Investigation of the Electromagnetic Shielding Effectiveness of Carded and Needle Bonded Nonwoven Fabrics Produced at Different Ratios with Conductive Steel Fibers

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ABSTRACT
The number of electrical and electronic devices in our daily life has increased. The devices produce electromagnetic waves which harm human and environments. In recent years, there has been an increasing interest in the reduction and control of electromagnetic waves.

The paper focuses on shielding of electromagnetic waves of nonwoven fabrics produced with needle punching technology from conductive stainless steel fibers. The needle punched nonwoven fabrics were produced with carding and needle punching technology by blending stainless steel fibers and normal staple polyester fibers at different ratios for electromagnetic shielding applications. The electromagnetic shielding effectiveness of the nonwoven fabrics with conductive stainless steel fibers was tested. After blending of stainless steel fibers and normal polyester fibers, the webs were formed by a wool-type carding machine and the after web folding operation, the webs were bonded by needle punching at constant working parameters. During production, the needle punch densities per cm^2 and needle penetration depth per mm were kept constant. Bulky needle punched nonwoven fabrics with low needling density were produced. The main objective of our research was to develop the nonwoven fabric for shielding against electromagnetic waves. In addition, the effect of the stainless steel fiber ratio used in the needle punched nonwoven fabrics on electromagnetic shielding effectiveness was investigated.

After production, the thicknesses of the needle punched nonwoven fabrics were tested. The electromagnetic shielding effectiveness, reflection and absorption values of the needle punched nonwoven fabric samples were measured at the frequency range of 15-3000MHz and presented in table and graphics. As the ratio of stainless steel fibers used in the nonwoven fabric increased, Electromagnetic shielding effectiveness values (EMSE) were increased in a linear manner and obtained results were discussed.

It was found that the electromagnetic waves were shielded about 90% at high frequencies, 85% at medium frequencies, and 80% at low frequencies by needle punched nonwoven fabric with 5% conductive stainless steel fiber.

The EMSE values such as 20dB, 25dB and 45dB were obtained at low frequency ranges (0-300MHz and 25dB, medium frequency ranges, 300-1200MHz and 45dB, and high frequency ranges, 1200-3000MHz) with the needle punched nonwoven fabric containing 25% conductive stainless steel fiber.

Keywords: nonwoven, stainless steel fiber (SSF), needle punched, electromagnetic shielding, needle punching, conductive textiles

INTRODUCTION

The number of electrical and electronic devices has increased in our daily life as a result of developing technology, modern life conditions, and increased welfare level. The electronic devices used at home, AC motors of kitchen devices, office devices, and equipment used at the workplace, communication devices and digital circuits, modems and mobile phones cause spreading of the electromagnetic radiation energy at radio frequency. The electromagnetic radiations with different frequencies can create negative effects on electronic devices, humans, animals, and living environments. Reduction and control of electromagnetic radiation level on humans, animals, and electronic devices has become important matter today. For this purpose, the production and development of electromagnetic shielding materials such as nonwoven, knitted, woven, or coated fabrics with conductive fibers or yarns are strongly required. There is controversy worldwide about potential health hazards associated with the exposure to electromagnetic fields. In addition, there is still no definite scientific evidence that demonstrates how the electronic devices harm human health and to which extent [1, 6].

A wide variety of conductive materials have been developed for shielding electromagnetic waves. The types of textile materials and structures are often classified as a separate group of smart textiles. The textile materials produced from conductive fiber or yarns such as steel, silver, and copper are usually used for shielding and preventing harmful effects or electromagnetic waves. For example, nonwoven fabrics with the staple steel and silver fibers for shielding electromagnetic waves can be produced. The woven and knitted fabrics have been produced by using conductive core yarns with stainless steel wire. It is also possible to convert conventional textile structure to conductive textile structures by coating with conductive chemical agents such as polyaniline or polypyrrole [7, 2, 8].

Many nonwoven and nonwoven coated fabrics with conductive fibers due to light weight, flexibility, easy production, greater blending options, and cost are used for electromagnetic shielding applications. Pflug et al. produced staple acrylic based needle punched nonwoven fabrics and they attempted to coat them chemically with Ni and physically coated with Cu and Ag. After coating operations, the coated nonwoven fabrics were laminated with polypropylene or acrylonitrile-styrene-acrylic ester films on a hot-press machine. They found that conductive composite structures with a metallised acrylic fiber content obtained 50-65dB electromagnetic shielding value at frequencies 50-1000MHz. It was found that the coated nonwoven fabrics obtained good electromagnetic shielding effectiveness [1, 9].
In another study, shielding effectiveness of the polypyrrole coated nonwoven fabrics in the frequency range 100-800MHz was investigated. A correlation between shielding effectiveness and surface conductivity of the polypyrrole coated nonwoven fabrics was found. The 37dB electromagnetic shielding effectiveness value was obtained for the coated nonwoven fabric sample with the lowest surface resistivity [5].

The nonwoven fabrics were produced from electrically conductive fibers by using stitch bonding and needle punching technology for physiotherapy applications where short-wave and microwave diathermy is used [2].

