Microwave interactive properties of cotton fabrics coated with carbon nanotubes/polyurethane composite

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In the present study, the inherent characteristic of carbon nanotubes to absorb/attenuate the energy of electromagnetic waves has been exploited. The results indicate that the incorporation of CNTs in the polyurethane matrix has significant effect on the microwave interaction properties. Fabrics are developed through coating process using formulations based on different concentrations of multi –walled carbon nanotubes in polyurethane matrix on two different types of fabrics, i.e. plain weave fabric & mesh fabric (netting). The coated fabrics have been evaluated for microwave interaction properties in X and Ku –band in terms of four parameters, viz. reflection, transmission , absorption, reflection loss, permittivity and surface resistivity of materials. The absorption of upto 40%, permittivity value of 25.0 in frequency range 8.2-12.4 GHz (X- Band) and reflection loss of 5-10 dB in frequency range of 2-18 GHz (X and Ku band) have been observed.

Keywords: Composite, Electrical conducting fabrics, Multi-walled carbon nanotube, Polyurethane, Radar absorbing materials, Reflection loss, Surface resistivity

1 Introduction

Fabric with microwave interactive property is a new concept where electronics and textiles are merged together. It is an emerging field and technology is yet to be explored for its full potential. Interaction of microwave, particularly, radar waves with the material (fabrics) is frequency dependent and is based on the principles of either scattering or absorption phenomenon of electromagnetic wave.¹

EMI shielding products in the form of coated fabrics, sheets, composites and structures will be the burning future requirement not only for defence but for civil applications also. The radar cross-section (RCS) reduction of armoured vehicles, equipments & stores and any military objects is the paramount requirement of army. When a radar wave is incident upon a material, it does not allow the wave to undergo reflection; it transmits the wave and then dissipates the energy, either by absorption or by destructive interference. In order to avoid reflection, the material should match the impedance of free space to that of the surface being shielded. These are known as radar absorbing materials (RAM). The materials which have radar absorbing properties can be used as structural materials, so that there is no additional weight for the target. The radar absorbing properties can be imparted to the target through mechanical design of the composite structure. These are known as radar absorbing structure (RAS).³ Deployment of such RAM coated fabric and RAS structure reduces the RCS of object and protects them from adversary’s radar detection devices. EMI shielding fabrics will also help in protecting human being from microwave hazards prevailing in the environment.

So far, many efforts have been made in recent years to develop radar absorbing materials. Al-Saleh and Sundararaj⁴ have studied the electromagnetic interference shielding mechanism of CNT/polymer composites. EMI shielding effectiveness on MWCNT/ polypropylene composites in the concentration of 1, 2.5, 5 & 7.5% and thickness of 0.34, 1.0 & 2.8 mm has been studied. Shielding effectiveness to the tune of 35dB was observed at 1mm thickness and 7.5% concentrations.

Lee et al.⁵ developed multilayered RAS structure using MWNT in glass/ Epoxy plain –weave fabric in the concentration of 0.0, 0.4, 0.7, 1.0, 1.3, 1.6, 3.0 & 5.0 % and thickness of 3.0, 5.0 & 15.0mm. It was observed that as the MWNT content increases, its permittivity also increases and reflectance loss of upto 20 dB is reported in the frequency range 9.1 - 10.1 GHz.
Lin et al. prepared Fe-filled carbon nanotubes for evaluation of microwave absorbing properties. They investigated the CNT encapsulated Fe nanowire composite synthesized by pyrolyzing ferrocene. The electrical tan δ and magnetic tan δ were enhanced on Fe-encapsulation of CNT. The unfilled carbon nanotube exhibited reflection loss below 10dB (max loss of -11.29 dB) in the frequency range 2-18 GHz. At 5 w % loading of SWNT/SCPU, composite shows strong absorbing peak of 22dB at 15.60 GHz and regular losses in the bandwidth of (10.87-13.0 GHz). Nicolaescu et al. prepared composite of single-walled carbon nanotubes with soluble cross-linked polyurethane at various loading of SWNTs (0 - 25 w %) and the material exhibited strong microwave absorption in the frequency range 2-18 GHz. At 5 w % loading of SWNT/SCPU, composite shows strong absorbing peak of 22dB at 8.8 GHz. Nicolaescu of Military Technical Academy of Romania has discussed about various techniques to reduce RCS of target. These include shaping, active cancellation, passive cancellation and application of radar absorbing materials. Eva et al. studied electromagnetic shielding properties of polypyrrole/polyester composites in the frequency band 1-18 GHz using para toluene-2-sulphonic acid as dopant and ferric chloride as oxidant. They observed shielding effectiveness of coated fabric to the tune of 80%. Dhawan et al. achieved -3 to -11dB shielding effectiveness in the range 8-12GHz using polypyrrole and polyaniline coating formulation on polyester, glass and silica fabrics by vapour phase polymerization.

