INVESTIGATION of ELECTROMAGNETIC SHIELDING EFFECTIVENESS of THE NEEDLE PUNCHED NONWOVEN FABRICS PRODUCED from STAINLESS STEEL and CARBON FIBRES

M. S. OZEN[1,2], I. USTA[1], M. YUKSEK[1], E. SANCAK[1,2,*], N. SOIN[2]
[1]Marmara University, Technology Faculty, Department of Textile Engineering, İstanbul, TURKEY
[2]Institute for Materials Research and Innovation (IMRI), University of Bolton, Bolton, UK
*Corresponding Author: esancak@marmara.edu.tr

ABSTRACT

Electromagnetic shielding effectiveness (EMSE) of needle punched, nonwoven fabrics produced using staple stainless steel and carbon fibres was investigated. Utilising carding and large scale industrial type needle punching machines, the webs of staple stainless steel and carbon fibres were produced, which were subsequently bonded on needle punching machine at approximately 132 punches/cm^2 and 13.5mm needle penetration depth. The effect of varying carbon fibre content was studied by varying the blend ratio of stainless steel and carbon fibres between 5-20%. The EMSE measurements of as-produced needle punched nonwoven fabrics were carried out using a coaxial transmission line method (ASTM D4935-10) in the frequency range of 15-3000 MHz. Within the range, the EMSE values were enhanced from 22.3 dB (95/5, stainless steel/carbon) to 44.7 dB (80/20, stainless steel/carbon), which was attributed to the enhanced conductivity of the fabrics. In fact, the surface resistivity of the samples reduced from 5.80E+3 Ω to 2.43E+2 Ω enhanced for 95:5 and 80:20 stainless steel/carbon blends.

Keywords: Carbon fibre, electromagnetic shielding, nonwoven, stainless steel fibre, needle punching

I. INTRODUCTION

The number of electromagnetic electronic devices and equipment ranging from televisions to mobile phones and wireless communication systems have dramatically increased all over the world. While, it is of little doubt that these advances have enhanced the standard of life for people worldwide, nevertheless these devices emit electromagnetic radiation. The electromagnetic radiation, particularly at high frequency tends to interfere with the electronics and for proper operation requires shielding. Moreover, it has been established that long term exposure to acute electromagnetic radiation can have harmful effects on human tissue and the radiation can interfere with certain bio-electronic devices such as pacemakers [1,2]. Electromagnetic shielding materials are thus necessary to protect the human health and electronic devices against harmful effects of these electromagnetic waves.

Metals are usually considered to be the best electromagnetic shielding materials for reflecting electromagnetic waves owing to their high conductivity and permeability. However, metals are bulky, expensive, and difficult to process, and suffer from oxidation and corrosion problems associated with exposure to ambient environment. In contrast, light weight and anti-corrosive properties of conductive polymer materials are extremely suitable for electromagnetic shielding [3]. Conductive polymers such as polyaniline, polypyrrole and polythiophene are usually deposited on textile or nonwoven fabric surface for shielding applications. Methods such as vacuum deposition of metals (metallization) of textile materials such as nylon, polyester, polyurethane have also been discussed in the literature [2], [4]. However, both these methods significantly deteriorate the fabric drape and garment comfort. Similarly, to add suitable conductivity to thermoplastic intrinsically nonconducting polymers, conductive nanomaterials of copper, carbon black, graphene, carbon fibres and carbon nanotubes have also been utilized [5]. In fact, electromagnetic interference shielding is a rapidly growing application of carbon materials, especially staple carbon fibres owing to their superior properties of high electrically conductivity, high tensile strength, high thermal conductivity & fire resistance and ease of processing. As described in the literature, high EMSE performance from short carbon fibre based materials is expected owing to their high electrical conductivity. In a topical review carried out by Chung et al, it was established that as the amount of carbon fibre in the material increases, EMSE of the material increases electromagnetic shielding materials made from continuous filament fibres have higher EMSE performance as compared to those prepared using short staple carbon fibres. EMSE performances of the materials produced from carbon fibre differ depending on carbon content. There many thermoset and thermoplastic composite materials reinforced with carbon fibre for EM applications. The materials made from continuous filament fibres have higher EMSE performance comparing to the materials produced from short staple carbon fibre [6,7]. In the literature, carbon fibre based textile structure have been processed through routes such as weaving and knitting techniques using steel, silver, carbon fibre, core yarns with metal wire and carbon fabric [2,8]. However, no studies on the preparation of high EMSE nonwoven textiles utilizing staple carbon fibres have been found in the literature.