The nonwoven fabrics with magnetic fibers made up of cellulose matrix and powdered magnetic modifier were produced. The fabrics were used as magnetic shields [3].

The nanofiber nonwoven materials with metallic coating were produced for electromagnetic shielding applications. The nanofiber nonwoven material with 500nm nanofiber was produced via an electrospinning method. The nonwoven material was coated with magnetic material by sputtering [4].

Our study presents a number of novel needle punched nonwoven fabrics produced with a combination of PES and SSF. This research was aimed to develop needle punched nonwoven fabrics with electromagnetic shielding properties for reducing the risk of radiation and providing protection for users and the environment. The needle punched nonwoven fabrics were manufactured by using carding and needle punching techniques. Several characteristics of the needle punched nonwoven fabrics including their dimensional properties, electromagnetic shielding effectiveness, reflection and absorption values in the frequency range of 15-3000MHz were tested and analyzed.

EXPERIMENTAL STUDY

In experimental study, stainless steel fibers and staple polyester fibers were used as raw materials. Electromagnetic shielding effectiveness of needle punched nonwoven fabrics produced with carding and needle punching technology from the fibers was investigated.

The evaluation of the electromagnetic shielding capabilities of the needle-punched nonwoven fabrics was made by measuring the shielding effectiveness. Shielding effectiveness was expressed in decibels (dB) and is a logarithmic representation of a ratio measurement.

Materials

In this study, staple stainless steel fibers and staple polyester fibers were used. The stainless steel fibers were provided by Bekaert Company in Belgium. Staple polyester fibers were supplied by Sasa Company in Turkey. The main characteristics and mechanical properties of the fibers are presented in *Table I.*

Bekaert Bekinox stainless steel fiber is a bicomponent fiber with sheath core structure. The fiber consists of two components at ratio 50/50%. The core part of the stainless steel fiber is steel fiber and sheath part of the fiber is polyester fiber. The polyester fiber is wound on the steel fiber. The staple length of the stainless steel fiber is about 90mm. The fibers are used for controlling static electricity, electromagnetic shielding, and anti-bacterial properties in nonwoven applications. In this study, the fibers were blended with standard polyester staple fibers at specific ratios. Fiber fineness and staple length of the standard PET polyester fiber was 3.33dtex and 60mm respectively.

The tensile properties of the fibers used at experimental study were tested at Instron4411 strength test device at 10mm test length and 10mm test speed based on TS EN ISO 5079 standard. The breaking strength and elongation results of the fibers are given in *Table I*.

TABLE I. Properties of the Fibers Used at Experimental Study.

The Properties of the Fibres	12.7dtex Stainless Steel Polyester/Steel Fibers		Polyester Staple Fiber
	Polyester Fiber Part	Steel Fibers Part	
The Fineness of the Fiber (dtex)	3.6	9.1	3.33
The Staple Length of the Fiber(mm)	90		60
The Diameter of the Fiber (µm)	-	12	12.5
The Fiber Producer Company	Bekaert		Advansa SaSa
The Strength of Total Breaking (gf)	15.78		14.40
The Strength of Breaking (g/dtex)	1.242		4.32
The Elongation of Breaking (%)	40.43		38.50

Five different blended webs were produced from stainless steel fibers and polyester fibers in blend ratios of 1/99, 10/90, 20/80, 30/70, 40/60 and 50/50. The stainless steel fibers were used at ratio 1-50%. Percentage ratios of the stainless steel fiber in the fiber mass were only changed. The fiber mass used for each needle punched nonwoven fabric were kept constant. Since Bekaert Bekinox stainless steel fiber consists of two components at ratio 50/50%, conductive real steel fiber ratio in the produced needle punched nonwoven fabrics was 0.5%, 5%, 10%, 15%, 20% and 25%. The aim of using the polyester staple fiber was to reduce the cost of the needle punched nonwoven fabric and to change the conductive steel fiber ratio used in the nonwoven fabric.

The needle punched nonwoven fabrics were produced from the staple stainless steel fibers and staple polyester fibers blended at specified ratios by using a carding machine and needle punching machine. The production was carried out on industrial type and large capacity machines instead of laboratory type carding and needle punching machines to produce nonwoven structure with better properties such as strength and dimensional stability. Fabrics were not made by an industry but produced by the author and then the needle punched nonwoven fabrics were tested for shielding effectiveness.

a) First, the fibers were opened and mixed by hand. The second mixture was carried out at the garnet type carding machine. One hundred grams of fiber mass was fed to the carding machine for each needle punched nonwoven fabric. As equal amounts of fiber were fed to the carding machine for all six needle punched nonwoven fabrics, the needle punched nonwoven fabrics with same mass per unit area were produced. Percentage ratios of the stainless steel fiber in the fiber mass were the only changes. The fiber mass used for each needle punched nonwoven fabric was kept constant.

The fibers were converted to webs by the carding machine. The blended fibers were fed to the carding machine. Parallel-laid webs were produced. A circular drum was used to collect the web from carding machine instead of cross lapping.

Then, the webs were fed to the needle punching machine. Automatex needle punching machines were used. The webs were bonded at both pre-needling and finishing needle punching. The properties and working parameters of the needle punching machines are given in *Table II*. Foster 15x18x40x3.5 R333 RBA type barbed needles were used in the all needle punching experiments.