The progress made so far on studies relating to EMI shielding and power attenuation/loss of microwave is in narrow frequency band with thick materials/structures, where it becomes difficult to tailor them into desired form/shape particularly for apparel purpose for defence personal equipments such as multi-spectral personal camouflage equipment (MSPCE). Therefore, it is needed to study/develop microwave interactive fabric in the form of thin flexible sheets (thickness < 1mm) applicable for wider frequency band. There are various materials and compounds which impart attenuation properties to the materials for electromagnetic waves and enable them for EM shielding. These are conducting polymer, milled carbon fibre, ferrite materials and other high dielectric materials. We have taken MWCNT for our study because it has high mechanical properties (Strength 10-60 GPa) and good electrical conductivity. It is in cylindrical form having more surface area and connectivity in nano scale rendering high electrical conductivity in the matrix and hence addition of small concentration of carbon nanotube in the resin offers good electrical properties.

In the present study, attempts have been made to develop coated fabrics with different concentrations of multi-walled carbon nanotubes (MWCNT) in polyurethane matrix. The coated fabric attributes the property of absorbing electromagnetic waves. The fabrics have been characterized for property of microwave interaction by studying various relevant parameters, such as % reflection, % absorption, % transmission, reflectance loss, dielectric properties and surface resistivity. With the MWCNT concentration of upto 20%, permittivity to the tune of 25.8, tan loss upto 1.44 and EMI shielding up to 90% for the entire X-band frequency (8.2-12.4 GHz) in thin flexible coated fabric (thickness ~ 1.0mm) have been achieved. This material (coated fabric) can easily be tailored/ designed to any shape/form.

2 Materials and Methods

Plain weave cotton matt fabric of 207.10 gsm with warp & weft 44 & 33 per inch; and an open structure Hucka - Back weave cotton fabric (netting fabric) of 60.57 gsm with warp & weft 41 per inch have been used.

Two components polyurethane - polyol of higher molecular weight (density 1.0 g/cc) and hexamethylene diisocyanate (purity 99.99%, molecular weight 168.20 g/mole & density 1.05 g/cc, Merck) were used as resin/matrix. Multi-walled carbon nano tube (diameter 110-170nm, length 5-9 µ and purity 90+%, Sigma Aldrich) was used as a filler material.

2.1 Preparation of Coating Formulations and Samples

Four samples (sample size 16.0 cm × 15.5 cm) of plain weave cotton matt fabric (marked PWC_1, PWC_2, PWC_3 & PWC_4) and four samples of cotton netting fabric (marked NC_1, NC_2, NC_3 & NC_4) were prepared using coating formulations of MWCNT using the concentration of 5, 10, 15 & 20 g in 100 mL polyurethane (PU) solution. Polyol and hexamethylene diisocyanate 50 mL each was mixed together to form a viscous solution. MWCNT was first dispersed in tetrahydrofuran (THF) and added to PU during coupling of two components. For making a homogeneous coating solution, this solution was put for magnetic stirring (for 30 min, 600 rpm, 30°C) and subsequently for sonication process (40 KHz, 40°C, 2 h), so that the carbon nano tubes might uniformly disperse in the viscous solution. Viscosity of coating solution was 3.28 Pa.s at a shear rate of 10.5 s⁻¹ (measured in modular compact viscometer, Physica,
For coating, Mathis Lab Coater, UK based lab model coating system has been used. It is a mechanized knife-over roller coating head with in-built drying & curing chamber. Samples were prepared with the coating parameters of knife speed 30 cm/min, curing time 30 min and temperature 120°C. Similarly, four samples of netting fabric were also prepared with the same concentrations and coating process.