In the present study, we aim to investigate the electromagnetic shielding effectiveness of stainless steel, carbon fibre needle punched nonwoven fabrics produced at different blend ratios (5-20 wt% of carbon fibre). In the frequency range of 15-3000 MHz, the 95/5, 90/10 and 80/20 blends of stainless staple steel/carbon fibres shoed EMSE values of 22.3dB, 35.4dB and 44.7dB, respectively. The observed results were further corroborated using electrical resistivity measurements and ANOVA statistical analysis. The developed needle punched nonwoven materials can find applications into RF shielding and lower end of microwave waves used for terrestrial wireless communication where they shield up to 99% of incident electromagnetic waves.

II. EXPERIMENTAL STUDY

II.1. Materials

For the experimental study, Bekaert Bekinox® stainless steel fibres were procured from Bekaert Ltd. (Belgium). These stainless steel fibre consists of electrically conductive stainless steel fibres as the core and the sheath consisting of wound polyester fibres (50/50 by weight, see thermos-gravimetric analysis in Fig. I) with a staple length of about 90 mm. Carbon fibres produced from polyacrylonitrile (PAN) were provided by DowAksa Ltd. (Turkey). The continuous carbon fibre filaments were converted to staple fibres by cutting at similar staple length to steel fibres. The physical, mechanical properties for both the staple fibres are provided in Table I. The tensile strength of the stainless steel fibres and carbon fibres were carried out on an Instron4411 device based on TS EN ISO 5079 standard. The device was adjusted for testing at 10mm/min test speed and 10mm gauge length. The stainless steel fibres were used for increasing conductive ratio in needle punched nonwoven fabric. The role of steel fibres on EMSE is to increase the EMSE value of nonwoven fabrics.

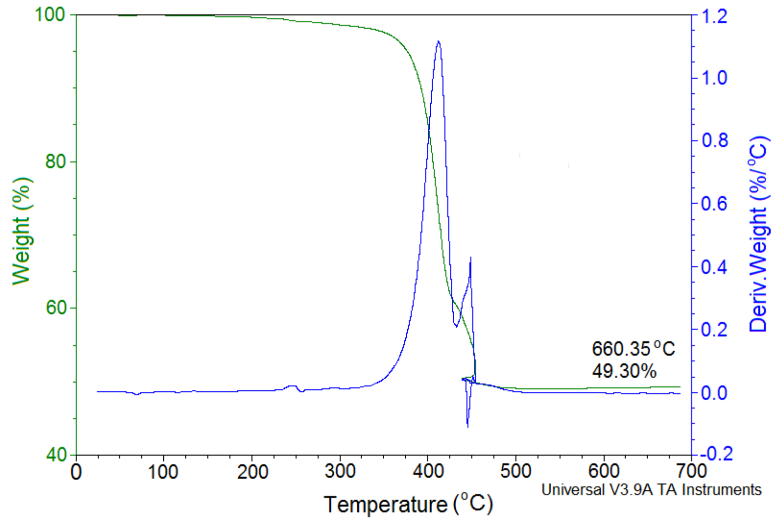


Figure I. TGA Analysis of Stainless Steel Fibre

Thermo-gravimetric analysis (TGA) was carried out for determining the amount of polyester sheath on the stainless steel fibre core. The TGA analysis was performed on a TA Instruments SDT 2960 DTA-TGA in the range of 20-700ºC at a heating rate of 10ºC/min under dry air flow. The TGA analysis shows that the residual weight of stainless steel fibres was 49.30%, which corresponds well with the data provided by the manufacturer [9]**.** The TG curve and corresponding derivative curve (DTG) of stainless steel fibre are given at Figure I. It was understood that the decomposition of the polyester component of the stainless steel fibre occurs in the range of 365-453°C with two DTG peaks at 412°C and 448°C. In figure I, the combustion of the polymer component produced enough energy that the temperature momentarily increased more than the programmed rate, which accounts for the unusual shape of the curve due to the cooling that followed the reactive overheating.

SEM images of the longitudinal view and cross section of the staple carbon and the stainless steel fibres used in the study are shown in Figure II. These SEM images indicate that both of these fibres have a cross section nearly circular. It was seen that the staple carbon fibre is finer than the stainless steel fibre as fibre fineness. Images of produced needle punched nonwoven fabrics presented in Figure III were taken at microscopy with magnification of 10x. The processing and analysis of these SEM images was performed with ImageJ software and ImageJ map images from colour differences of the staple carbon and the stainless steel fibres were obtained. The ImageJ map images show clearly the increase in the amount of the carbon fibres.