The punch density at pre-needling and finish needle punching was held constant at 38punches per cm^2 and 116punches/cm^2 respectively. A total 154 punches per cm^2 were applied to each nonwoven fabric. The needle penetration depth was 11mm at the pre-needling machine and 8.1mm at the finish needle punching machine. The needle penetration depth was gradually decreased from pre-needling to finish needling. The mass per unit area of the produced needle punched nonwoven fabrics was about 425g/m^2.

TABLE II. Working Parameters of the Needle Punching Machines.

	Pre-Needling Machine	Second Needling Machine
The number of needle	33000	85000
The rotation of the needling machine (rpm/min)	700	951
The speed of the web feeding (m)	4.4m	8.4m
The speed of the fabric delivery (mm)	8.2m	10.5m
Distance between needle boards (mm)	13mm	13.2mm
The depth of the penetration (mm)	11.0mm	8.1mm
Needle punch density per cm^2 (punches/cm^2)	38.06	116.65

The thickness of each needle punched nonwoven fabric was measured based on TS EN ISO 9073-2 with James H. Heal thickness tester. Thickness test results of the needle punched nonwoven fabrics are given in *Table III.*

TABLE III. Thickness Values of the Needle Punched Nonwoven Fabrics.

Fabric Type	Thickness (mm)
The nonwoven fabric with 1% stainless steel fibres	6.433
The nonwoven fabric with 10% stainless steel fibres	5.488
The nonwoven fabric with 20% stainless steel fibres	5.361
The nonwoven fabric with 30% stainless steel fibres	4.895
The nonwoven fabric with 40% stainless steel fibres	4.373
The nonwoven fabric with 50% stainless steel fibres	4.087

The thickness values of the needle punched nonwoven fabrics decreased with increasing stainless steel fibers content.

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 based on the frequency, the distance of the shield from the source, the thickness of the shield, and the shield material. Shielding effectiveness (SE) is normally expressed in decibels (dB) as a function of the logarithm of the ratio of the incident and exit electric (E), magnetic (H), or plane-wave field intensities SE(dB)=20log(E0/E1), SE(dB)=20log(H0/H1), and SE(dB)=20log(F0/F1) respectively.

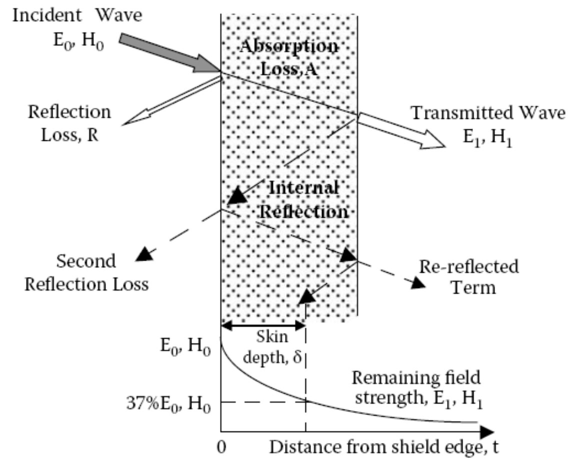

FIGURE 1. Graphical Representation of EMI Shielding.

With any kind of electromagnetic interference, there are three mechanisms contributing to the effectiveness of a shield. Part of the incident radiation is reflected from the front surface of the shield, part is absorbed within the shield material, and part is reflected from the shield's rear surface to the front where it can aid or hinder the effectiveness of the shield depending on its phase relationship with the incident wave, as shown in *Figure 1*.

The electromagnetic shielding effectiveness of the produced needle punched nonwoven fabrics were determined based on ASTM D 4935-10, the coaxial transmission line method for planar materials standard. This standard determines the shielding effectiveness of the textile structures 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 and a flanged outer conductor [13, 14]. *Figure 2* shows the EMSE testing apparatus.

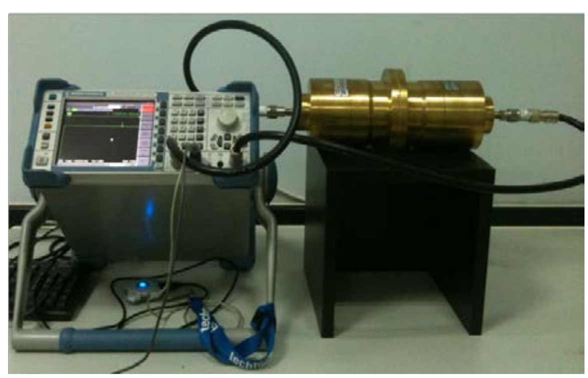

FIGURE 2. Set up of EMSE Testing Apparatus.

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 45 gram per cm^2 pressure was applied to each needle punched nonwoven fabric during testing. Six different needle punched nonwoven fabrics were produced. Five measurements relating shielding from each needle punched nonwoven fabric were carried out.

A reference measurement for the empty cell was required for the shielding-effectiveness assessment (*Figure 3a*). 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 3b*). The size of the cross section of reference sample (*Figure3c*) and load sample (*Figure3d*) are also shown in *Figure 3*. The reference and load measurement were preformed on the same material.