2.2 Test Methods

2.2.1 Add-on and Thickness

The add-on is the additional mass of coating formulation on textile substrate and is measured by high precision electronic balance with accuracy of 0.1 mg. Thickness of samples was measured by Wallace test equipment thickness gauge tester (England) under 200 g/cm² pressure.

2.2.2 SEM Study

The surface properties and morphological structure of the samples were examined under SEM equipment (Model No. EVO 50, CARL ZEISS, Low Vacuum SEM). The SEM image is formed by the back scattered electron and secondary electron. The darker part of image is formed by the low energy electron and bright part by high energy electron.

2.2.3 Surface Resistivity

Surface resistivity was determined by the ratio of DC voltage (U) drop per unit length (L) to the surface current (I) per unit width (D) [ \( \rho_s = (U/L)/(I/D) \) ]. Surface resistivity is one of the important characteristic of the materials which offers the electromagnetic wave to permeate through the material. The matching value of resistivity is 377 Ω/□ which is the impedance of free space. Surface resistivity has been measured by the apparatus resistance/ resistivity probe (Model No. 8038B) as per ASTM D257 method. The surface resistivity (Rs) is reduced to formulae Rs = 10 × Rm Ω/□; where Rm = resistance measured by probe.

2.2.4 Scattering Parameters

Scattering parameters (S-parameters) are the results of microwave evaluation of material by HVS free space measurement system (Fig.1). It consists of two antennas, viz transmitter and receiver, and a sample holder between them. Source of microwave is a vector network analyzer. S-parameters were calculated from the power incident and power received at the horns. These are mainly S_{11} & S_{21} parameters. S_{11} parameter is a measure of reflecting behaviour of surface, whereas S_{21} parameter depicts about propagation behaviour of wave through the material.

2.2.5 Reflection Loss

Reflection loss has been measured by single horn antenna reflectometer measurement system. The source of microwave from 10MHz – 50 GHz is vector network analyzer (Agilant, E8364B). Single horn antenna is receiving and transmitting the power of microwave, the signals are passed from network analyzer to horn antenna through coaxial cable. Power of incident rays and reflected rays was measured, thereby power absorbed by the material i.e. reflection loss (power attenuation) was calculated. The instrument directly measures reflection loss value. For our study, the reflection loss has been measured in the frequency range 2-18 GHz.

3 Results and Discussion

3.1 Add-on and Thickness

The add-on and thickness of the coated samples have been measured and the results are given in Table 1. Add-on ranges from 16.01g to 10.08g for plain weave fabric (sample PWC_1 to PWC_4) and from 2.10 g to 3.78 g for netting fabric (sample NC_1 to NC_4).

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Coated sample weight, g</th>
<th>Add-on in the sample, g</th>
<th>Add-on gsm</th>
<th>CNT content in sample gsm</th>
<th>Thickness mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWC_1</td>
<td>21.15</td>
<td>16.01</td>
<td>645.6</td>
<td>30.72</td>
<td>1.55</td>
</tr>
<tr>
<td>PWC_2</td>
<td>18.89</td>
<td>13.75</td>
<td>573.0</td>
<td>52.08</td>
<td>1.53</td>
</tr>
<tr>
<td>PWC_3</td>
<td>19.71</td>
<td>14.57</td>
<td>587.6</td>
<td>76.6</td>
<td>1.49</td>
</tr>
<tr>
<td>PWC_4</td>
<td>15.22</td>
<td>10.08</td>
<td>406.5</td>
<td>67.74</td>
<td>1.35</td>
</tr>
<tr>
<td>NC_1</td>
<td>3.60</td>
<td>2.10</td>
<td>84.67</td>
<td>4.03</td>
<td>0.56</td>
</tr>
<tr>
<td>NC_2</td>
<td>3.16</td>
<td>1.66</td>
<td>66.93</td>
<td>6.05</td>
<td>0.55</td>
</tr>
<tr>
<td>NC_3</td>
<td>5.10</td>
<td>3.59</td>
<td>144.75</td>
<td>18.87</td>
<td>0.72</td>
</tr>
<tr>
<td>NC_4</td>
<td>5.28</td>
<td>3.78</td>
<td>152.42</td>
<td>25.40</td>
<td>0.74</td>
</tr>
</tbody>
</table>