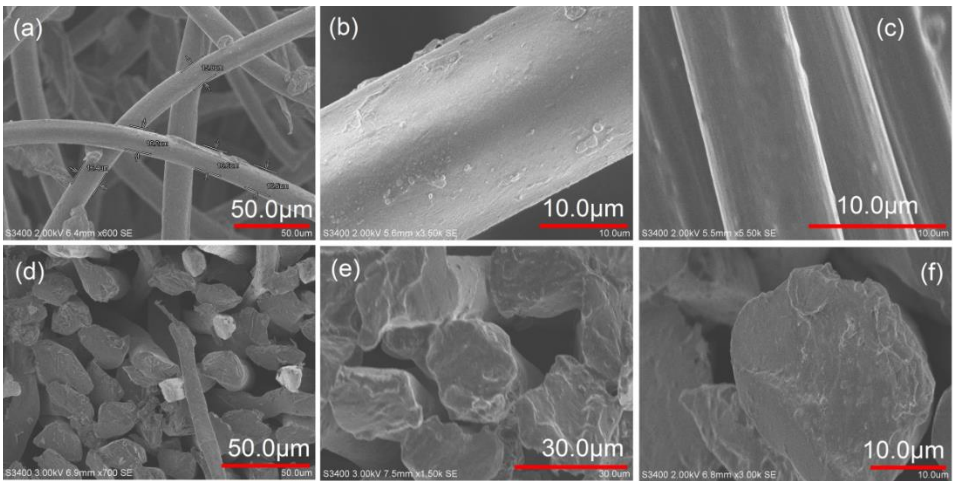
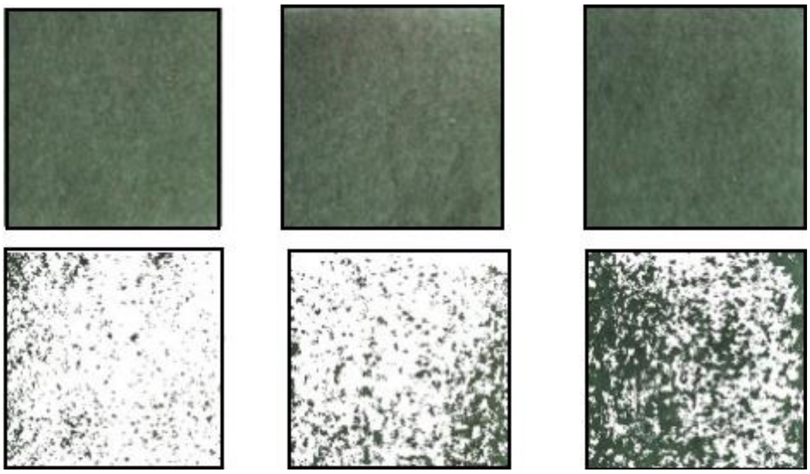


Figure II. SEM (a, b) Longitudinal Images of Stainless Steel and (c) Carbon Fibres and (d, e, f) Cross-Sectional Images of Stainless Steel Fibre



C-SS-1 C-SS-2 C-SS-3

Figure III. Needle Punched Nonwoven Fabric Samples (taken at x10 magnification)

Table I. Properties of the Fibres Used at Experimental Study

The Properties of the Fibres	12.7dtex Stainless Steel Polyester/Steel Fibres (Bekaert)		Staple Carbon Fibre (DowAksa)
	Polyester Fibre Part	Steel Fibres Part	
Fineness of the Fibre (dtex)	3.6	9.1	0,66
Staple Length of the Fibre(mm)	90		100
Diameter of the Fibre (µm)	-	12	6.45
Breaking Load (cN)	15.47		14.35
Breaking Strength (cN/tex)	12.18		217.42
Elongation at Break (%)	40.43		1.8

Table II. Weight Percentage of Fibres Used in Needle Punched Nonwoven Fabrics

Nonwoven Fabrics	Weight, %			Conductive Part (%)	Non-Conducting Part (%)	Areal Density (g/m^2)	Thickness (mm)
	Stainless Steel Fibres		Carbon Fibres				
	Polyester part	Steel part					
C-SS-1	47.5	47.5	5	52.5	47.5	256.74	2.47
C-SS-2	45	45	10	55.0	45	274.49	2.37
C-SS-3	40	40	20	60.0	40	244.39	2.38

