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Short Communications

Development of metallic core-spun yarns and hybrid conductive fabrics for electromagnetic shielding applications

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Various metallic core-sheath yarns have been prepared and conductive fabrics are woven using sample loom for electromagnetic shielding applications. The core-sheath yarn is prepared using stainless steel and polyester slivers with different proportions of SS fibre content. The conductive fabrics are produced with different warp and weft patterns. The shielding effectiveness (SE) of fabric has been tested in the frequency range from 50 MHz to 1.5 GHz according to ASTM D4935. The test results reveal that the fabric with cell type structures shows better shielding effectiveness (SE) than the plain weave structures. The increase in metal content does not influence the SE of fabric having conductive fibres in one direction. However, fabric having conductive fibres in warp and weft directions shows improved shielding effectiveness. When the grid size is increased, the shielding effectiveness is decreased. It is concluded that the fabric with small grid size and cell type weave structures could provide effective shielding as compared to plain woven fabric in low frequency range.

Keywords: Conductive fabrics, Electromagnetic shielding, Metallic core-spun yarn, Stainless steel hybrid yarn, Vector network analyser

The growing science and technology advances the invention of several scientific instruments with most innovative technology. Such devices should work properly without getting interruption from other systems. But in practical, micro/radio waves radiated from the systems cause interferences and data insecurity to the other devices which results in inefficiency of the system. In order to secure electronic systems from undesired wave interference, an electromagnetic (EM) shield is essential. In the last few decades, lot of efforts have been made to develop good shield by means of different methods. Generally, when EM waves strike on the material surface, they get attenuated by means of different mechanisms according to characteristics of wave and materials, namely reflection, multiple reflection and absorption. The efficiency of the shielding material is measured in decibel (dB). The power of the incident wave is generally divided into 3 parts, namely reflection (P_{ref}), transmission (P_{trans}) and absorption (P_{abs}). Hence, the incident power (P_{in}) could be written as

$$P_{in} = P_{ref} + P_{trans} + P_{abs} \quad \dots (1)$$

The shielding effectiveness (SE) of the shield could be defined as the ratio of power transmitted to the power of incident wave, as shown in following equation: 2.

$$SE(dB) = 10 \log \frac{P_{trans}}{P_{inc}} \quad \dots (2)$$

Initially, metal was used as microwave shielding material but not found successful due to many limitations. In recent years, polymers loaded with several conductive fillers such as carbon and Ni are used as electromagnetic shield[1]. Next to conductive polymers, flexible conductive fabrics are used as electromagnetic shield[2]. Usually, conductive fabric is prepared by incorporating conductive fibres, such as carbon, copper, stainless steel, etc. in warp and/or weft directions[3]. In order to design an excellent shield, selection of conductive fibre is important that depends on several material characteristics, such as magnetic permeability, dielectric permittivity, etc.

The electromagnetic shields should have low reflection and high absorption characteristics[4]. As stainless steel (SS) has good magnetic permeability and shielding characteristics, most of the researchers have chosen SS fibre as base material for preparing conductive fabrics. In a study[5], the SS and polyester (PET) fibre blended hybrid yarn was prepared for developing the conductive knitted fabrics for EMI shielding application. The structure of fabric, number of fabric layers and the blending proportion of SS and PET fibres were varied. The fabric with 30/70 of SS/PET yarn showed larger SE than other combinations at 300 kHz to 3 GHz. Similarly, an increase in number of fabric layers also improved the SE at 0.3 - 60 MHz due to thicker fabric structure.

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In another study[6], the shielding behaviour of fabrics made by core yarn, ply yarn and cover yarn was investigated in the frequency from 9 kHz to 3 GHz. It was found that core yarn fabric showed better shielding effectiveness than cover and plied yarn fabrics. Analysing the weave types, 1/1 plain weave fabric displayed higher shielding effectiveness than 2/2 twill and 3/1 twill weave fabrics due to formation of smaller square meshes. Similarly, the shielding behaviour of fabric having SS core yarns was investigated to understand the effect of 3/1 twill and cellular weave structures[7]. The shielding effectiveness test was carried out using free space measurement technique in the frequency range 800-3000 MHz. In high frequency region, the cellular fabrics have shown better shielding effectiveness than 3/1 twill fabrics where the weft yarns were present horizontal to the antenna polarization. However, this was not true for low and medium frequency band for the fabrics having SS weft yarns placed vertical to the antenna polarization. In an earlier study, the authors have prepared woven fabrics made of polyester and stainless steel/polyester blended conductive yarns for shielding the frequency of 300 kHz to 1.5 GHz[8]. It was observed that the larger proportion of conductive fibres provided higher shielding effectiveness due to better electrical conducting network. In addition, fabric with doubled SS/PET yarn exhibited higher shielding effectiveness compared to fabric with single SS/PET yarn. The effect of grid size on shielding behaviour of fabrics was further analysed by the authors with respect to different metal content and orientation angle and the results were reported in detail[9].