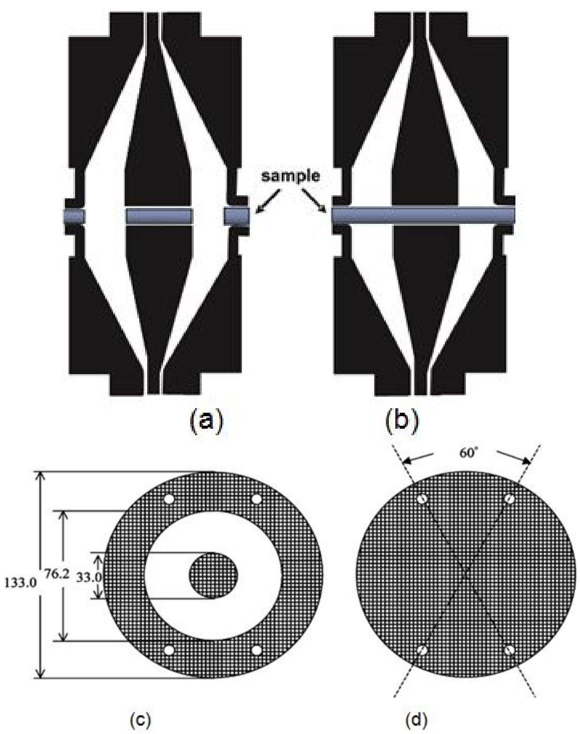

FIGURE 3. A cross-section of the shielding effectiveness test fixture (a) reference sample in the jig and (b) load sample in the jig. Specific dimensions of the specimens for shielding effectiveness measurement (unit: mm), (c) Reference sample (d) Load sample.

The shielding effectiveness was determined from (Eq. 1) decribes the ratio of the incident field to that which passes through the material.

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

Where P1 (watts) is the received power with the fabric present and P2 (watts) is the received power without the fabric present. The input power used was 0 dBm, corresponding to 1 mW.

The reflectance (R_e) and the transmittance (T_r) of the composite were also measured and the absorbance (A_b) was calculated using following Eq. (2):[15]

$$A_b = 1 - T_r - R_e \tag{2}$$

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):

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

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

R_e and T_r were obtained by the measurement of S-parameters, S_{11} (orS_{22}) and S_{12} (orS_{21}) for the reflection and the transmission, respectively.

The shielding effectiveness measurements were carried out between 15MHz to 3000MHz. 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.

S-parameters are the basic measured quantities of a network analyzer. They describe how the DUT modifies a signal that is transmitted or reflected in forward or reverse direction. For a 2-port measurement the signal flow is as follows.

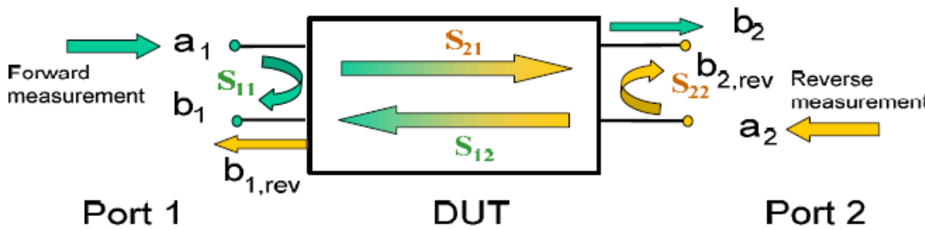

FIGURE 4. S Parameters.

S11 is the input reflection coefficient, defined as the ratio of the wave quantities b1/a1, measured at PORT 1 (forward measurement with matched output and a2 =0).

S21 is the forward transmission coefficient, defined as the ratio of the wave quantities b2/a1 (forward measurement with matched output and a2 = 0).

S12 is the reverse transmission coefficient, defined as the ratio of the wave quantities b1 (reverse measurement with matched input, b1, rev in the figure above and a1 = 0) to a2.

E S22 is the output reflection coefficient, defined as the ratio of the wave quantities b2 (reverse measurement with matched input, b2, rev in the figure above and a1 = 0) to a2, measured at PORT 2.

RESULTS

The results demonstrate the importance of the conductive stainless steel fiber ratio used in the needle punched nonwoven fabrics on electromagnetic shielding effectiveness. Absorbance, reflectance and EMSE values were evaluated and discussed in detail. The entire spectrum of the frequency has been divided into three parts; low, medium, and high; in order to see clearly the differences between electromagnetic shielding values .

Reflectance and Absorbance Measurements

Absorbance (Ab) and reflectance (Re) (Tr) values measured from the needle punched nonwoven fabrics produced from stainless steel fibers and normal staple polyester fibers in different blend ratios are shown in *Figures 5-10*. The 15-3000MHz frequency range for evaluating the Absorbance (Ab), Reflectance (Re), and Transmission (Tr) measurement values were determined. The evaluation of the absorbance and reflectance measurements nonwoven fabric samples were carried out at low, medium, and high frequency ranges.

