

# Study on textile comfort properties of polypropylene blended stainless steel woven fabric for the application of electromagnetic shielding effectiveness

**S Palanisamy, V Tunakova, D Karthik, A Ali, and J Militky**

Technical University of Liberec, Faculty of Textile Engineering, Department of Material Engineering, Studentska 2, Liberec 461 17, Czech Republic.

E-mail: sundaramoorthy.palanisamy@tul.cz

**Abstract.** In this study, the different proportion of conductive component blended with polypropylene yarn were taken for making conductive textile samples for analysis of electromagnetic shielding effectiveness, fabric bending moment and air permeability. The ASTM D4935 coaxial transmission line method was used to study the electromagnetic shielding. Electromagnetic shielding effectiveness of textile structures containing different percentage of metal content ranges from 1 to 50 dB at high frequency range. Breathability of structures, more precisely air permeability was considered as one of important parameters for designing of electromagnetic radiation protective fabrics for certain applications. The bending moment of samples is decreases with increasing metal component percent.

## 1. Introduction

Recently, the usage of electrical and electronic devices has grown rapidly. Many devices such as AC motors, digital computers, calculators, printers, modems, electronic typewriters, digital circuits, transmission lines, electronic home appliances including Wi-Fi routers and cellular phones are capable of emitting electromagnetic (EM) waves that can result in some electromagnetic interference (EMI) problems [1]. The EM spectrum contains an array of EM waves increasing in frequency from extremely low frequency and very low frequency, through radio frequency (RF) and microwaves to infrared (IR) light, visible light, ultraviolet (UV) light, X-rays and gamma rays [2]. Many devices contribute to such exposure such as cell phones with frequencies of 900 and 1800MHz, microwave ovens of 2450 MHz, radar signal communication systems extending from 1 to 10,000 MHz, and FM/AM radio broadcasts of 30-300 MHz and 300-3000 KHz, respectively [3]. The use of electronic equipment causes EM radiation, which can be harmful for the performance of electronic and electrical equipment and also for human health [4]. Therefore, it has become essential to shield against all interference sources of EM energy [5]. When an EM wave enters an organism, it causes heat to come out by vibrating the molecules. The heat developed on the tissues is mainly a result of the Foucault currents flowing in the liquids of the cells. To prevent the negative effects of EM waves, shielding is necessary. EM shielding can be described as prevention of EM radiation transmission by a material [6].

Currently, many studies exist on EM shielding using conductive materials for textile fabrics. Incorporation of conductive fillers and fabric surface coatings are the two major methods to develop EMI shielding fabrics [7]. Conductive fabrics can also be made of 100% metal fibre yarns like stainless steel (SS), copper etc.; however, they are difficult to process. These types of yarns tend to



have low flexibility due to high stiffness of metal fibres, which produces heavier and uncomfortable fabrics. To reduce this effect, totally metallic yarns are replaced by two component fibre blends, where conductive fibre represents one component and traditional fibre represents the second one to reduce the overall stiffness of the fabric and touch the properties of fabrics made of traditional fibres [8]. In this study, 25% of 12  $\mu\text{m}$  diameter staple stainless steel fibers and 75 % of 12.5  $\mu\text{m}$  diameter staple polyester fibres were used to produce needle punch nonwoven fabric. The EM shielding effectiveness (SE) results shows that 20 dB, 25dB and 45 dB was obtained at frequency range of 0-300 MHz, 300-1200MHz and 200-3000MHz respectively [9]. Woven fabrics made of metal fibres (8  $\mu\text{m}$  diameter staple stainless steel) mixed with traditional and high performance fibres shows EM SE higher than 35 dB for frequency 1.5 GHz, which means that more than 99.9% of EM was attenuated [10,11].