Hence, stainless steel fibre was selected in this study for developing flexible conductive fabric. The SS/PET blended yarn and pure polyester filaments were used to prepare the conductive woven fabrics. Since, plain weave structure has better shielding effectiveness than twill weave structure, 1/1 plain weave was selected as one of the structures[10]. As reported in the literature, cellular weave fabrics provides high shielding effectiveness than twill weave, a new cellular weave was proposed in this study. In addition, the shielding behaviour of cellular fabrics has not been investigated in low frequency ranges. The effect of conductive doubled yarn on shielding effectiveness of cellular fabrics has not been studied. Hence, in this study, 1/1 plain and cellular fabrics made from SS/PET blended yarn have been prepared and analysed for shielding effectiveness in the low frequency range (50 MHz to 1.5 GHz).

Experimental

Materials

The 100% stainless steel sliver of 1.92 ktex supplied by Baekert Belgium, and 100% polyester draw frame sliver of 5.92 ktex purchased from Vardhman group of company were used for preparing the conductive yarns. The properties of SS fibre were 51 mm fibre length, 12 micron diameter, 91 decitex linear density, 15 cN tensile strength and 1.5% breaking elongation. In addition, the polyester filament of 1350 tex was also used. The polyester sliver constitutes the staple fibres with the average length of 90 mm and the linear density of 3.6 dtex.

Preparation of Conductive Friction Spun Yarn

As small amount of SS fibre is sufficient to impart the shielding effectiveness, staple SS fibre was chosen in this study (though the SS filament yarn performs better), considering the other advantages of SS/polyester blended yarn. The 100% stainless steel sliver was fed in LR6S ring spinning machine and the polyester filament was fed from the back of the front roller to produce a SS blended yarn as shown in Fig 1. This SS blended yarn was used during the preparation of core sheath yarn in DREF-III friction spinning machine. The final blended yarn has the linear density of 756 den. The total draft applied and twist in the yarn were 26 and 18.18 twists per inch (Z twist) respectively. The prepared SS blended yarn was fed as core yarn in Dref-III spinning machine. In order to study the effect of different proportions of conductive core fibres in the blended yarn on shielding behaviour, the amount of sheath polyester fibre was varied using the friction spinning system.

For the sheath, 100% polyester sliver was fed in the drafting system. The inlet speed of polyester fibre (sheath) was 0.1 m/min. The suction drum speed was 3010 rpm. The number of feed polyester sliver has been changed from 3 to 5 for preparing three different

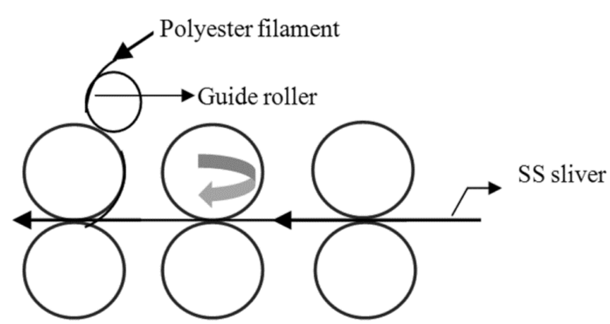

Fig. 1 — Drafting device of ring frame

SS proportions (Y1, Y2, Y3) in the core of the final yarn. For preparing the other three different yarns (YD1, YD2, YD3), the blended SS yarn was doubled by using Two-for-one Twister machine (Veejay Lakshmi Vj-150-MS) with 5.4 TPI in S-direction and the same was used in the core for preparing core-spun yarn. As mentioned earlier, the number of sliver fed in the sheath was changed from 3 to 5 to prepare the different SS proportion in the core of the yarn. The details of the prepared yarn samples are given in Table 1.

Weaving of Conductive Fabrics

Using CCI sample loom, different fabrics were woven from the prepared conductive core yarns. By combining the polyester and conductive core yarns, twenty different fabrics were prepared in the loom having plain weave and special cell type weave structures as shown in Fig 2. Table 2 shows the list of fabrics produced with different warp and weft patterns having plain and cell type weave structures. The fabrics prepared have the areal density in the range of 150 – 200 g/m^2 and the warp and weft thread densities of 15.7 ends/cm and 13.4 picks/cm respectively.