II.2. Method

Carbon content was chosen as 5%, 10% and 20% by weight with the samples being mixed according to the weight percentage as shown in Table II. Carding and needle punching technologies were used for the web formation and subsequent bonding. As the shielding effectiveness depends not only upon electrical conductivity of the fibre, but also upon its homogeneous distribution, before the carding operation, the staple carbon fibres and stainless steel fibres were opened and blended together. As the fibres used in experimental study are conductive, no antistatic agent was used. The nonwoven webs were formed with carding machine from stainless steel fibres and staple carbon fibres. To obtain homogeneous mixing, these fibres were carded twice at carding machine. The second mixture was done at industrial type needling machine. In the wool type carding machine used for the first stage, the fibre feeding speed was about 0.75m/min, the main cylinder speed was about 640m/min, and the doffer cylinder speed (delivery speed) was about 21m/min. These webs were wound and collected on the rotating drum and were further needled at about 132 punches per cm^2 by DILO needle punching machine. Foster 15x18x40x3.5 R333 RBA barbed needles were used at this needle punching machine. As observed in the SEM images (Figure II), the diameter of stainless steel fibre is between 15-16µm. Thus, the with 36 and 40 working gauge are highly suitable for these 1.5 and 6 denier fibres. During the production, the needle penetration depth was adjusted to 13.5mm in order to prevent breakage of carbon fibres. The working parameters of the needle punching machine are given in Table III.

Table III. Working Parameters of the Needle Punching Machine

Needle punching machine rotation (rpm/min)	585
Web feeding speed (m/min)	3.3
Fabric delivery speed (m/min)	5.1
Depth of needle penetration (mm)	13.5
Distance between needle boards (mm)	19
Needle punch density per cm^2 (punches/cm^2)	131.8

Now, the needle punching technology is based on mechanical bonding of fibres by interlocking staple fibres using long barbed felting needles. The needle punching parameters such as needle penetration, needle punch density was determined to bond fibres well without causing breaking of the stainless steel and carbon fibres. As compared to standard polymeric fibres, they are more susceptible to damage upon repeated mechanical effects. As metallic fibres exhibit poor recovery from bending and can break away easily especially when processed at the second and third needling stages, only pre-needling operation was applied to web and needle punch density was kept low (Table III). It has been shown in the literature that repeated needling and very high punch densities can result in the breakage of fibres, reducing their EMSE values [2]. The areal density and thicknesses (measured using James H.Heal thickness tester, according to TS EN ISO 9073-2) of needle punched nonwoven fabrics are listed in Table II, with the corresponding percentages of conductive and non-conductive parts. It is an established fact that upon increasing of needling density/punch density and the depth of needle penetration, the thickness of resulting fabric is reduced. In our previous studies, it has been observed that as the thickness of nonwoven fabric decreases, the electromagnetic shielding effectiveness of nonwoven fabric decreases too [10]. The types of needle barb are classified according to fibre carrying capacities. Increasing of fibre carrying capacities of barbs reduce the thickness of nonwoven fabric too. This result affects the EMSE of nonwoven fabric [11].

II.3. EM Shielding Effectiveness (EMSE) Measurements

Shielding can be specified in the terms of reduction in magnetic and electrical field or plane-wave strength caused by shielding. The effectiveness of a shield and its resulting EMI attenuation are dependent on the frequency, the distance of the shield from the source, the thickness of the shield, and the shielding material.

Shielding effectiveness (SE) is normally expressed in decibels (dB) as a function of the logarithmic ratio of the incident and exit electric (E), magnetic (H), or plane-wave field intensities and defined by SE (dB) = 20 log (E0/E1), SE (dB) = 20 log (H0/H1), and SE (dB) =20 log (F0/F1) respectively.

The electromagnetic shielding effectiveness of the as-produced needle punched nonwoven fabrics were determined using the ASTM D 4935-10 coaxial transmission line standard method for planar materials standard. This standard determined the shielding effectiveness of the textile structures using the insertion-loss method and is shown in Figure IV. The technique involves irradiating a flat, thin sample of the base material with an EM wave over the frequency range of interest, utilizing a coaxial and a flanged outer conductor [12].