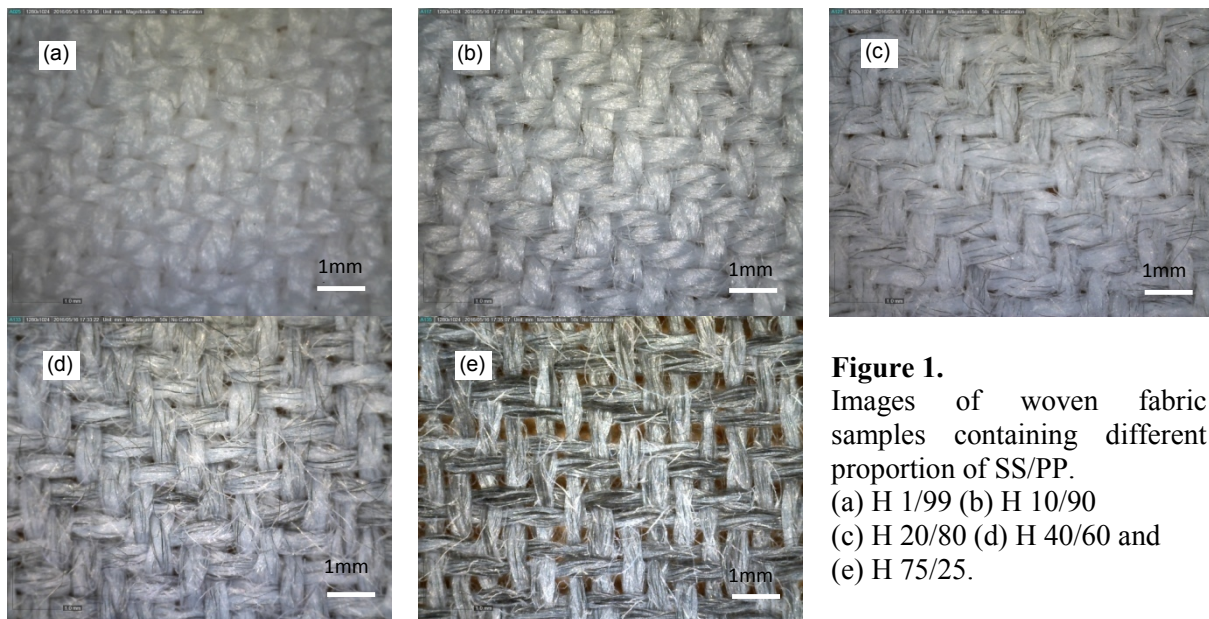
The objective of this study is to investigate electromagnetic shielding ability of conductive textile samples based on different stainless steel component percentage in textile samples. Samples were tested for EMI SE, air permeability and bending moment as per the standards.

## 2. Materials and methods

The woven twill weave fabric samples were produced using hybrid yarn (H) of SS fiber blended with Polypropylene (PP) fiber in five different proportions are 1:99, 10:90, 20:80, 40:60 and 75:25 is shown in table 1. Both warp yarn and weft yarn used for producing woven fabric is having count of 50 Tex and stainless steel fiber used is 8  $\mu\text{m}$  diameters. The gram per square meter of fabrics is tested as per ASTM D 3776 and thickness of the fabrics is tested as per ASTM D 1777; tested values are shown in table 1. The figure 1 shows the microscopic images of fabric samples at magnification of 50 times and 1mm scale is marked in white to measure the actual size of the images.

**Table 1.** Woven sample specification.

Sample Code	Sample details	GSM	Thickness (mm)
H 1/99	Hybrid yarn 1% SS/ 99 % PP woven fabric	233	0.80
H10/90	Hybrid yarn 10% SS/ 90% PP woven fabric	221	0.76
H 20/80	Hybrid yarn 20% SS/ 80% PP woven fabric	208	0.71
H 40/60	Hybrid yarn 40% SS/ 60% PP woven fabric	206	0.58
H 75/25	Hybrid yarn 75% SS/ 25% PP woven fabric	160	0.82



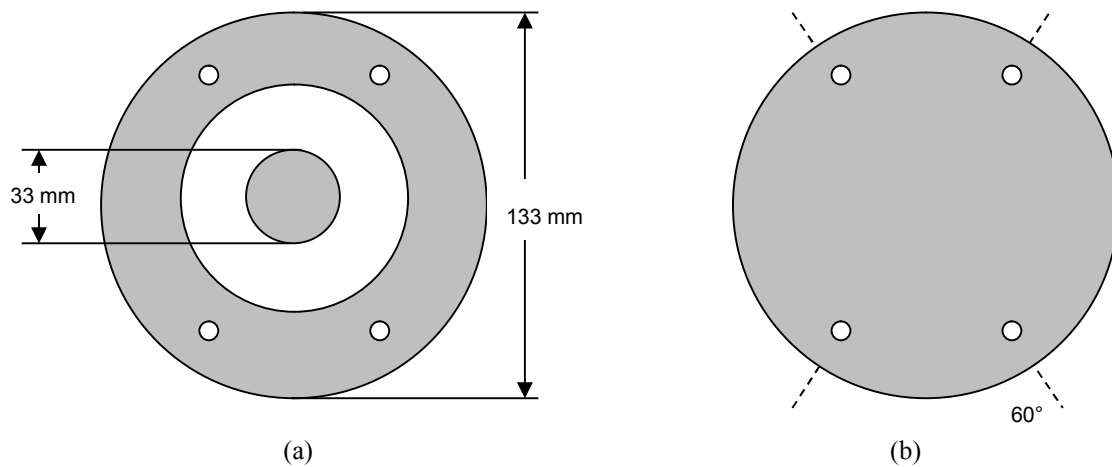
**Figure 1.**

Images of woven fabric samples containing different proportion of SS/PP.