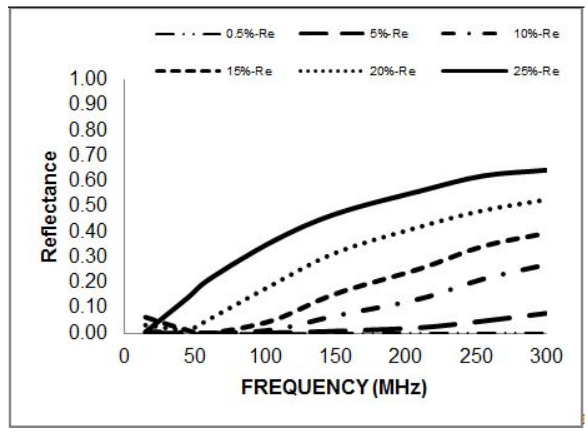

FIGURE 5. Reflectance of nonwoven fabrics with different percentage of stainless steel fibers between 15-300MHz.

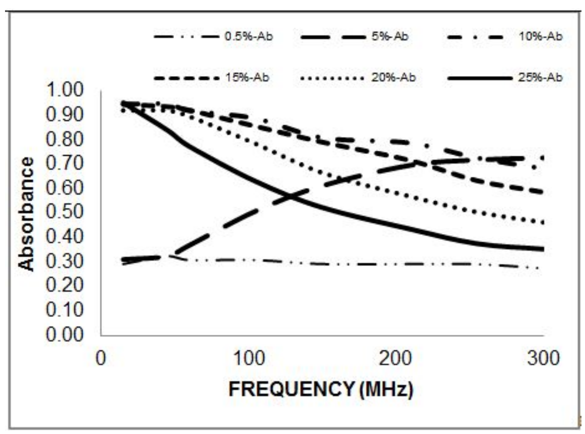

FIGURE 6. Absorbance of nonwoven fabrics with different percentage of stainless steel fibers between 15-300mhz.

Figure 5 and *Figure 6* show absorbance and reflectance values in the low frequency range of 15-300MHz. It can clearly be seen that the reflectance values increase as the frequency increases but the absorbance values decrease mostly. In the low frequency range, as the frequency increases, the reflectance values increase together with an increased of amount of the stainless steel fibers, the absorbance values of the needle punched nonwoven fabrics containing 10%, 15%, 20% and 25% stainless steel fibers decrease, except for the fabrics containing 0.5% and 5% stainless steel fibers.

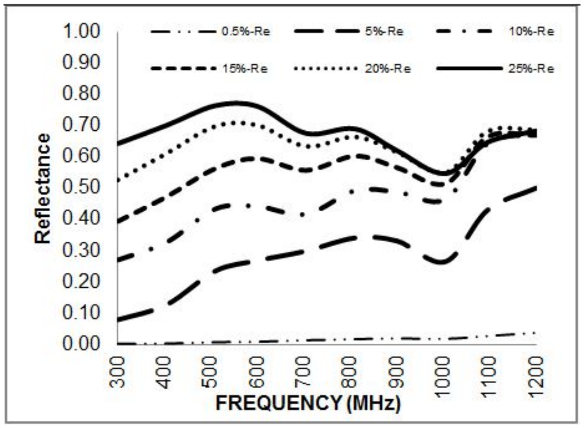

FIGURE 7. Reflectance of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers Between 300-1200Mhz.

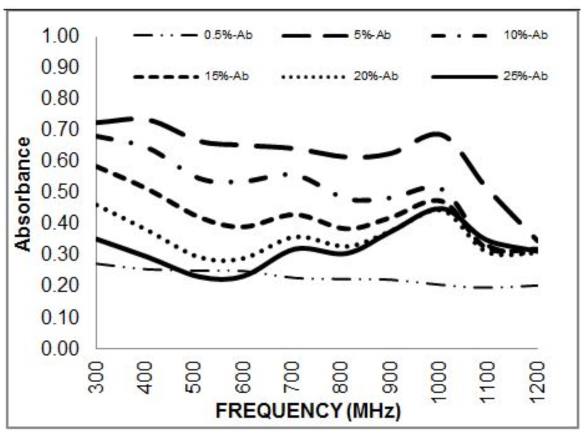

FIGURE 8. Absorbance of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers between 300-1200Mhz.

The properties of the absorbance and reflectance of the needle punched nonwoven fabrics were investigated at the medium frequency wave range of 300-1200MHz and the results were shown at *Figure 7* and *Figure 8.* The absorbance and reflectance behavior of the needle punched nonwoven fabrics containing 0.5% of the stainless steel fibers is different from other needle punched nonwoven fabrics of the stainless steel fibers. In the medium frequencies range, it was seen that as the amount of the stainless steel fibers increases, the reflectance values increase at floating mode. The highest reflectance value at medium frequency range of 300-1200MHz was found for fabrics containing 25% stainless steel fiber. It was understood that as the frequency increase, the absorbance values decrease at floating mode. *Figure 5* and *Figure 7* clearly show that as the frequency increases, there is an obvious increase in reflectance values and an obvious decrease in absorbance values, except for fabrics containing 0.5% stainless steel fiber ratio. The reflectance value at the medium frequency range is higher than that at the low frequency range.