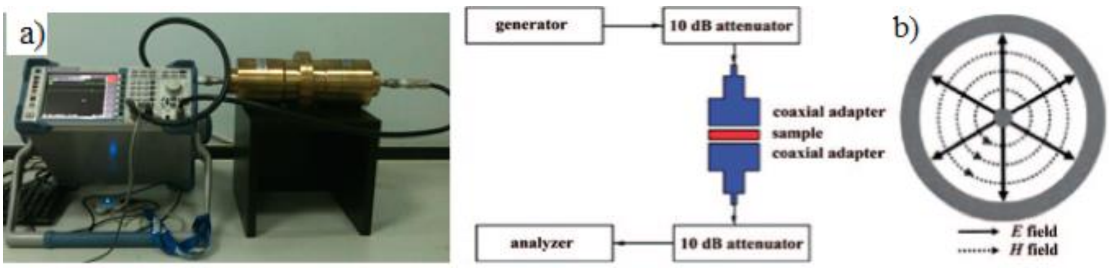


Figure IV. (a) Set-up with coaxial adapters (b) electric (E) and magnetic (H) field distribution inside a coaxial line [8]

For our analysis, a shielding effectiveness test fixture (Electro-Metrics, Inc., model EM-2107A) was used to hold the sample with a network analyzer generating and receiving the EM signals. Test specimens were kept between the two metal coaxial electrodes in contact. A pressure of 45 grams per cm2 for each needle punched nonwoven fabric was applied during testing. The shielding effectiveness was determined from (Equation1), which is the ratio of the incident field to that which passes through the material.

$$\mathrm{EMSE} = 10\log\left(\frac{\mathrm{P_1}}{\mathrm{P_2}}\right) \tag{1}$$

Where P1 (watts) is power received with the fabric present and P2 (watts) is received power without the presence of the fabric. The input power used was 0 dB, corresponding to 1 mW. The reflectance (R_e) and the transmittance (T_r) of the composite were also measured and the absorbance ($\mathrm{A_b}$) was calculated using following Eq. (2):

$$\mathrm{A_b} = 1 - T_\mathrm{r} - R_\mathrm{e} \tag{2}$$

Where, Re and Tr are the square of the ratio of reflected (Er) and transmitted (Et) electric fields to the incident electric field (Ei), respectively, as following Eqs. (3) and (4):

$$R_\mathrm{e} = \left|\frac{E_r}{E_i}\right|^2 = |S_{11}(or\ S_{22})|^2 \tag{3}$$

$$T_\mathrm{r} = \left|\frac{E_t}{E_i}\right|^2 = |S_{21}(or\ S_{12})|^2 \tag{4}$$

R_e And T_r were obtained by the measurement of S-parameters, S_{11} (or S_{22}) and S_{12} (or S_{21}) for the reflection and the transmission, respectively. The measurement device consists of a network analyzer, which is capable of measuring incident, transmitted and reflected powers and a sample holder. The shielding effectiveness is determined by comparing the difference in attenuation of a reference sample to the test sample, taking into account the incident and transmitted power. The EMSE values of the three different needle punched nonwoven fabrics C-SS-1 (95/5), C-SS-2 (90/10) and C-SS-3 (80/20) as described in Figure V were measured in the range of 15-3000MHz with the presented results being the average of five readings.

III. RESULTS and DISCUSSION

3.1. Surface Resistivity

The surface resistivity of the needle punched nonwoven fabrics with the stainless steel and carbon fibre are shown in Figure V(c). It was observed that the needle punched nonwoven fabric with 20% staple carbon fibre (C-SS-3) had the lowest surface resistivity (2.43E+02 Ω) as compared to the needle punched nonwoven fabrics containing 10% (1.51E+03 Ω) and 5% (5.83E+03 Ω) carbon fibre. By definition, a lower surface resistivity implies higher conductivity [27,28] and hence it can be said that the nonwoven fabrics with 20wt.% carbon fibre is more conductive than the other nonwoven fabrics. Conductivity is one of the significant parameters affecting the EMSE properties of materials. It is well established that the materials having higher conductivity tend to show higher EMSE performance [7].