(a) H 1/99 (b) H 10/90  
(c) H 20/80 (d) H 40/60 and  
(e) H 75/25.

### 2.1. Electromagnetic shielding effectiveness evaluation

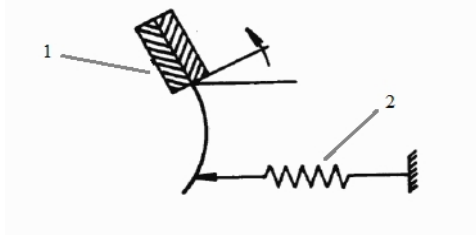
SE of sample set was measured according to ASTM D4935-10, for planar materials using a plane-wave, far-field EM wave. SE of samples was measured over frequency range of 30 MHz to 1.5 GHz. The standard mentioned above determines the shielding effectiveness of the fabric using the insertion-loss method. A reference measurement for the empty cell was required for the shielding effectiveness assessment. A “through” calibration by the help of the reference sample was made first. A load measurement was performed on a solid disk shape sample subsequently. The reference and load specimens must be of the same material and thickness. Sample (both reference and load) geometries according to ASTM D 4935-10 are shown in Figure 2. The measurement was carried out at 5 different places of textile samples because of subsequent statistical analysis.



**Figure 2.** Illustrations of (a) reference and (b) load sample.

### 2.2. Fabric bending and air permeability measurements

The device TH5 (Czechoslovak patent) was designed for the measuring of bending moment as shown in figure 3; it provides the bending stiffness of the measured resistance force against the bending of the fabric. The method working under cantilever principle gives immediate stiffness of fabrics. The device senses the strength which will use to the strip of fabric on the sensing element. The strip has the standard fixed length ( $L = 1.5$  cm) and the width ( $b = 2.5$  cm).



**Figure 3.** Schematic diagram of the device TH5.  
(1 – Clamping jaw, 2 – Sensing element)

The relationship for calculated the bending moment is shown in equation (1)

$$M_0 = F_l \times K \quad (1)$$

Where,  $M_0$  is bending moment for 1 cm width of the sample [mN. cm],  $F_l$  is the maximum value of the fabric force [N] and  $K$  is constant ( $K = L/b = 0.604$ ).

Air permeability ( $A$ ) [ $\text{l}/\text{mm}^2/\text{s}$ ] of the samples was measured using Textest FX 3300 at 100 Pa as per ISO 9237 standard.

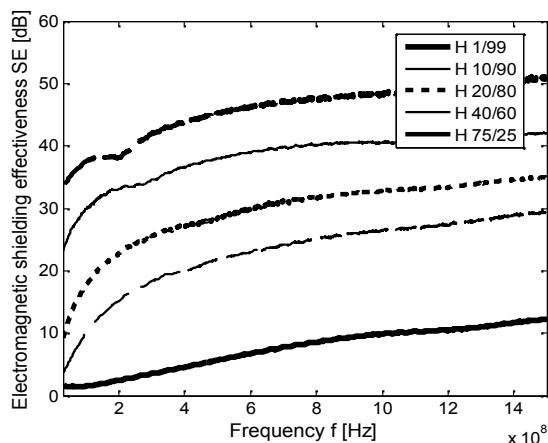
### 3. Results and discussion

#### 3.1. Electromagnetic shielding ability of samples

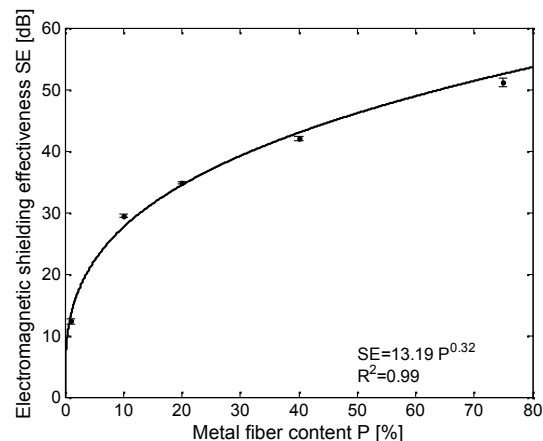
**3.1.1. Frequency dependent electromagnetic shielding effectiveness.** Figure 4 shows the dependence of electromagnetic shielding effectiveness (SE) in decibel [dB] on whole measured frequency range (from 30MHz to 1.5 GHz) for all samples.

