Electromagnetic shielding effectiveness of needle-punched composite nonwoven fabrics with stainless steel fibres

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ABSTRACT – REZUMAT

Electromagnetic shielding effectiveness of needle-punched composite nonwoven fabrics with stainless steel fibres

In the study, electromagnetic shielding efficiency (EMSE) absorption and reflectivity properties of fabric produced from staple stainless-steel fibres and recycled staple polyester fibres by carding and needling technologies were investigated. The bi-component core/sheath polyester fibres at a fixed ratio of 20% in producing all nonwoven fabrics were used. The staple stainless-steel fibres and recycled staple polyester fibres were blended at 13 different ratios such as 1%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5%, 25%, 27.5%, 30%. The fibre webs were formed at wool type carding machine and then the folded webs were bonded mechanically with needle punching machines. Half of the produced nonwoven composite fabrics were bonded by thermal bonding technology with oven and calender machines. As the conductive fibres were costly, the study aimed to obtain optimum shielding effectiveness with the usage of minimum conductive fibres. Electromagnetic shielding properties, absorption and reflection characteristics of needle-punched nonwoven fabrics with calendered or un-calendered were performed by coaxial transmission line method according to ASTM-D4935-10 in the frequency range of 15 MHz to 3000 MHz. It is a known fact that electromagnetic shielding effectiveness increases with the increase in the amount of conductive fibre. It was found that nonwoven fabric produced with a usage of 17.5% stainless steel fibre has at least 90% electromagnetic shielding percentage in general use with 15 dB at a frequency of 1800 MHz. Increased stainless steel fibre content in nonwoven fabrics resulted in decreased nonwoven fabric thickness and tensile strength. Such a nonwoven composite material with electromagnetic shielding property could be used for construction and building applications.

Keywords: *electromagnetic shielding (EM) effectiveness, electromagnetic radiation, stainless steel fibre, recycled polyester fibre, needle punching, nonwoven fabric, bi-component core/sheath binder fibres, thermal bonding technology*

Eficienţa ecranării electromagnetice a neţesutelor compozite intreţesute cu fibre de oțel inoxidabil

În cadrul studiului, au fost investigate proprietățile de absorbție și reflectivitate ale eficienței ecranării electromagnetice (EMSE) ale materialului textil produs din fibre scurte de oțel inoxidabil și fibre scurte de poliester reciclat, prin tehnologii de cardare și interţesere. Au fost utilizate fibre de poliester bicomponente miez/manta la un raport fix de 20% în producția tuturor neţesutelor. Fibrele scurte de oțel inoxidabil și fibrele scurte de poliester reciclat au fost amestecate în 13 rapoarte diferite, cum ar fi 1%, 2,5%, 5%, 7,5%, 10%, 12,5%, 15%, 17,5%, 20%, 22,5%, 25%, 27,5%, 30%. Vălurile de fibre au fost formate la o mașină de cardare de tip lână și apoi vălurile pliate au fost consolidate mecanic cu mașini de interţesere. Jumătate dintre neţesutele compozite produse au fost consolidate prin tehnologia de lipire termică cu etuve şi calandre. Deoarece fibrele conductoare erau foarte scumpe, scopul studiului a fost de a obține o eficiență optimă de ecranare cu utilizarea unui minimum de fibre conductoare. Proprietățile de ecranare electromagnetică, caracteristicile de absorbție și reflexie ale neţesutelor interţesute, calandrate sau necalandrate, au fost realizate prin metoda liniei de transmisie coaxiale conform ASTM-D4935-10 în intervalul de frecvență de la 15 MHz la 3000 MHz. Este un fapt cunoscut că eficiența ecranării electromagnetice creşte odată cu creşterea cantității de fibre conductoare. S-a descoperit că neţesutul produs cu utilizarea a 17,5% fibre de oțel inoxidabil are cel puțin 90% procent de ecranare electromagnetică în utilizare generală cu 15 dB la frecvența de 1800 MHz. Conținutul crescut de fibre de oțel inoxidabil în neţesute a dus la scăderea grosimii materialului neţesut și a rezistenței la tracțiune. Un astfel de material compozit nețesut cu proprietăți de ecranare electromagnetică ar putea fi utilizat pentru aplicații în construcţii.

Cuvinte-cheie*: eficienţa ecranării electromagnetice (EM), radiații electromagnetice, fibră de oțel inoxidabil, fibră de poliester reciclat, interţesere, neţesut, fibre de legătură bicomponente miez/manta, tehnologie de consolidare termică*

INTRODUCTION

Today, humanity is faced with a very serious danger that is invisible, intangible, and odourless. The danger is determined as electromagnetic radiation caused by electromagnetic waves. Most of the people in the world are seriously unaware of the electromagnetic radiation danger [1]. The level of electromagnetic radiation (EM) with extensive usage of electrical and electronic appliances in addition to the rapid development of wireless communication has been increasing day by day. Electromagnetic pollution caused by electromagnetic radiation is a form of energy propagated through free space or material medium in the form of electromagnetic waves and is a very serious danger to human health and life on Earth.

Electromagnetic fields (EMFs) are defined as packets of energy that have no mass [2]. Electromagnetic fields in the universe occur naturally and artificially. Magnetic fields and lightning in the earth are the natural electromagnetic fields. All electronic devices, base stations and electric power transmission lines are artificial/man-made electromagnetic fields [3]. Electromagnetic radiation is generally classified into non-ionizing, which is known as not having enough energy to break chemical bonds and believed as harmless to humans and ionizing radiation, which is potentially harmful to cells and DNA chains [4]. The human body is very exposed to electromagnetic waves in non-ionizing radiation categories at various frequencies and wavelengths during daily life [1].

The International Agency for Research on Cancer (IARC) classify radiofrequency electromagnetic fields as possibly carcinogenic to humans. However, there is no study showing scientific evidence between electromagnetic radiation and cancer. The effect of exposure to electromagnetic fields (EMF) on the body and cells depends on the electromagnetic field frequency and its strength [1]. The strength of an EMF decreases with increasing distance from the source. In addition to that, EMF pass through the body at low frequency, while at radio frequencies the fields are partially absorbed and penetrate only a short depth into the tissue. The structural changes in the frontal cortex, brain stem and cerebellum of the Wistar albino rats' heads exposed to microwave irradiation for 1 hour per day for two months [5].