The properties of the absorbance and reflectance of the needle punched nonwoven fabrics were investigated at the higher frequency wave range of 1200-3000MHz, and the results are shown in *Figure 9* and *Figure 10*.

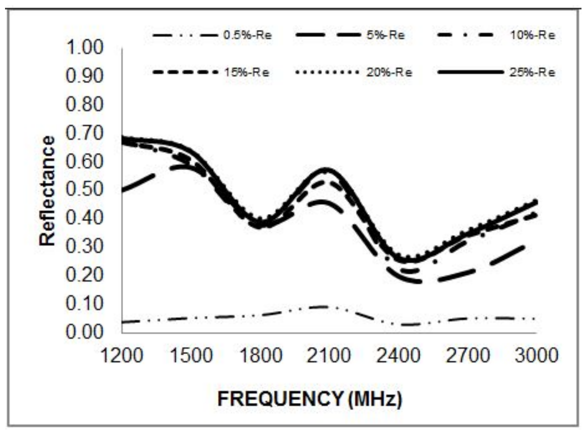

FIGURE 9. Reflectance of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers Between 1200-3000Mhz.

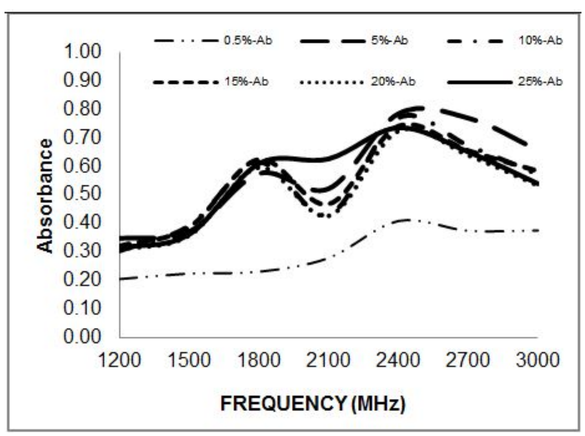

FIGURE 10. Absorbance of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers Between 1200-3000Mhz.

It was clearly seen that the reflectance and absorbance curves at the high frequency range is different from that of low and medium frequency range. As seen in *Figure 9*, reflectance curves decrease continuously and at floating mode, except for the reflectance curve of fabric containing 0.5% stainless steel fiber at high frequency range. *Figure 5, Figure 7* and *Figure 9* clearly show that as the frequency increases, the reflectance values of the needle punched nonwoven fabrics at the low and medium frequency range increase in a linear manner and floating mode respectively. Conversely, the reflectance values the high frequency range decrease at floating mode. It was understood that as the amount of stainless steel fiber used in needle punched nonwoven fabrics increases, reflectance values also increase at all frequency ranges. The nonwoven fabrics containing 20% and 25% conductive stainless steel fiber obtained the highest reflectance values at all frequency ranges.

Figure 10 shows absorbance curves at high frequency ranges. In the high frequency range, different from low and medium frequency range, as the frequency increases, absorbance values of the needle punched nonwoven fabrics also increases at floating mode. It was seen that the absorbance values of the needle punched nonwoven fabrics at the high frequency range is higher than that of low and medium frequencies.

Electromagnetic Shielding Effectiveness (EMSE) Measurements

Figure 11, Figure 12, and Figure 13 show electromagnetic shielding effectiveness (EMSE) values of fabrics produced from stainless steel fibers at different ratios of 15-3000MHz frequency ranges. *Figure 11* shows EMSE values of the needle punched nonwoven fabrics at the low frequency range of 15-300MHz.

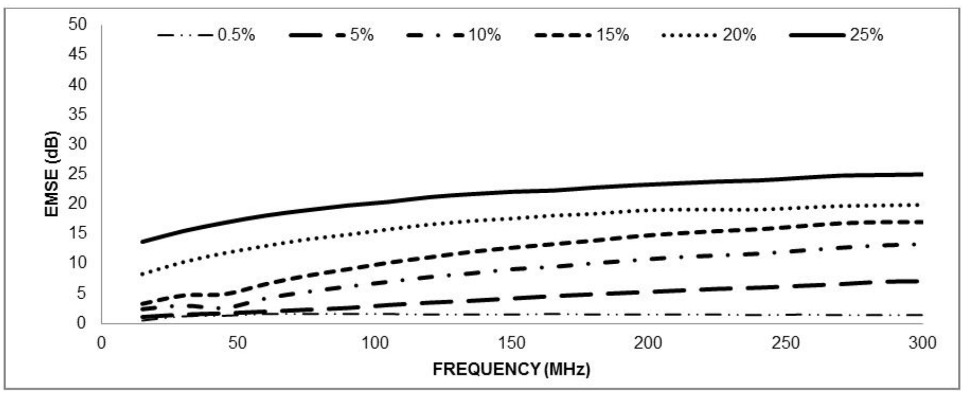

FIGURE 11. Electromagnetic Shielding (EMSE) of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers between 15-300MHz.