Figure 4 shows EM SE of hybrid yarn woven samples with different stainless steel fiber content ("H") which is increasing logarithmically with the increasing frequency. It is visible that EM SE values for woven samples are increasing (up to 50 dB at frequency 1.5 GHz) with increasing metal fiber content (1, 10, 20, 40 and 75 percentages of SS) in sample on whole frequency range. The increase in metal fiber content is showing increasing SE due to more reflection character of SS fiber.

**3.1.2. Relation between SE on P.** Figure 5 shows the graph of metal fiber content percentage versus EM SE at frequency 1.5 GHz. that electromagnetic shielding effectiveness increases with increasing stainless steel fiber content for woven samples totally made of hybrid yarns containing 1%, 10 %, 20 %, 40 % and 75% of SS.



**Figure 4.** Graphs of electromagnetic shielding effectiveness SE [dB] vs. frequency,  $f$  [Hz].



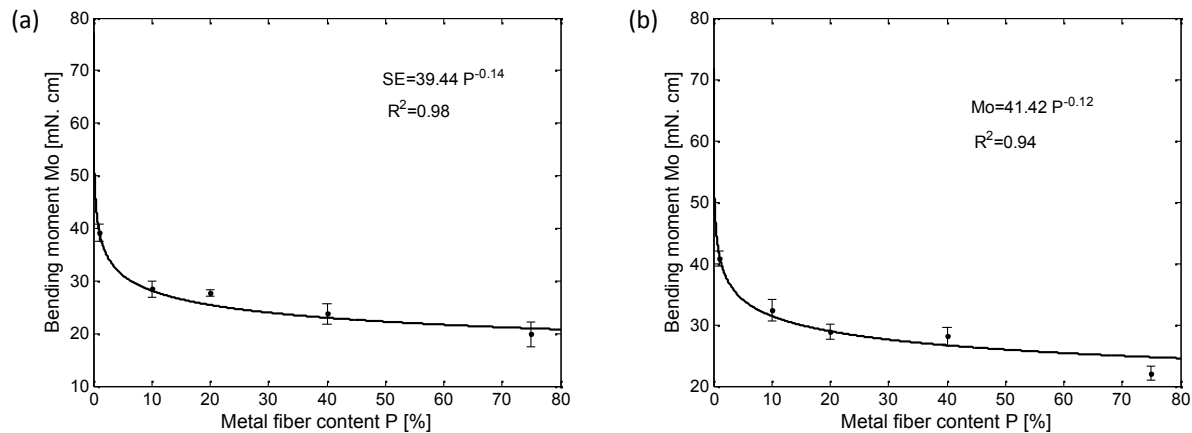
**Figure 5.** The dependence of EM SE at 1.5 GHz frequency on metal fiber content for woven samples.

Sample with the highest content of metal fiber reaches the highest EM SE of 51 dB for frequency 1.5 GHz, sample containing the lowest proportion of conductive component displays the lowest EM SE of 12 dB for frequency 1.5 GHz. The overall SE is increasing according to power function with metal fiber content ( $P$ ). At very low percent of conductive fiber loading, the SE is more or less equal to zero like a pure matrix (polypropylene yarn). At 3% to 7% of metal fiber content, the SE value increases drastically over a very narrow range of conductive fiber concentration which is called as percolation threshold ( $P_0$ ). The solid line in this graph (see fig. 5) corresponds to the linear regression model with parameter obtained by the minimizing sum of squared differences. A high  $R^2$  value (0.99) confirms prediction ability of the developed regression models. This linear regression model can be used for prediction of the ' $P$ ' value for sufficient shielding.