Various studies have been conducted in previous literature regarding the harmful impact of electromagnetic radiation on living organisms. It was found that electromagnetic radiation causes structural changes in the frontal cortex, brain stem and cerebellum of the rats. The authors said that this deterioration can cause disease including loss of these areas' function and cancer development. The non-ionizing electromagnetic radiations emitted from cell phones, laptops, Bluetooth, microwave, or wireless networks might have detrimental effects on female fertility [4]. It was said that non-ionizing radiations can have destructive effects on the ovary and uterus, affecting several reproduction parameters in females. The low-frequency electromagnetic fields generated by car electronics, physiotherapy equipment and LCD monitors may be a cause of oxidative stress in the human body and may lead to free radical diseases [6]. The scientific evidence about hazards causing electromagnetic fields is increasingly strong and in vivo and in vitro scientific experimental studies demonstrate adverse effects on male and female reproduction of the mobile phone frequencies [4]. There is some evidence for elevations in breast cancer risk among women who wear their mobile phones in their bra [7]. There is a parallelism in time between increased use of mobile phones, increased exposure coming from wi-fi, smart meters, other wireless devices and male hyperfertility in addition to sperm abnormalities in semen [8]. Long-term exposure to electromagnetic radiation emitted from electronic devices and wireless communication can cause many health risks such as depression, headaches, insomnia, nervousness and even cancer [9]. Electromagnetic radiation causes serious health problems for humans and other living creatures according to the above scientific studies. Due to these reasons, today, electromagnetic shielding materials have great attention.

As conductive textile materials are so expensive, it is important to use them at specific rates. Textile clothes and building materials with high-performance electromagnetic shielding properties should be produced to remove the adverse effects of electromagnetic waves. Today, textile clothes such as jackets, shirts, pants, and coats having EM shielding properties are necessary to manufacture. Indeed, building materials with EM insulation effectiveness in addition to sound and heat insulation properties are needed. All textile clothes must be produced with electromagnetic shielding effectiveness properties for human health. The negative effects of electromagnetic radiation can be reduced by using conductive textile materials such as conductive fibre or yarn. Stainless steel fibre produced by Bekaert/Belgium, silver-coated polyamide fibres manufactured by R-Stat/France, carbon-coated polyester fibres by Shakespeare/UK and carbon fibres are some of the conductive fibres.

Considering these effects, the needle-punched composite nonwoven fabrics were designed and manufactured with carding, needle-punching technologies and machines from staple recycled polyester fibres, bi-component sheath/core type low melting binder fibre and staple stainless-steel fibres. Half of the needle-punched nonwoven fabrics were bonded with oven and calender cylinders by using thermal bonding technology. As a result, two different needle-punched composite nonwoven fabrics with calendered and uncalendared were obtained. The tensile strength and thickness properties of nonwoven composite fabrics were measured. The electromagnetic shielding effectiveness, absorption, and reflection properties of calendered and uncalendared needle-punched nonwoven composite fabrics were tested, compared, and evaluated. As the conductive staple stainless steel fibres are very expensive, the amount of conductive stainless steel fibres for optimum shielding effectiveness in general use and professional use was explored.

EXPERIMENTAL STUDY

Material and method

The Bekaert Bekinox® VS 12/060/2000 type stainless steel fibres were obtained from Bekaert Company in Belgium. Bekaert Bekinox® VS metal fibre is a stretch-broken sliver of very fine stainless-steel fibres. The diameter of the fibre with 100% Bekinox® was around 12 μm. The fineness is 9.1 dtex (8.2 denier). The specific weight is 8.03 g/cm^3.

The specific electrical resistance of the fibres is 0.90 $\Omega \cdot mm^2/m$. The tensile strength and average elongation percentage of the fibre is 17 cN and 1% respectively.

Production of nonwoven fabrics

The needle-punched nonwoven fabrics were manufactured in three stages. In the first stage, the webs were produced at the laboratory-type carding machine and then the carded webs were needle punched at the laboratory-type needling machine with a meter working width. In the last stage, the needle-punched fabrics are bonded by thermal method in the oven.

The nonwoven fabrics were manufactured through carding followed by needle punching machines. Half of the nonwoven composite fabrics were thermally bonded with a calender cylinder and oven. The carding process was carried out by a laboratory-type Mesdan carding machine. The sheath/core bi-component binder fibres were used at a 20% blending ratio for all nonwoven fabrics. The stainless-steel fibres were mixed with recycled polyester fibres at weight ratios of 1%, 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 25%, 30%. The webs were produced at carding machines as two passages. The carded webs were bonded at pre and main needle punching machines. Half of the nonwoven fabrics were thermally bonded with calender cylinders and air-through bonding technologies in the oven. Two different nonwoven fabric sets produced as needle-punched and thermally bonded have been completed. The calendered and non-calendered nonwoven fabric samples and their properties are shown in figures 1 and 2 and table 1, respectively.

Measurement of electromagnetic shielding effectiveness

All measurements were repeated three times on different areas of the fabric, and the average values of the measurements were then given. A coaxial transmission line method specified in ASTM D4935-10 was used to test the EMSE of the nonwoven fabrics. The specimen was prepared with a standard test size of various thicknesses. The outer ring of the specimen was 133 mm in diameter. Two specimens were

Table 1

PHYSICAL PROPERTIES OF CALENDERED AND NON-CALENDERED NONWOVEN FABRICS

Sample codes	Areal density (g/m^2)	Thickness (mm)	Fibres composition of nonwoven fabrics (%)	
			Bi-component (PES)	Stainless Steel
Non-calendered reference	332.68	4.795	100	0
Non-calendered 1% SS	349.25	5.010	99	1
Non-calendered 2.5% SS	332.68	4.685	97.5	2.5
Non-calendered 5% SS	412.91	5.150	95	5
Non-calendered 7.5% SS	379.54	5.235	92.5	7.5
Non-calendered 10% SS	405.82	4.980	90	10
Non-calendered 12.5% SS	388.22	4.870	88.5	12.5
Non-calendered 15% SS	402.28	4.605	85	15
Non-calendered 17.5% SS	386.28	4.435	82.5	17.5
Non-calendered 20% SS	384.34	4.630	80	20
Non-calendered 22.5% SS	395.54	4.345	77.5	22.5
Non-calendered 25% SS	401.37	4.180	75	25
Non-calendered 27.5% SS	413.02	3.885	72.5	27.5
Non-calendered 30% SS	395.65	3.905	70	30
Calendered reference	407.08	4.545	100	0
Calendered 1% SS	405.02	4.595	99	1
Calendered 2.5% SS	358.62	4.095	97.5	2.5
Calendered 5% SS	443.77	4.380	95	5
Calendered 7.5% SS	461.25	4.395	92.5	7.5
Calendered 10% SS	469.25	4.150	90	10
Calendered 12.5% SS	479.77	4.320	88.5	12.5
Calendered 15% SS	457.37	4.065	85	15
Calendered 17.5% SS	476.00	3.965	82.5	17.5
Calendered 20% SS	441.48	4.035	80	20
Calendered 22.5% SS	432.91	4.145	77.5	22.5
Calendered 25% SS	488.34	3.725	75	25
Calendered 27.5% SS	465.94	3.400	72.5	27.5
Calendered 30% SS	447.65	3.540	70	30