In accordance with the surface resistivity measurements, the EMSE measurements showed a similar trend. Figure V(a) shows the EMSE values of needle punched nonwoven fabrics produced from stainless steel fibres with staple carbon fibres at different ratios in the 15-3000 MHz frequency ranges. As the frequency increases, the EMSE values of all the needle punched nonwoven fabrics shows an almost linear increase. The structures with smaller gaps between conductive fibres display higher overall EMSE shielding effectiveness at high frequency, moreover, bigger gaps between conductive fiber display higher overall EMSE shielding effectiveness at low frequency [13-16]. It was clearly seen that, as the amount of carbon fibre used in needle punched nonwoven fabrics increases, EMSE values also increase in the 15-3000MHz frequency ranges. The C-SS-3 nonwoven fabric with 20% carbon fibre obtained the highest 44.7dB EMSE value in the 3000MHz frequency range, while the C-SS-2 and C-SS-1 samples showed 35.4 dB and 22.3 dB, respectively in the same frequency range. These values are significantly higher than the control sample of pristine stainless steel needle punched nonwoven fabric. These values are similar to those observed by Kim and Chung, who investigated properties of electromagnetic shielding effectiveness of carbon fibre nonwoven mat, nickel coated carbon fibre nonwoven mat, filament carbon fibre woven fabric and nickel/copper coated polyester knitted fabric. In their study, the highest shielding effectiveness of 53dB at 1.0GHz was attained by the metal-coated polyester knitted fabric. It was found that nonwoven fabric with nickel coated carbon fibre was superior for shielding compared to bare carbon fibre nonwoven mat [17]. Similarly, Ting-Ting, L. et.al developed a composite structure with three layers consisted of carbon woven fabric and needle punched nonwoven fabrics for wall interlayer and package interline applications. Nonwoven fabrics consisting of staple

Kevlar fibres, melt staple polyester, nylon6 staple fibres and carbon woven fabrics, which were combined by using pre-needle punching machine and the structure further bonded with calendaring machine at 160°C. It was found that hot-pressed composites with three layers reached an optimal electromagnetic shielding effectiveness of 65dB in very high frequency range between 2000-3000MHz [18]. However, with multiple steps, the processing of the material is much more time consuming unlike our samples. From this experimental study, it was understood that the staple carbon fibres had considerable effect on electromagnetic shielding effectiveness results.

Morari et.al studied electrical conductivity and electromagnetic shielding effectiveness of composite materials made from silicone rubber with carbon and ferrite powder in microwaves and terahertz frequency ranges [19]. Chang et.al studied the electromagnetic shielding of waterborne polyurethane composite film added carbon fibre, nickel nanoparticles and multiwalled carbon nanotubes by polymer blending method. At 1000MHz frequency, the shielding effectiveness of conductive composite film prepared by carbon fibre/nickel nanoparticles reached to 28dB. At loadings of 33wt% carbon fibre in conjunction with 13wt% carbon nanotubes, the shielding effectiveness reached 33.7dB at 1000MHz [20]. Huang et.al investigated electromagnetic shielding effectiveness of cement based composites filled with carbon black and carbon fibre. The shielding effectiveness gradually improved with the increase of carbon fibre content and attained a maximum of 21dB at 1.5GHz. It was emphasized that carbon fibre is a much more effective additive than carbon black for EMI shielding [21]. As mentioned earlier, most of the existing studies focus on composite structures, knitted or woven fabrics coated with conductive polymers such as polypyrolle, polyaniline or conductive powders, composites and fabrics produced with conductive core yarn. There is a significant lack of literature on the electromagnetic shielding properties of nonwoven fabrics produced from directly conductive fibres.

Figure V(b) shows the absorbance and reflectance values measured from needle punched nonwoven fabrics samples the 15-3000 MHz frequency ranges. All the nonwoven samples show decreased reflectance and increased absorbance amount of electromagnetic waves with increasing of frequency [22-25]. According to Chung, the primary mechanism of EMI shielding is usually reflection, which requires mobile charge carriers such as electrons which interact with the electromagnetic fields in the radiation. Similarly, a secondary mechanism of the EMI shielding is associated with absorption which occurs when the EM shield has electric/magnetic dipoles which can interact with the electromagnetic fields in the radiation [7]. Both the reflection and absorption of electromagnetic waves are related with properties of conductive fillers. For our samples, the absorption values reduce as a function of the frequency in the range of 15-2000 MHz with a corresponding increase in the reflectance values. This behaviour is expected considering the absorption values for stainless steel and carbon fibers are much higher than reflectance amount of electromagnetic waves. Figure V (a,b) shows the values of absorbance, reflectance and EMI shielding values at frequencies 15-3000 MHz. Three measurements from one each nonwoven fabric sample was done.