*Sample size 16 cm x 15.5 cm.
NC_1 to NC_4). Thickness ranges from 1.55 mm to 1.35 mm for plain weave fabric and from 0.56 mm to 0.74 mm for netting fabric samples.

3.2 Morphological Study

The morphological behavior of samples has been studied. SEM micrographs of samples (PWC_1 to PWC_4) for plain weave fabric at magnification of ×10,000 are shown in Figs 2(a) - (d). It is observed that CNTs are uniformly distributed in polyurethane matrix. It is also observed that the density of CNT increases as CNT concentration increases from 5% to 20%. In Fig. 2(a) dot represents cross-sectional view of CNT; some longitudinal views are also seen. In Figs 2(b), (c) & (d), longitudinal views are more prominent and CNTs network in PU matrix is clearly observed.

3.3 Surface Resistivity of Coated Fabrics

The surface resistivity ($R_s$) of fabrics is given in Table 2. It is observed that as the concentration of CNT increases from 5% to 20% (PWC_1 to PWC_4), the surface resistivity has significantly decreased. With increase in CNT from 5% to 20%, the resistivity decreases from 7M $\Omega/$□ to 400 $\Omega/$□ from sample PWC_1 to PWC_3. Sample PWC_4 has shown little bit higher resistivity (1400 $\Omega/$□) than sample PWC_3 due to less add-on. For netting fabrics, it decreases from 45M $\Omega/$□ to 1850 $\Omega/$□.

3.4 Permittivity

Permittivity has been calculated on the basis of S-parameters by the in-built algorithm in the HVS free space measurement system. The permittivity has been measured in frequency range 8.2-12.4 GHz for both plain weave and netting coated fabrics and the results are summarized in Table 2. It is observed that as the CNT (w% of MWCNT) concentration increases from 5% to 20% (from PWC_1 to PWC_4), real and imaginary values of permittivity go on increasing. Real part increases from 6.14 to 25.8 for plain weave fabrics and from 2.66 to 11.49 for netting fabrics. Imaginary part increases from 0.81 to 20.14 for plain weave fabric and from 0.29 to 8.63 for netting fabric. It is observed that for the same sample, both

Fig. 2—SEM images of plain weave coated fabric with (a) 5% CNT, (b) 10% CNT, (c) 15% CNT, and (d) 20% CNT in PU at ×10000 magnification
Table 2—Effect of CNT concentration on resistivity, permittivity and tan loss

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Permittivity</th>
<th>Loss tangent</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Real ((\varepsilon^\prime))</td>
<td>Imaginary ((\varepsilon^\prime))</td>
<td>(\varepsilon^\prime)</td>
</tr>
<tr>
<td>PWC_1</td>
<td>6.14 - 6.07</td>
<td>0.81 - 0.58</td>
<td>0.13 - 0.09</td>
</tr>
<tr>
<td>PWC_2</td>
<td>14.97 - 14.81</td>
<td>4.71 - 3.27</td>
<td>0.31 - 0.22</td>
</tr>
<tr>
<td>PWC_3</td>
<td>24.78 - 25.80</td>
<td>18.28 - 12.53</td>
<td>0.73 - 0.48</td>
</tr>
<tr>
<td>PWC_4</td>
<td>22.72 - 22.23</td>
<td>20.14 - 14.75</td>
<td>0.88 - 0.66</td>
</tr>
<tr>
<td>NC_1</td>
<td>2.77 - 3.04</td>
<td>0.21 - 0.14</td>
<td>0.16 - 0.095</td>
</tr>
<tr>
<td>NC_2</td>
<td>4.22 - 4.29</td>
<td>1.52 - 1.17</td>
<td>0.529 - 0.37</td>
</tr>
<tr>
<td>NC_3</td>
<td>6.62 - 6.43</td>
<td>6.30 - 5.02</td>
<td>0.73 - 0.63</td>
</tr>
<tr>
<td>White grey fabric</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netting fabric (unwashed)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netting fabric (washed)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3—Measurements of \(S_{11}\) & \(S_{21}\) parameters of coated fabrics