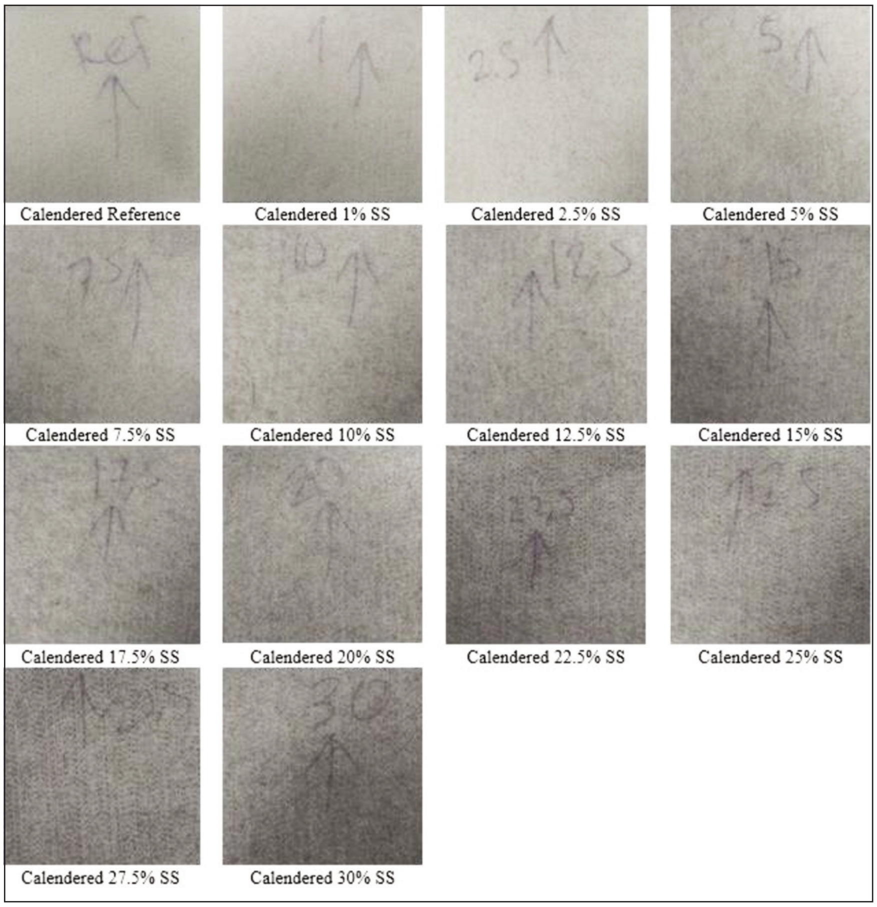

Fig. 1. Calendered nonwoven fabric samples (taken at x10 magnification)

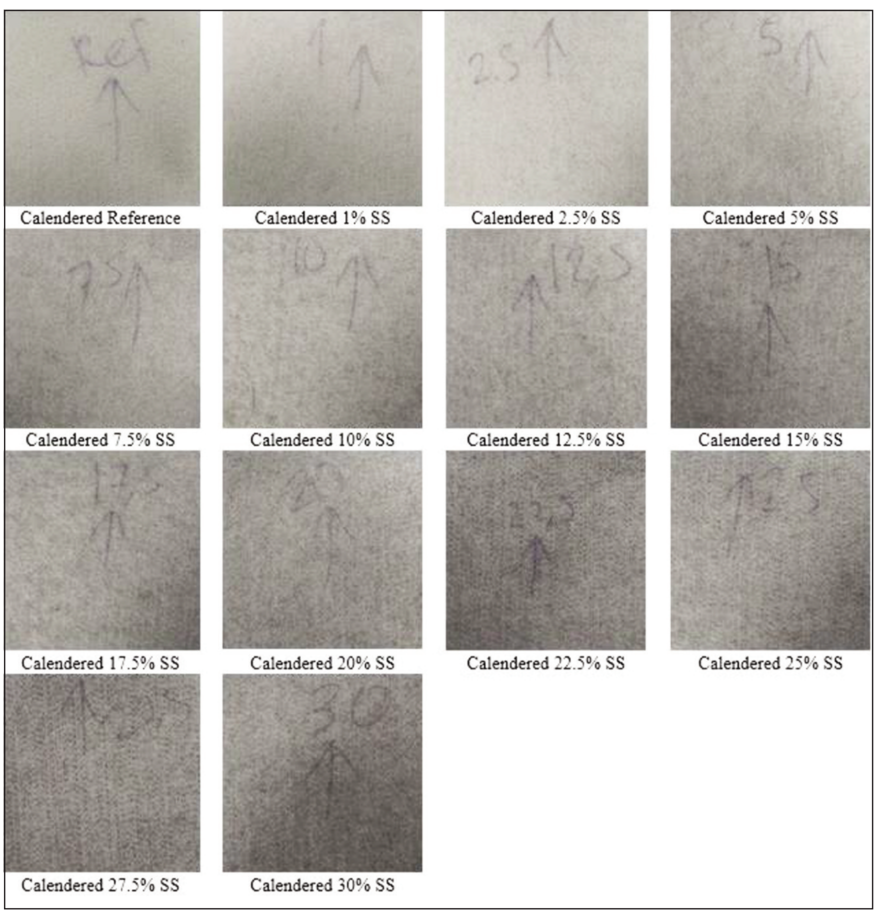

Fig. 2. Non-calendered nonwoven fabric samples (taken at x10 magnification)

required to be produced for the test, one for reference and another for load testing.