As shown in Figure V (d), the density specific EMSE of nonwoven fabrics in comparison with values reported by other researchers [10]. The nonwoven fabric (E) with stainless steel fibre was compared with the nonwoven fabrics (B, C, D) with steel fibre and carbon fibre and multi-axial fabric (A) with 100% carbon fibre. It can be seen that the nonwoven fabrics with stainless steel and carbon fibers have higher specific EMI SE than the nonwoven fabric with 100% stainless steel fiber and lower specific EMI SE than the multi-axial fabric with 100% carbon fiber, possibly resulting from material properties. It is known that the stainless steel fibre consists of 50/50% polyester and steel fibre. As it is not possible to produce a needle punched nonwoven fabric from carbon fibres without crimp by carding and needle punching technology, the nonwoven fabrics were compared with multi axial fabric (A) consisting of 100% carbon filament fibres.

In order to ascertain and demonstrate the effect of carbon fibre on the EMSE values of stainless steel-carbon fibre samples, one-way ANOVA analysis with SPSS 13.0 was carried out and the statistical results were evaluated at 5% significance level. The analysis clearly shows effect of increasing the percentage of carbon fibre on EMSE of needle punched nonwoven fabrics. Through the analysis, three groups are identified, referring to the nonwoven fabrics with different carbon rates (Group I: % 5 C, Group II: %10 C, Group III: %20 C). The results in Table IV show that there is a significant difference across the groups in terms of the mean score of EMSE. Besides, a post hoc test - Tukey test for multiple comparisons- was used to determine which of these groups differ from each other. Accordingly, each fabric with different carbon rate was varied by the others in significant way ($p<.05$). The needle punched nonwoven fabrics with 20%, 10% and 5% blend of staple carbon fibre have obtained average EMSE values of 39.49dB, 30.98dB and 17.67dB respectively. As a result, it is found that EMSE increases with increasing of percentage of carbon fibre into the needle punched nonwoven fabrics.

EM shielding textiles has two classes, professional and general use. Table IV shows the performance specifications of EM shielding textiles both in general use and professional use. While EM shielding textiles in general use achieve shielding up to a level of 30dB, professional use products achieve shielding from at least 30dB up to 50dB and higher. The casual wears, uniforms (computer and Telecom Company), aprons, maternity dress or protective covers for consumer electronic products are considered and evaluated as the EM shielding textiles in general use. Otherwise, the medical devices, safety uniform, shielding material for electronic component, assembly equipment and other applications are accepted and evaluated as EM shielding textiles in professional use [26].