#### 3.2. Bending moment analysis

The bending moment of the sample is important while using fabric for garment and apparel applications. Figure 6 shows the bending moment ( $M_0$ ) depends on metal fiber content percent ( $P$ ) of woven samples in both warp way (fig. 6(a)) and weft way (fig. 6(b)). The decrease in bending moment

due to increase in metal fiber content is clearly visible in graphs for both warp and weft way of the samples. In warp way, the  $M_0$  value is about 39 mN.cm for 1% SS sample and 20 mN.cm for 75% SS sample; it shows that the fabric bulkiness or resistance to bending is decreases by increasing metal fiber content (fig 6(a)) also visible in air permeability results (fig. 7). The weft way  $M_0$  values also shows the behavior similar to warp way, double the time decrease in  $M_0$  value for sample containing 75% metal content compared with 1% metal content (fig. 6(b)).

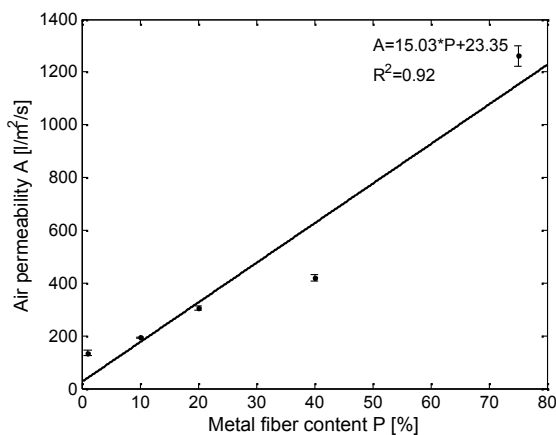


**Figure 6.** The dependence of  $M_0$  on metal fiber content (a) Warp way and (b) Weft way.

The overall  $M_0$  is decreasing according to power function with  $P$ . The solid line in graphs (see fig. 6) corresponds to the linear regression model with parameter obtained by the minimizing sum of squared differences. A high  $R^2$  value (0.99 & 0.94) confirms prediction ability of the developed regression models. This linear regression model can be used for prediction of the ' $P$ ' value for sufficient bending moment.

### 3.3. Comparison of air permeability results

Figure 7 shows the dependence of mean values of air permeability ( $A$ ) on the metal fiber content percentage ( $P$ ) for woven samples totally made of hybrid yarns.



**Figure 7.** The dependence of air permeability  $A$  [ $l/m^2/s$ ] on metal fiber content  $P$  [%] for woven samples.

Results shows that the air permeability increases linearly (from 134 to 1262  $l/m^2/s$ ), with the increase of metal fiber content (from 1 % to 75 %). The dependence of  $A$  on  $P$  can be simply approximated by line. The solid line in the graph corresponds to the linear regression model with parameters obtained by the minimizing sum of squared differences. Correlation coefficient  $r \sim 0.96$



refers to very good positive fit and therefore air permeability increases as metal fiber content in the hybrid yarn increases. This phenomenon is caused by the fact, that metal fibers are finer compared to polypropylene fibers and yarns with higher metal fiber content have lower diameter compared to yarns with lower metal fiber content. By using yarns with lower diameter while remaining other parameters of woven fabric constant, larger pores are created in the structure of fabric which allows easier penetration of both air (air permeability) and water vapor (water vapor permeability).

#### 4. Conclusions

The woven twill weave fabric was prepared by hybrid yarn of 8  $\mu\text{m}$  dia. stainless steel fibers blended with polypropylene fibers in ratio of 1:99, 10:90, 20:80, 40:60 and 75:25. The produced five different proportion of woven fabric samples are analysed for electromagnetic shielding, bending moment and air permeability. In electromagnetic shielding analysis, the EM SE of hybrid yarn woven samples with different stainless steel fiber content is increasing logarithmically with the increasing frequency. It is visible that EM SE values for woven samples are increasing (from 12 dB to 51 dB at frequency 1.5 GHz) with increasing metal fiber content (1, 10, 20, 40 and 75 percentages of SS) in sample on whole frequency range. SE values at 1.5 GHz of samples H 40/60 and H 75/25 having 42 dB and 51 dB has graded as 'very good', H10/90 and H 20/80 having 29 dB and 35 dB graded as 'good' and H 1/99 having 18 dB graded as 'moderate' [12]. The linear regression model ( $R^2=0.99$ ) confirm that the prediction of SE value based on P. Bending moment value is decreases by increasing the metal fiber content percentage and its linear regression model confirm that the prediction of  $M_0$  value based on P. Air permeability value and image analysis of fabric samples confirm that the decreases in  $M_0$  value mainly based on yarn bulkiness. Air permeability of the samples also increases by increasing the metal fiber content and linear regression model confirms it.

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