Various researchers have described the detailed set-up and testing procedure using a plane-wave electromagnetic field in the frequency range of between 0.1 and 3 GHz [25]. A network analyser (Rohde Schwarz, ZVL) to generate and receive the EM signals and a shielding effectiveness test fixture (Electro-Metrics, Inc., EM-2107A) were used to measure the EMSE, which was measured in decibels (dB) in this investigation. Where P1 (watts) received power with the fabric present, and P2 (watts) received power without the fabric present. The input power used was 0 dB, corresponding to 1 W [10, 26].

This standard determined the shielding effectiveness of the fabric using the insertion-loss method. The technique involved irradiating a flat, thin sample of the base material with an EM wave over the frequency range of interest, utilizing a coaxial transmission line with an interrupted inner conductor and a flanged outer conductor. A reference measurement for the empty cell was required for the shielding effectiveness assessment (figure 3, *b*). The reference sample was placed between the flanges in the middle of the cell, covering only the flanges and the inner conductors. A load measurement was performed on a solid disk shape, which had a diameter the same as that of the flange (figure 3, *c*). The reference and the load measurement were performed on the same material. The shielding effectiveness was determined from equation 1, which is the ratio of the incident field to that which passes through the material. The total shielding effectiveness (SE_T) that includes contributions due to reflection and absorption can be expressed as:

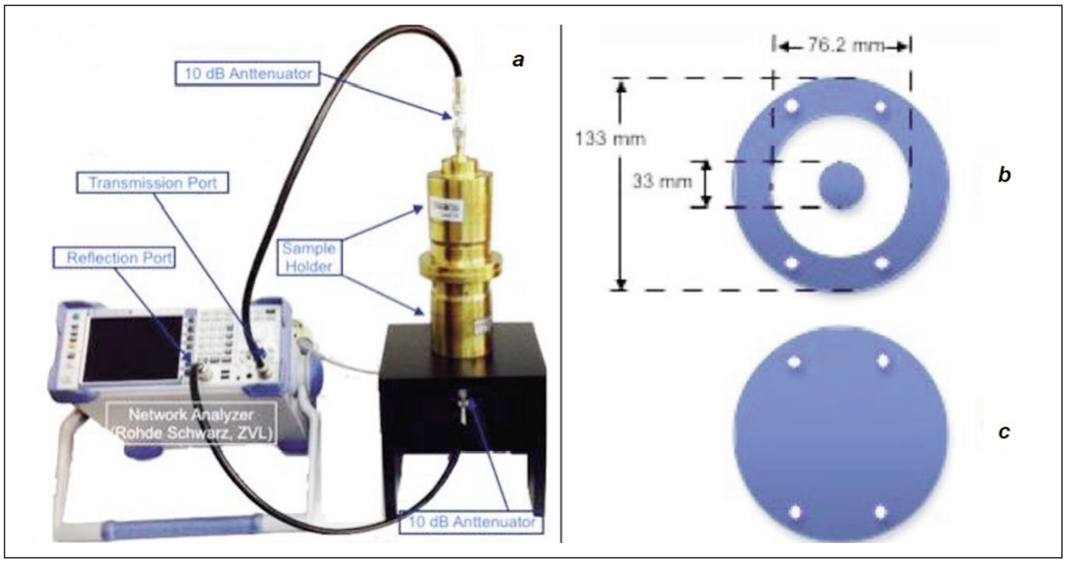

Fig. 3. Graphical representation of: *a* – set up of the Electromagnetic Shielding Effectiveness testing apparatus; *b* and *c* – specimen for reference and load respectively

$$SE_T(\text{dB}) = 10 \log_{10} (P_T / P_I) = 20 \log_{10} (E_T / E_I) = = \log_{10} (H_T / 20H_I) = \quad (1)$$

where P_I (E_I or H_I) and P_T (E_T or H_T) are the power (electric or magnetic field intensity) of the incident and transmitted EM waves, respectively. The scattering parameters S_{11} (S_{22}) and S_{12} (S_{21}) of VNA are related to reflectance (R) and transmittance (T), respectively. Therefore, attenuations due to reflection (SE_R) and absorption (SE_A) can be conveniently expressed as [11]:

$$T = |E_T / E_I|^2 = |S_{12}|^2 \ (= |S_{21}|^2), \quad R = |E_R / E_I|^2 = |S_{11}|^2 \ (= |S_{22}|^2) \quad (2)$$

$$A = (1 - R - T),\ A_{eff} = (1 - R - T)/(1 - R) \quad (3)$$

$$SE_R(\text{dB}) = 10 \log_{10} (1 - R) \quad (4)$$

$$SE_A(\text{dB}) = 10 \log_{10} (1 - A_{eff}) = = 10 \log_{10} [T / (1 - R)] \quad (5)$$

RESULTS AND DISCUSSION

Electromagnetic shielding efficiency

The shielding performances of the nonwoven fabrics are measured in non-calendered and calendered nonwoven. The electromagnetic shielding effectiveness (EMSE) performance of non-calendered and calendered nonwoven fabrics with conductive fibres (Stainless-Steel) measured between 0.1 and 3 GHz frequency range are presented in figures 4 and 5, respectively. It can be observed that the EM shielding properties of all non-calendered and calendered nonwoven fabrics have similar behaviours in figure 4 and figure 5, respectively. The shielding effectiveness of non-calendered and calendered nonwoven fabrics reveals that as frequency increases, EMSE values show a tendency to decrease between 0.1 and 0.3 GHz frequency range, then a tendency to rise between 0.3 and 3 GHz frequency range slightly in figures 4 and 5, respectively. As expected, The EMSE values increase with the increasing amount of conductive fibres in non-calendered and calendered nonwoven fabrics, as seen in figures 4 and 5, respectively. In this context, the frequency increases with decreasing of the wavelength [13–16]. Therefore, with an increase of conductive fibres, the amount of conductive materials increases (per unit area), and this increase in conductivity values leads to a higher EMSE. It is seen that non-calendered and calendered nonwoven fabrics containing 13 different ratios of conductive fibres are divided into 3 groups in terms of their Electromagnetic Shielding efficiency perfor-