In the 100-300MHz frequency range, as the frequency value increases, EMSE values of the all needle punched nonwoven fabrics increase slightly, except for fabric containing 0.5% stainless steel fibers. In the low frequency range, it was seen that as the amount of stainless steel fiber used increase, the EMSE values also increase. The fabric containing 25% stainless steel fibers obtained the highest EMSE value at the low frequency range.

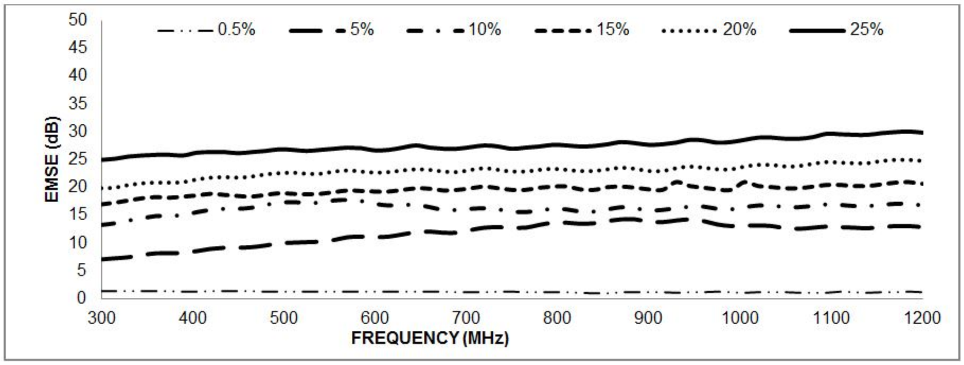

FIGURE 12. Electromagnetic Shielding (EMSE) of Nonwoven fabrics with Different Percentage of Stainless Steel Fibers Between 300-1200MHz.

Figure 12 shows the shielding effectiveness of needle punched nonwoven fabrics at the medium frequency range of 300-1200MHz. In the medium frequency range of 300-1200MHz, fabrics produced with different ratios of stainless steel fibers show different EMSE behavior than those of the low frequency range. In the medium frequency range of 300-1200MHz, it was understood that as the frequency value increases, EMSE values of the all needle punched nonwoven fabric with stainless steel fiber at different ratios remain at a horizontal level. In the medium frequency range, the lowest EMSE value was found for fabric containing 0.5% stainless steel fiber. The fabrics with 25% stainless steel fiber obtained the best EMSE value at the medium frequency range. In the medium frequency range, it was seen that as the amount of the stainless steel fibers used increases, EMSE values also increase. It was found that the EMSE values at the medium frequency rangewas higher than that at low frequency range.

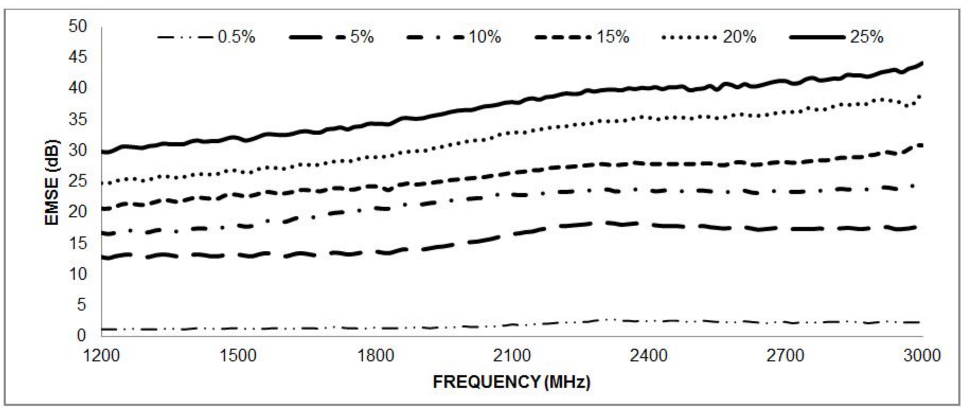

FIGURE13. Electromagnetic Shielding (EMSE) of Nonwoven Fabrics with Different Percentage of Stainless Steel Fibers between 1200-3000MHz.

Figure 13 shows the shielding effectiveness of needle punched nonwoven fabrics at the high frequency range of 1200-3000MHz. It was seen that, as the frequency increases, the effectiveness of electromagnetic shielding the entire needle punched nonwoven fabrics (EMSE) also increases continuously, except for fabric containing 0.5% stainless steel fiber. In the high frequency range, the highest 45dB EMSE value was observed for fabric containing 25% stainless steel fiber at 3000MHz frequency.

CONCLUSION

Needle punched nonwoven fabrics with stainless steel fibers were successfully produced by using carding and needle punching machines and technologies. The production study of the needle punched nonwoven fabrics was carried out at large scale machines instead of using laboratory type machines to obtain more reliable results. The stainless steel fibers were blended with staple polyester fibers to decrease stainless steel fiber ratio and to reduce cost of the nonwoven fabrics. Needle punched nonwoven fabrics containing different ratios 0.5%, 5%, 10%, 15%, 20%, 25% of stainless steel fiber were produced. The reflectance, absorbance and EMSE values of the fabrics were measured and presented graphically.

