient of varied carbon based epoxy composite samples in the domain of shielding. However, the heavy graphite based sample attenuation matches and overcome respectively with 1wt% and 2Wt% for filled triangle and rhombus SWCNT-filled composite sample performance<sup>54</sup>.

In the Figure 7, X-ray mass attenuation coefficient of different carbon-based epoxy composite samples is depicted. Upper and lower boundary curves attained from the  $\mu$  values charted for carbon and oxygen are discussed to provide idea of the materials attenuation power in respect to known elements<sup>54, 55</sup>.



**Figure 6.** X-ray linear attenuation coefficient of varied carbon based epoxy composite samples.



**Figure 7.** X-ray mass attenuation coefficient of different carbon-based epoxy composite samples

## 4. Conclusion

It is imperative from the review of literature that despite of many solutions proposed with CNT coating, still there are many shortcomings that are envisaged in the process. For instance, textile fabric having a thin film of CNTs has resulted in X-ray attenuation of 70%. Hence there is essential need for developing better solutions than the previous solution by CNT composites. In the other dimension, lead-shielding products like the lead aprons play a vital role in personal protection from high level radiation, But taking into consideration the toxic impacts better kind of solutions are necessary. Hence, there is intrinsic need for improved solutions that eliminates the lead coat impact and also offers robust solution for radiation shielding, with sustainable solutions.

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