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>(S_{11}) parameters</th>
<th>(S_{21}) parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWC_1</td>
<td>6.25 - 4.43</td>
<td>1.83 - 2.62</td>
</tr>
<tr>
<td>PWC_2</td>
<td>3.66 - 2.54</td>
<td>4.90 - 6.07</td>
</tr>
<tr>
<td>PWC_3</td>
<td>2.07 - 1.33</td>
<td>9.43 - 10.10</td>
</tr>
<tr>
<td>PWC_4</td>
<td>2.79 - 2.34</td>
<td>9.58 - 10.20</td>
</tr>
<tr>
<td>NC_1</td>
<td>20.72 - 18.90</td>
<td>0.18 - 0.23</td>
</tr>
<tr>
<td>NC_2</td>
<td>14.91 - 12.98</td>
<td>0.91 - 1.12</td>
</tr>
<tr>
<td>NC_3</td>
<td>7.99 - 6.74</td>
<td>3.14 - 4.05</td>
</tr>
<tr>
<td>NC_4</td>
<td>7.59 - 6.17</td>
<td>3.63 - 4.19</td>
</tr>
</tbody>
</table>

The permittivity values (real & imaginary) are found to be almost constant in the entire X-band. All the samples have shown consistent properties of permittivity.

3.5 Reflection, Transmission and Absorption Properties

The reflection, transmission and absorption behavior of samples in frequency range 8.2-12.4 GHz (X-band) have been studied with the help of S-parameters (Table 3). With the decrease in \(S_{11}\) parameter, reflection increases and with the increase in \(S_{21}\) parameter, EMI shielding property increases. For lossless material, the power flow is at any point by electromagnetic wave is given by Poynting wave equation \(P_a = (1/2) \times E^2/\eta \times W/m^2\). For lossy materials, \(E_x\) (electrical component) and \(H_y\) (magnetic component of electromagnetic wave) are not in time phase and power density attenuates as per equation \(P_a = (1/2) \times E^2/\eta \times e^{2\alpha x} \times \cos \theta \times W/m^2\), where \(\alpha = [(\sigma/2) \times (\mu/\varepsilon) \times (1/2)]\) is an attenuation factor and \(\theta\) is the phase difference between electrical and magnetic components of wave.

The reflection is calculated with the help of \(S_{11}\) parameters using the following formula:

\[
% \text{Reflection} = 10^{(S_{11}\ \text{parameter} /10)} \times 100 \quad \text{... (1)}
\]

Transmission is calculated with the help of \(S_{21}\) parameters using the following formula:

\[
% \text{Transmission} = 10^{(S_{21}\ \text{parameter} /10)} \times 100 \quad \text{... (2)}
\]

Adding Eqs (1) & (2) and subtracting from 100, the % absorption is achieved, as shown below:

\[
% \text{Absorption} = [100 - (% \text{Reflection} + % \text{Transmission})] \quad \text{... (3)}
\]

It is found that as the surface conductivity increases, \(S_{11}\) parameter decreases i.e. sample becomes more reflective and \(S_{21}\) parameter increases i.e. less transmission of wave.

The surface reflectivity is found to be dependent on percentage content of CNT in the PU formulation. As the CNT increases from 5% to 20%, the reflection increases from 25-30% to 55-60%, absorption increases from 12% to 30% and transmission decreases from 55-65% to 10% from sample PWC_1 to PWC_4 in the frequency range 8.2 - 12.4 GHz. This has offered the attenuation of electromagnetic wave. Sample PWC_4 has shown about 90% EMI shielding properties. The reflection, transmission and absorption with frequency are more clearly expressed in Fig. 3 for plain weave fabric.
The same formulations have also been applied to open mesh fabric; reflection values are smaller (upto 25%), absorption properties are same as observed for plain weave fabric and transmission is more because of open fabric (Fig.4). It is observed that in spite of being open fabric (netting fabric), the transmission has reduced from 80% to 40% from sample NC_1 to NC_4 and absorption increases from 3% to 40 %. For both class of coated fabrics, a common trend has been observed that as the permittivity increases, the absorption also increases and thereby samples show more EMI shielding effectiveness.