Table 2

PERFORMANCE SPECIFICATION OF EM SHIELDING TEXTILES IN GENERAL AND PROFESSIONAL USE [12]			
Percentage of electromagnetic shielding (ES)	**Shielding effectiveness (SE) in general use**	**Shielding effectiveness (SE) in professional use**	**Grade**
SE > 99.9%	SE > 30 dB	SE > 60 dB	5 Excellent
99.9% ≥ SE > 99%	30 dB ≥ SE > 20 dB	60 dB ≥ SE > 50 dB	4 Very Good
99% ≥ SE > 90%	20 dB ≥ SE > 10 dB	50 dB ≥ SE > 40 dB	3 Good
90% ≥ SE > 80%	10 dB ≥ SE > 7 dB	40 dB ≥ SE > 30 dB	2 Moderate
80% ≥ SE > 70%	7 dB ≥ SE > 5 dB	30 dB ≥ SE > 20 dB	1 Fair

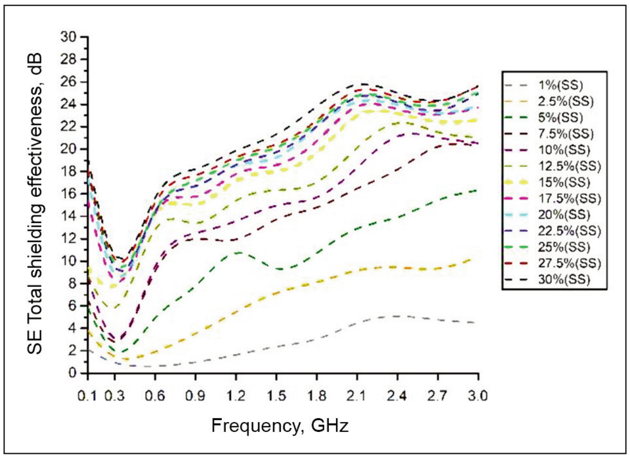

Fig. 4. Electromagnetic shielding effectiveness (EMSE) non-calendered nonwoven fabrics

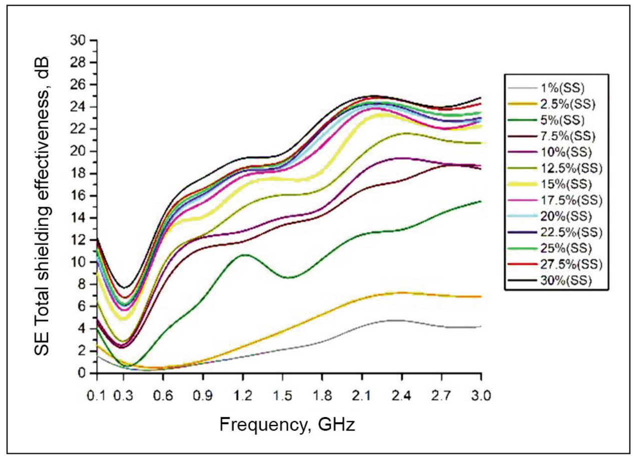

Fig. 5. Electromagnetic shielding effectiveness (EMSE) calendered nonwoven fabrics

mances. The electromagnetic shielding efficiencies of 2–3 dB increase with the increase of conductive stainless-steel fibres in the non-calendered and calendered nonwoven fabrics group containing 1%, 2.5%, and 5% conductive stainless-steel fibres. The electromagnetic shielding efficiencies of 1–2 dB increase with the increase of conductive stainless-steel fibres in the non-calendered and calendered nonwoven fabrics group containing 7.5%, 10%, and 12.5% conductive stainless-steel fibres. Conductivity is an effective parameter on the electromagnetic shielding effectiveness [17–21]. The electromagnetic shielding efficiencies of 0–1 dB increase with the increase of conductive stainless-steel fibres in the non-calendered and calendered nonwoven fabrics group containing 15%, 17.5%, 20%, 22.5%, 25%, 27.5% and 30% conductive stainless-steel fibres. It is observed that EMSE values increase with increasing amounts of conductive stainless-steel fibres. It is seen that the optimum level of electromagnetic shielding efficiency performance is obtained in non-calendered and calendered nonwoven fabrics containing 15% conductive stainless-steel fibres.

Absorption and reflection results

The reflection and absorption behaviour of the nonwoven fabrics are shown in figure 6. It can be observed that the reflection values observed across the measurement range showed an opposite trend to the absorption values, with the absorption values increasing and reflection values decreasing with an increase in the frequency. The absorption values are consistently higher than reflectance values for non-calendered and calendered nonwoven fabrics with 1%, 2.5%, 5%, and 7.5% conductive stainless-steel fibres between 0.1 and 0.3 GHz frequency range. This behaviour of fabrics with conductive composite fibres is related to the properties of the materials. For instance, stainless-steel fibres are defined as more absorbent materials rather than being reflective in terms of the attenuation of electromagnetic waves especially increasing frequencies [22–25, 27]. As can be seen, the reflectance values decrease when the absorption values increase. The absorption values of non-calendered and calendered nonwoven fabrics with 1%, 2.5%, 5%, and 7.5% conductive stainless-steel fibres decrease gradually with increases of frequency between 0.3 and 1.8 GHz frequency range. In between the 1.8 and 3 GHz frequency ranges, the reflection values decrease progressively with a rise in frequency. Moreover, as compared to each other non-calendered and calendered nonwoven fabrics with 1%, 2.5%, 5%, and 7.5% conductive stainless-steel fibres consistently showed 1–2 dB higher EMSE values across the between 0.1 and 3 GHz frequency range. This difference became more significant at higher frequency values which is between 1.8 and 3 GHz frequency range where the difference reached nearly 2 dB. Besides, the calendered nonwoven fabrics display lower EMSE values than non-calendered nonwoven fabrics between 0.1 and 3 GHz frequency range.