In electromagnetic shielding, the advantages of nonwoven fabrics compared to knitted or woven fabrics cannot be ignored. The effectiveness of the electromagnetic shielding of the nonwoven structures is very different from traditional textile structures, such as knitted and woven.

The shielding of the electromagnetic waves is carried out with absorption or reflection by the conductive material of the electromagnetic wave incoming from the source. Whereas the high ratios of the incoming electromagnetic waves are reflected back at low or medium frequencies, at high frequencies, incoming electromagnetic waves are absorbed by the material. Electromagnetic shielding of the nonwoven fabrics produced with other conductive fibers will be researched in future studies.

It was observed that as the stainless steel fiber ratio used at the needle punched nonwoven fabrics increases, the effectiveness of the electromagnetic shielding (EMSE) also increases at low, medium and high frequencies. The higher the frequency, the shorter the wave length, so the electromagnetic wave length to nonwoven fabric comes perpendicularly and at right angles. As a result, it can be said that the isotropic oriented stainless steel conductive fibers in a nonwoven fabric structure make more effective electromagnetic shielding [10, 11, 12].

In the low frequency range (15-300MHz), the absorbance values of the needle punched nonwoven fabrics decrease, except needle punched nonwoven fabrics containing 0.5% and 5% stainless steel fibers. In the medium frequency range (300-1200MHz), the absorbance values of the needle punched nonwoven fabrics decrease at floating mode, except for fabrics with 0.5% stainless steel fibers. In the high frequency range (1200-3000MHz), the absorbance values of all needle punched nonwoven fabrics increase at floating mode.
In the low frequency range, as the frequency increase, it was found that the reflectance values increase continuously. In the medium frequency range, as the frequency increase, the reflectance values increase at floating mode. In the high frequency range, it was seen that, as the frequency increase, the reflectance values decrease at floating mode, different from low and medium frequency ranges.

It was found that the EMSE values of the needle punched nonwoven fabrics show linear behavior at low, medium, and high frequency range. Especially, in the high frequency range, the EMSE values increase continuously.

It was found that as the frequency increases, the effectiveness of the electromagnetic shielding of the needle punched nonwoven structures increases depending on amount of stainless steel fibers used in the nonwoven structure. It is evident that the conductivity of the needle punched nonwoven structures depends on ratios of stainless steel fibers used.

The sharp declines and rises can be seen at the effectiveness of the electromagnetic shielding of the traditional textile structure. The effectiveness of the electromagnetic shielding of the traditional textile structure can be high or low depending on frequency; whereas the effectiveness of the electromagnetic shielding of the nonwoven structures show linear behavior.

As the nonwoven fabrics show satisfactory electromagnetic shielding results, it is estimated that the use of nonwoven fabrics for electromagnetic shielding will increase, because nonwoven fabrics can be produced bulkier and more cost effectively compared to woven and knitted fabrics. It is obvious that there is a relationship between the thickness of needle punched nonwoven fabric and electromagnetic shielding effectiveness.

Nonwoven fabrics are produced from conductive staple steel fibers for electromagnetic shielding. Woven and knitted fabrics are made of conductive core yarns with metal wire for electromagnetic shielding. When the nonwoven fabrics consist of conductive fibers, the number of electromagnetic shielding materials in the nonwoven fabric structure is greater than for woven and knitted fabric.

Electromagnetic waves travel horizontally. After the electromagnetic wave hits to a conductive core yarn with metal wire in the woven or knitted fabric, there is no second one conductive core yarn behind conductive core yarn for shielding of electromagnetic waves. The result yields a lower value of electromagnetic shielding effectiveness. The situation is completely different for needle punched nonwoven fabric consisting of conductive fibers. As nonwoven fabric consists of the staple fibers, after the electromagnetic wave hits a conductive fiber in the needle punched nonwoven fabric, it meets a second conductive fiber behind the first conductive fiber. Eventually, it can be possible to obtain higher electromagnetic shielding values with needle punched nonwoven fabrics.

TABLE IV. Evaluation of Electromagnetic Shielding Effectiveness for General Use.

Grade	5 Excellent	4 Very Good	3 Good	2 Moderate	1 Fair
Percentage of Electromagnetic Shielding	ES＞99.9%	99.9%≧ES 99.0%	99.0%≧ES＞90%	90.%≧ES＞80.%	80%≧ES＞70%
Shielding Effectiveness	SE＞30dB	30dB≧SE＞20dB	20dB≧SE＞10dB	10dB≧SE＞7dB	7dB≧SE＞5dB

As the effectiveness of electromagnetic shielding values were evaluated from *Table IV*, it was found that the electromagnetic waves by needle punched nonwoven fabric with 25% stainless steel fiber were shielded about 99.9% at high frequencies, 99.5% at medium frequencies and 99% at low frequencies. The satisfactory electromagnetic shielding values were obtained in wide bandwidth (1200-3000MHz). The highest EMSE value of 20dB at low frequency ranges 0-300MHz, EMSE value of 25dB at the medium frequency ranges 300-1200MHz, and EMSE value of 45dB at high frequency ranges 1200-3000MHz were found with the needle punched nonwoven fabric containing 25% conductive steel fiber.

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