3.6 Study of Reflection Coefficient

Reflection coefficient is expressed by the equation \( \Gamma_R = (\eta_2 - \eta_1) / (\eta_2 + \eta_1) \), where \( \eta \) is the impedance of medium and is equal to \( \sqrt{\mu/\varepsilon} \). From sample PWC_1 to PWC_4, the permittivity increases from 6.14 to 25.80 with the increases in CNT content and the impedance decreases from 150.8\( \Omega \) to 73.85 \( \Omega \). Using the above relations, the reflection coefficient (\( \Gamma_R \)) has been worked out which increases from -0.428 to -0.672. This shows that with the increase in permittivity, impedance decreases and the materials becomes more reflective. The trend of increase in reflection coefficient is also correlated to the reflecting behaviour of samples. As seen from Fig. 3, the % reflection increases from 20-30% (PWC_1) to 50-60% (PWC_4).

3.7 Reflection Loss and Tan Loss

3.7.1 Mechanism for Lossy Materials

There are two specific mechanisms of interaction between material and microwave, namely (i) dipole interaction and (ii) ion conduction. Both the mechanisms require effective coupling between components of the target material and the rapidly oscillating electric field of the microwaves. Dipole interactions occur with polar molecules. The polar molecules respond to the alternating field by oscillating in a manner opposite to the field, which results in energy absorption. This absorption is measured as reflection loss. The Tan Loss is calculated as the ratio of absorption to the total power loss.

Fig. 3—Graphical presentation of plain weave coated fabric for reflection, transmission and absorption properties for samples PWC_1(a), PWC_2(b), PWC_3(c), and PWC_4(d).
ends of molecule tend to align themselves and oscillate in step with the oscillating electric field of the microwaves. Broadly, the more polar a molecule the effectively it will couple with and be influenced by the microwave field. For materials having ion conduction molecules, two types of current generate on incidence of electromagnetic waves, viz. (i) conduction current due to charge carrier particles and (ii) displacement currents due to change of electric flux. Both have phase difference and this produces tan loss and hence material becomes lossy. The phenomenon of electromagnetic wave, its interaction with coated fabric in terms of reflection, transmission and absorption are shown in Fig. 5. Tan loss is defined as the ration of imaginary to real part of permittivity ($\varepsilon''/\varepsilon'$). It is also expressed as ratio of conduction current to displacement current in the materials when electromagnetic waves fall on it ($\tan \delta = J_{cd}/J_{dis}$. This factor is a measure of lossy character for materials. Higher value is of tan loss, more is the lossy material.

**Fig. 4**—Graphical illustration of netting coated fabric for reflection, transmission and absorption properties for samples NC_1(a), NC_2(b), NC_3(c), and NC_4(d)

**Fig. 5**—Interaction of microwave with conducting fabric (a) electromagnetic wave and (b) incidence, reflection and transmission of wave with conducting fabric

**Reflection Loss**

Reflection loss is a measure of attenuation property of the materials. Dielectric materials are the lossy materials. These materials possess sufficient level of conductivity and permittivity which attribute loss to the power of electromagnetic waves while propagating through it. Reflection loss has been measured in single horn reflectometer in the frequency band 2-18 GHz for both types of samples,
i.e. plain weave and netting coated fabrics. The comparative study is shown in Fig. 6. For plain weave fabric, the reflection loss is found to be frequency dependent [Fig. 6 (a)]. Sample PWC_1 has shown its peak loss of 15.57 dB at frequency 16.0 GHz; sample PWC_2, peak loss of 17.09 dB at 12.0 GHz; sample PWC_3, peak loss of 9.5 dB at 6.5 GHz and sample PWC_4, peak loss of 10.98 dB at 13.5 GHz. The peak loss occurs at the frequency where phase difference between reflected rays is 180°; destructive interference takes place between rays reflected from the front and back surfaces of the coated fabrics. Sample PWC_2 has shown highest peak but the band of significant loss is from 10 GHz to 16 GHz. Similarly, for sample PWC_1, the peak loss is fair (15.57 dB) but its band of significant loss is 14-18 GHz. Sample PWC_4 has given higher value of loss (> 8dB) in frequency band of 5-17 GHz. Overall, sample PWC_4 has shown better reflection loss in wider frequency band.