The reflection and absorption behaviour of the nonwoven fabrics are shown in figure 7. It can be observed that the reflection values observed across the measurement range showed an opposite trend to the absorption values, with the absorption values increasing and reflection values decreasing with an increase in the frequency. The absorption values are consistently higher than reflectance values for non-calendered and calendered nonwoven fabrics with 10%, 12.5%, 15%, and 17.5% conductive stainless-steel fibres between 0.1 and 0.3 GHz frequency range. This behaviour of fabrics with conductive composite fibres is related to the properties of the materials. As can be seen, the reflectance values decrease when the absorption values increase. The absorption values of non-calendered and calendered nonwoven fabrics with 10%, 12.5%, 15%, and 17.5% conductive stainless-steel fibres decrease gradually with increases of frequency between 0.3 and 1.8 GHz frequency range. In between the 1.8 and 3 GHz frequency ranges, the reflection values decrease progressively with a rise in frequency. Moreover, as compared to each other non-calendered and calendered nonwoven fabrics with 10%, 12.5%, 15%, and

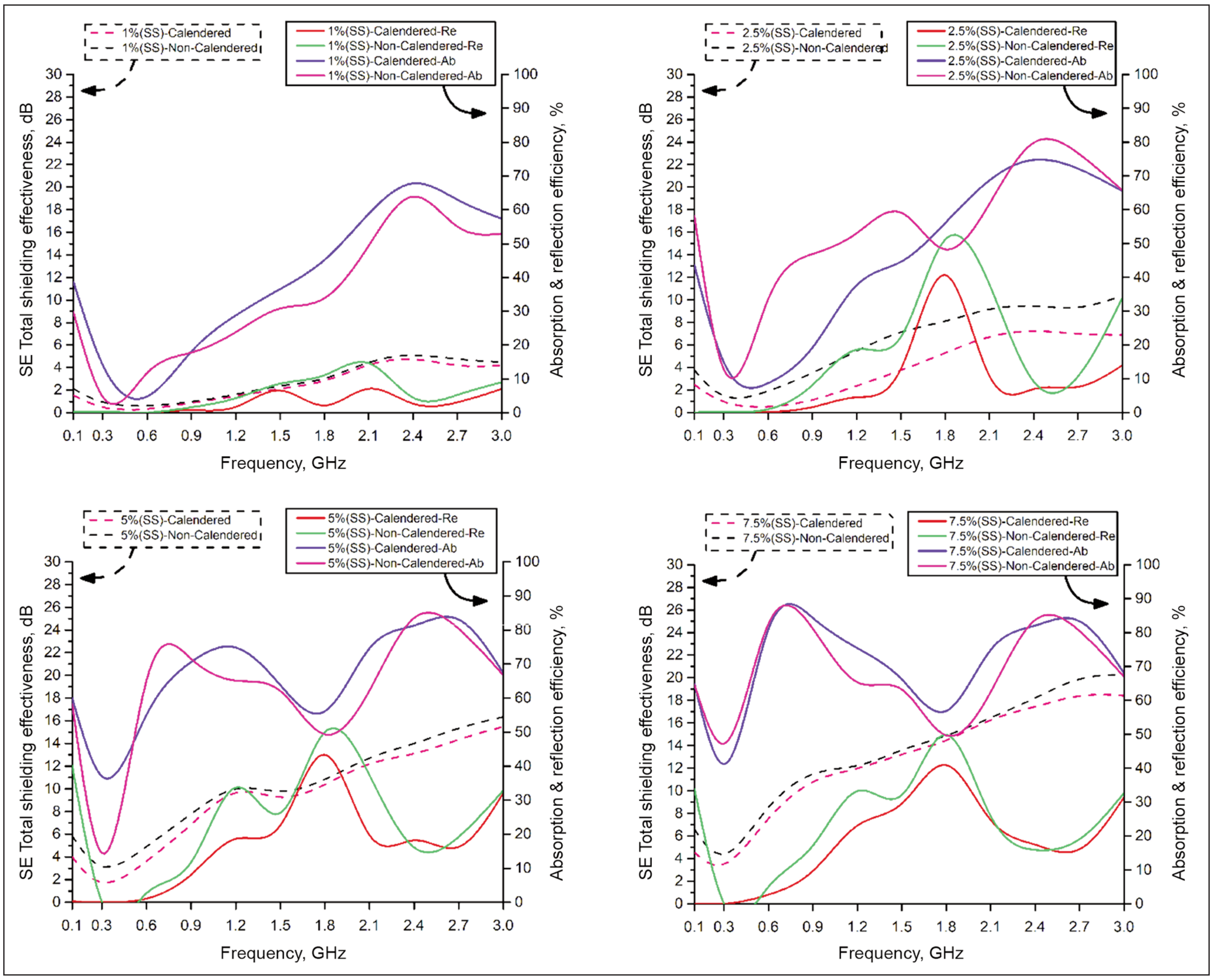

Fig. 6. Absorption and reflection results of calendered and non-calendered nonwoven fabrics with 1%, 2.5%, 5%, and 7.5% conductive stainless-steel fibres

17.5% conductive stainless-steel fibres consistently showed 1–2 dB higher EMSE values across the between 0.1 and 3 GHz frequency range. This difference became more significant at higher frequency values which is between 1.8 and 3 GHz frequency range where the difference reached nearly 2 dB. Besides, the calendered nonwoven fabrics display lower EMSE values than non-calendered nonwoven fabrics between 0.1 and 3 GHz frequency range.

The reflection and absorption behaviour of the nonwoven fabrics are shown in figure 8. It can be observed that the reflection values observed across the measurement range showed an opposite trend to the absorption values, with the absorption values increasing and reflection values decreasing with an increase in the frequency. The absorption values are consistently higher than reflectance values for non-calendered and calendered nonwoven fabrics with 20%, 22.5%, 25%, and 27.5% conductive stainless-steel fibres between 0.1 and 0.3 GHz frequency range. This behaviour of fabrics with conductive composite fibres is related to the properties of the materials. As can be seen, the reflectance values decrease when the absorption values increase. The absorption values of non-calendered and calendered nonwoven fabrics with 20%, 22.5%, 25%, and 27.5% conductive stainless-steel fibres decrease gradually with increases of frequency between 0.3 and 1.8 GHz frequency range. In between the 1.8 and 3 GHz frequency ranges, the reflection values decrease progressively with a rise in frequency. Moreover, as compared to each other non-calendered and calendered nonwoven fabrics with 20%, 22.5%, 25%, and 27.5% conductive stainless-steel fibres consistently showed 1–2 dB higher EMSE values across the between 0.1 and 3 GHz frequency range. This difference became more significant at higher frequency values which is between 1.8 and 3 GHz frequency range where the difference reached nearly 2 dB. Besides, the calendered nonwoven fabrics display lower EMSE values than non-calendered nonwoven fabrics between 0.1 and 3 GHz frequency range.