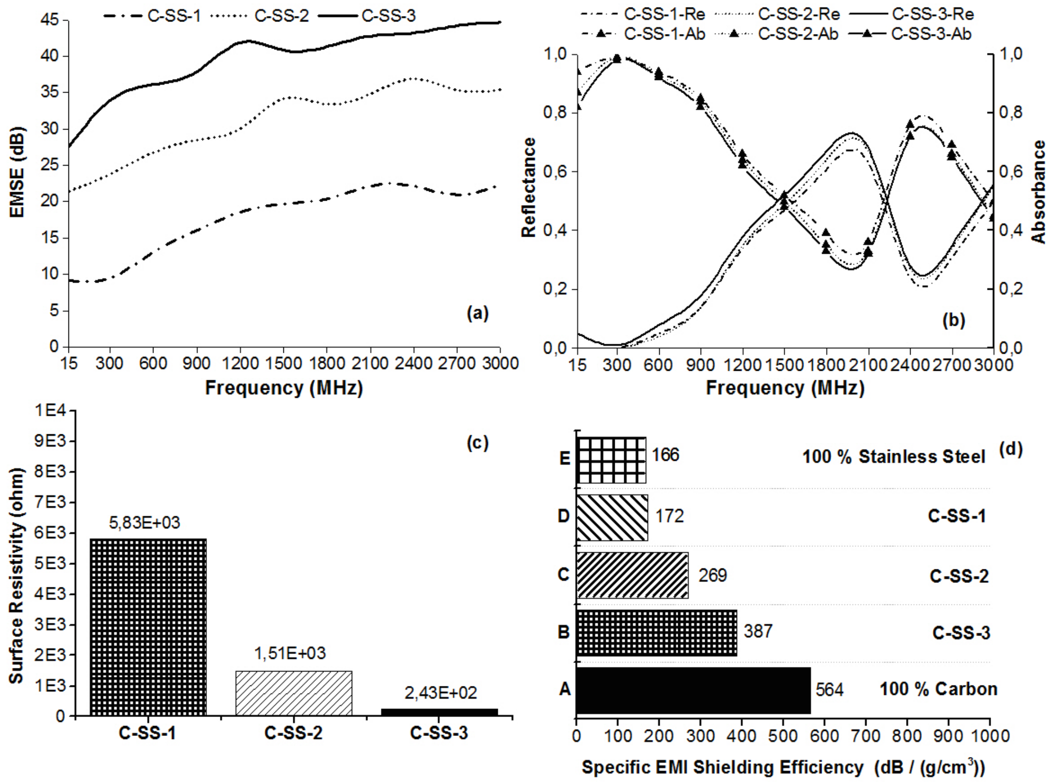


Figure V. (a) EMI Shielding Efficiency of Needle Punched Nonwoven Fabrics with Different Percentage of Carbon Fibres between 15MHz and 3000MHz. **(b)** Absorbance and Reflectance Results of Needle Punched Nonwoven Fabrics with Different Percentage of Carbon Fibres between 15MHz and 3000MHz. **(c)** Surface Resistivity Results for Needle Punched Nonwoven Fabrics. **(d)** The Comparative of Specific EMI Shielding Efficiency of Our Data with Other Reported Results

Table IV. Performance Specifications of Electromagnetic Shielding Textiles in General and Professional Use [26]

Grade	5 Excellent	4 Very Good	3 Good	2 Moderate	1 Fair
Percentage of Electromagnetic Shielding (ES)	SE>99.9%	99.9%≥ SE>99%	99%≥SE> 90%	90%≥SE> 80%	80%≥SE> 70%
Shielding Effectiveness (SE) in General Use	SE>30dB	30dB≥SE >20dB	20dB≥SE >10dB	10dB≥SE >7dB	7dB≥SE> 5dB
Shielding Effectiveness (SE) in Professional Use	SE>60dB	60dB≥SE >50dB	50dB≥SE >40dB	40dB≥SE >30dB	30dB≥SE >20dB

Table V. One-way ANOVA model for EMSE

Dependent Variable	Nonwoven Fabrics Containing Different Ratio of Carbon Fibre				F test statistics
	N	Mean	Std. Deviation	Std. Error	

	(I)	(II)	(III)	(I)	(II)	(III)	(I)	(II)	(III)	(I)	(II)	(III)	F	df1;2	Sig.
EMSE	11	11	11	17.67	30.98	39.49	4.97	5.23	5.21	1.50	1.58	1.57	50.399	2;30	.000

Multiple Comparisons (Tukey HSD)

EMSE		Mean Difference	Std. Error	Sig.
(I)	(II)	-13.31*	2.19	.00
	(III)	-21.82*	2.19	.00
(II)	(I)	13.31*	2.19	.00
	(III)	-8.51*	2.19	.00
(III)	(I)	21.82*	2.19	.00
	(II)	8.51*	2.19	.00

Note:

(1) Significance level (2-tailed): $p<.05$
(2) Group I: C-SS-1 (%5C)
Group II: C-SS-2 (%10C)
Group 3: C-SS-3 (%20C)
(3) EMSE; Electromagnetic Shielding Effectiveness, N: The number of measurement; df: degree of freedom; Sig: Significant; Std: Standardized

CONCLUSION

In this study, electromagnetic shielding effectiveness of needle punched nonwoven fabrics produced from staple carbon and stainless steel fibres with carding and needle punching technologies was investigated. Firstly, the staple carbon fibres were mixed with the staple stainless steel fibres at 5%, 10% and 20% blend ratios. It was observed that on increasing the carbon fibre ratio in the needle punched nonwoven fabrics a significant increase in electromagnetic shielding effectiveness can be observed. In fact, the needle punched nonwoven fabric with 20/80% carbon/steel fibre content display highest EMSE of 44.7dB in 3000MHz frequency range as compared to 35.4dB and 22.3dB for 10/90% and 5/95% carbon/steel fibre content, respectively. Further analysis of the EMSE behaviour showed that the absorbance and reflectance behaviours of all needle punched nonwoven fabrics are similar to each other in 15MHz and 3000MHz frequency range. The enhanced EMSE behaviour was attributed to significant reduction in the surface resistivity from 5.83E+03Ω for 5/95% carbon/stainless steel blend to 2.43+E02 Ω for 20/80% carbon/stainless steel blend, which was further confirmed through one-way ANOVA analysis. The developed high EMSE needle punched nonwoven fabrics produced from stainless steel and carbon fibres have potential applications in defence applications such as military tent, military secret room, protective cover, missile cover and building as an EMI shielding material.

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