Netting fabric surface is found to be more irregular and uneven in thickness; it has shown frequent path difference of λ/2 giving higher losses in narrow band. From Fig. 6(b), it is observed that for sample NC_1 and NC_2, the losses are small (0 - 4 dB) due to low concentration of CNT. Sample NC_3 has shown max loss of 23.57 dB at 14.5 GHz and more than 10 dB loss is observed in 12-18 GHz frequency band. The peak of maximum loss is at different frequency for different sample because of different CNT concentrations and thicknesses of samples. Sample NC_4 has shown a loss of 6 - 12 dB in the frequency band 13 - 17 GHz with peak loss of 12 dB at 16 GHz. Sample NC_3 has shown better reflection losses than other samples in its group.

**Tan Loss**

Tan loss has been measured with the help of algorithm based on S-parameters in-buit with the vector network analyser. Tan loss values are given in Table 2. It is observed that with the increase in CNT content, it increases from 0.13-0.09 (PWC_1) to 0.88-0.66 (PWC_4) for plain weave fabric and from 0.16-0.095 (NC_1) to 1.44 - 1.25 (NC_4) for netting weave fabric. Loss tangents of netting fabric are higher (1.44) than plain weave fabric (0.88) because of irregular surface. It is to note that tan loss ranges to a very low value (< 0.01) for lossless perfect dielectric materials. For lossy materials, tan loss is > 0.1. Therefore, sample PWC_1- PWC_4 for plain weave fabric and sample NC_3 & NC_4 for netting fabric are found adequate lossy in the stated frequency bands.

**4 Conclusion**

Fabrics coated with formulations of multi-walled carbon nanotube have shown an efficient radar absorbing properties in frequency of X-Band (8.2-12.4 GHz). It is seen that as the CNT concentration increases from 5% to 20%, the surface resistivity decreases and conductivity increases which makes the surface more reflective. Also, with the increase in CNT concentration, permittivity (both real and imaginary) increases in both types of coated fabric which results in increase of radar wave absorption properties. Reflection and transmission are found to be governed by $S_{11}$ and $S_{21}$ parameters respectively.

For plain weave coated fabric (PWC_4) with add-on of 406.5 gsm (CNT content 67.74 gsm), surface resistivity of upto 1400 Ω/□, permittivity
value of 22.72 -22.23 (real), absorption of 40-50%, reflection of 50-60% and tan loss of 0.88-0.66 have been achieved. For sample PWC_4, only 10% energy passes through it and hence EMI shielding is upto 90%. For netting coated fabric (NC_4) with add-on of 152.42 gsm (CNT content 25.40 gsm), surface resistivity of upto 1850 Ω/□, permittivity value of 11.59-11.21 (real), absorption of 35-40%, reflection of 20-25% and tan loss of 1.44-1.25 have been achieved.

Reflection losses are found to be entirely frequency dependent. The reflection loss patterns for plain weave fabric and netting fabric are entirely different because of geometrical construction of fabric. Sample PWC_1 shows maximum reflection loss (peak value) of 16dB at 16GHz; sample PWC_2 shows 17dB at 12GHz; sample PWC_3 shows 10dB at 6GHz and sample PWC_4 shows 11dB at 13 GHz. It is noticed that as the CNT concentration increases, the loss of frequency band width also increases and the curve tends to become flattened. Netting samples NC_3 & NC_4 have shown high value of reflection loss in narrow band, particularly in the frequency range 10-18 GHz, the maximum losses upto 24 dB (NC_3) and 12 dB (NC_4) are observed. Thus, peak reflection loss occurs in different frequency bands for different samples.

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References