The reflection and absorption behaviour of the nonwoven fabrics are shown in figure 9. It can be observed that the reflection values observed across the measurement range showed an opposite trend to the absorption values, with the absorption values increasing and reflection values decreasing with an increase in the frequency. The absorption values are

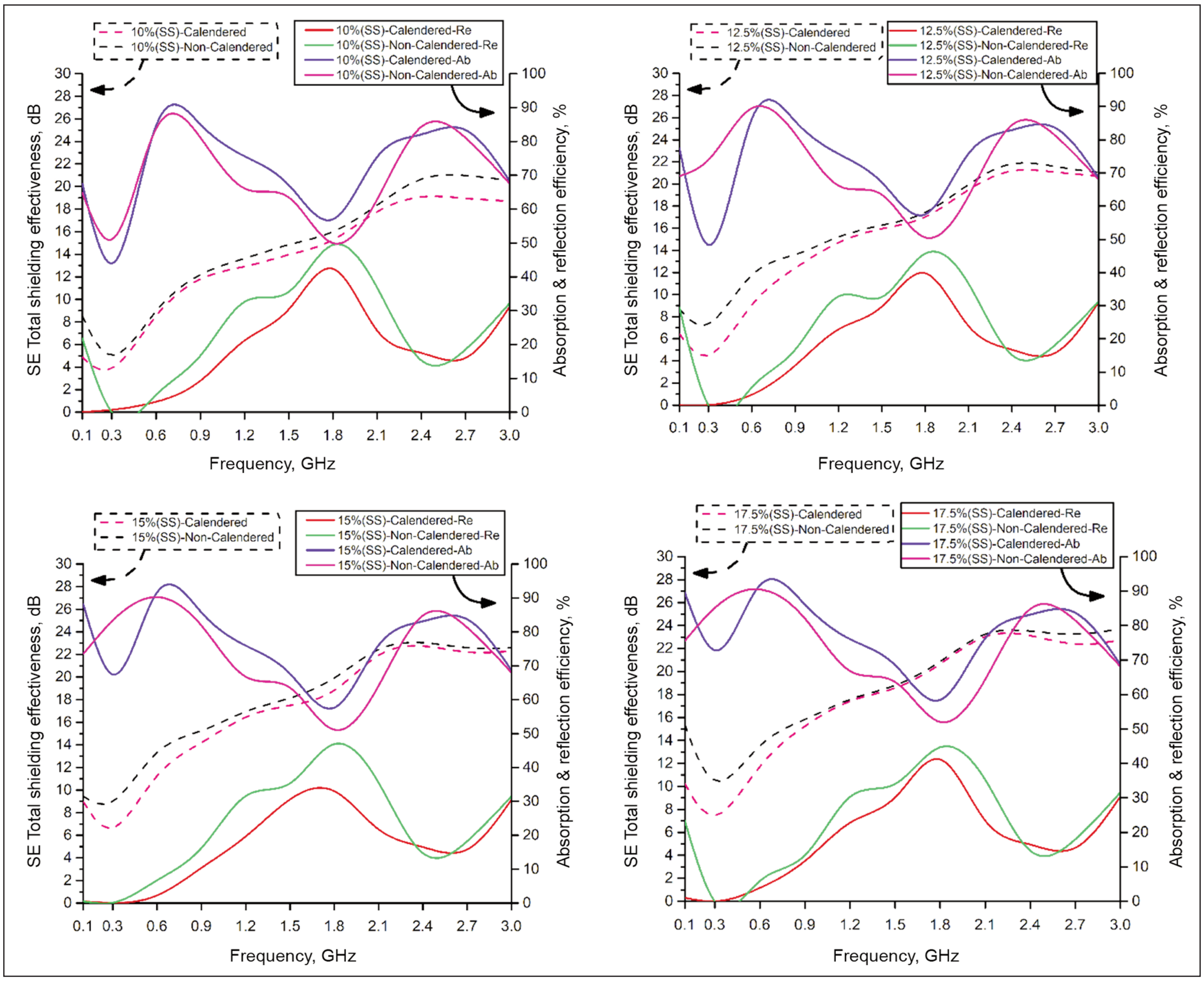

Fig. 7. Absorption and Reflection results of calendered and non-calendered nonwoven fabrics with 10%, 12.5%, 15%, and 17.5% conductive stainless-steel fibres

consistently higher than reflectance values for non-calendered and calendered nonwoven fabrics with 30% conductive stainless-steel fibres between 0.1 and 0.3 GHz frequency range. This behaviour of fabrics with conductive composite fibres is related to the properties of the materials. As can be seen, the reflectance values decrease when the absorption values increase. The absorption values of non-calendered and calendered nonwoven fabrics with 30% conductive stainless-steel fibres decrease gradually with increases of frequency between 0.3 and 1.8 GHz frequency range. In between the 1.8 and 3 GHz frequency ranges, the reflection values decrease progressively with a rise in frequency. Moreover, as compared to each other non-calendered and calendered nonwoven fabrics with 30% conductive stainless-steel fibres consistently showed 1–2 dB higher EMSE values across the between 0.1 and 3 GHz frequency range. This difference became more significant at higher frequency values which is between 1.8 and 3 GHz frequency range where the difference reached nearly 2 dB. Besides, the calendered nonwoven fabrics display lower EMSE values than non-calendered nonwoven fabrics between 0.1 and 3 GHz frequency range.

CONCLUSIONS

In this study, the needle-punched nonwoven composite fabrics with EMI shielding properties were manufactured through a production process consisting of carding, cross lapper, needle punching machine and oven by blending stainless steel fibres, recycled polyester fibres and sheath/core bi-component binder fibres at different ratios. Increased stainless steel fibre content also resulted in higher EMI shielding effectiveness. The main objective of this study is to compare the properties of electromagnetic shielding effectiveness (EMSE) of non-calendered and calendered nonwoven fabrics. The non-calendered nonwoven fabrics have higher EMSE values than the calendered nonwoven fabrics. The highest electromagnetic shielding found in this work was 26 dB for non-calendered and calendered nonwoven fabrics containing a 15% 1.8–2.4 GHz frequency range. The optimum level of electromagnetic shielding efficiency performance is obtained in non-calendered and calendered nonwoven fabrics containing 15% conductive stainless-steel fibres. For higher shielding values, the percentage of stainless steel should be increased. EMSE values were evaluated,

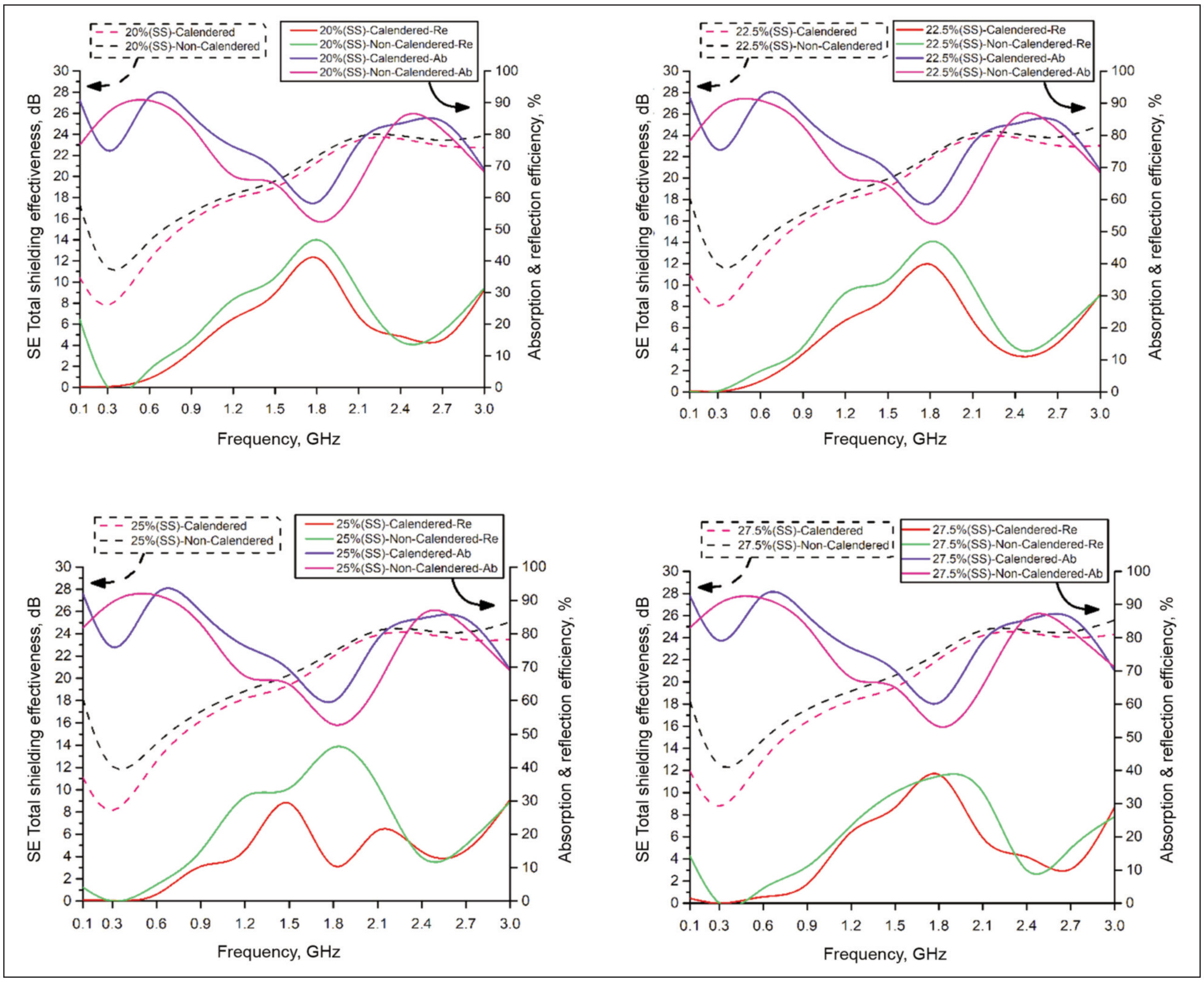

Fig. 8. Absorption and reflection results of calendered and non-calendered nonwoven fabrics with 20%, 22.5%, 25%, and 27.5% conductive stainless-steel fibres

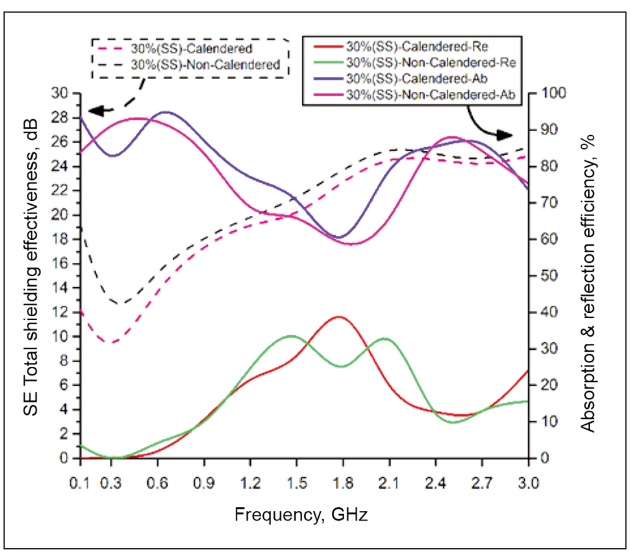

Fig. 9. Absorption and reflection results of calendered and non-calendered nonwoven fabrics with 30% conductive stainless-steel fibres

as shown in table 2, it was observed that non-calendered and calendered nonwoven fabrics containing 15%, 17.5%, 20%, 22.5%, 25%, 27.5% and 30% conductive stainless-steel fibres shield around 90 % and 99 % of electromagnetic waves between 0.1–0.6 GHz and 0.6–3 GHz frequency range, respectively. The non-calendered and calendered nonwoven fabrics containing 7.5%, 10% and 12.5%, conductive stainless-steel fibres shield around 80 % and 90 % of electromagnetic waves between 0.1–0.6 GHz and 0.6–3 GHz frequency range, respectively. The non-calendered and calendered nonwoven fabrics containing 1%, 2.5% and 5%, conductive stainless-steel fibres shield around 70 % and 80 % of electromagnetic waves between 0.1–0.6 GHz and 0.6–3 GHz frequency range, respectively. Concurrently, this suggests that these fabrics containing 1%, 2.5%, %5, 7.5%, 10%, 12.5% and 15% conductive stainless-steel fibres are highly suitable for most of the class-II (general) applications. The developed high EMSE non-calendered and calendered nonwoven fabrics containing 17.5%, 20%, 22.5%, 25%, 27.5% and 30% stainless steel fibres have potential applications in defence applications such as military tents, military secret rooms, protective covers, missile cover and building as an EMI shielding material.

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