Assessment of Shielding Behaviour of Woven Conductive Fabrics

The prepared woven conductive fabrics were tested for shielding effectiveness using co-axial transmission line holder according to the ASTM D4935 in the frequency range of 50 MHz to 1.5 GHz. The images of reference and load samples are shown in Fig 3.

Results and Discussion

Shielding Effectiveness of Fabric Samples

In order to assess the shielding efficiency of fabric samples, the losses due to absorption and reflection have been measured by vector network analyser. All the samples are assessed for shielding effectiveness (SE) in the frequency range from 50 MHz to 1.5 GHz. Samples are conditioned in room temperature (27ºC) for 24 h before testing them.

Effect of Thread Pattern on Shielding Behaviour of Cell Type Weave Fabrics

To analyse the effect of conductive yarn pattern on shielding behaviour of cell type fabrics, samples F1-F6 are analysed. The shielding behaviour of cell type fabrics in the frequency range from 50 MHz to 1.5 GHz is shown in Fig 4(a). It is found that, different sheath-core yarns are used for preparing F1, F2 and F3 fabrics. The test results reveal that the SE of all the fabrics are observed to be same with the maximum shielding effectiveness of 30 dB. Despite the sheath PP fibre content varies, the overall weight of the SS fibre in the fabric remains same. The increase in sheath fibre content from 45% to 55% does not change the shielding behaviour. This is because of the fact that polyester fibre is transparent to EM waves (no attenuation occurs), and hence it does not change the shielding behaviour of fabrics. In case of F4, F5 and F6 fabric samples, two plies of SS blended yarn are used to prepare the samples. The sheath ratio of the yarns is varied from 30% to 40%. From Fig 4(a), it is clear that the F4-F6 fabric samples show higher SE of -40 dB than other fabric samples (F1-F3). This is due to increased metal content which enhances the attenuation characteristics of fabrics. However, no significant difference is found in shielding effectiveness among the samples F4-F6.

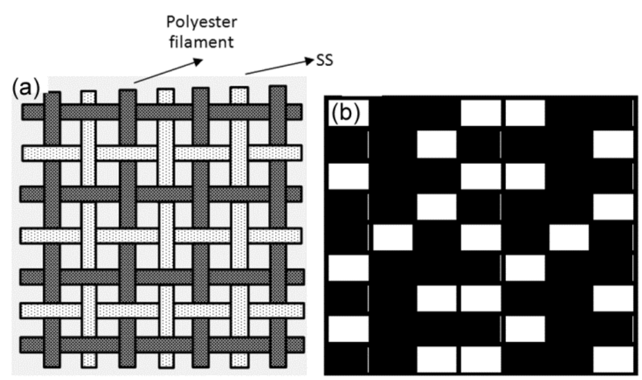

Fig. 2 — Weave patterns used in fabric production (a) plain weave 1p/1m, and (b) cell type weave

Table 1 — Combinations of metallic core – sheath yarns

Sample code	Core yarn	Total core-sheath yarn denier	Denier of SS fibre in yarn	Denier of polyester fibre in yarn	Proportion of SS fibre	Proportion of polyester fibre
Y1	Single	1077	605	472	55	45
Y2	Single	1206	605	601	50	50
Y3	Single	1330	605	725	45	55
YD1	Double	1820	1210	610	70	30
YD2	Double	2228	1424	804	65	35
YD3	Double	1955	1210	745	60	40

Table 2 — Warp and weft patterns of woven fabric samples

Sample No.	Weave pattern	Warp yarn type	Weft yarn type and repeat pattern
F1	Cell type	Polyester filament (150D)	Y1-YD1-P-P-P
F2	Cell type	Polyester filament (150D)	Y2-YD2-P-P-P
F3	Cell type	Polyester filament (150D)	Y3-YD3-P-P-P
F4	Cell type	Polyester :SS blended yarn	Y1-YD1-P-P-P
F5	Cell type	Polyester :SS blended yarn	Y2-YD2-P-P-P
F6	Cell type	Polyester :SS blended yarn	Y3-YD3-P-P-P
F7	Plain weave	Polyester filament (150D)	Y1-P-P-P-P-P-Y1Y1-P-P-P-P-P-Y1Y1Y1-P-P-P-P-P
F8	Plain weave	Polyester filament (150D)	Y2-P-P-P-P-P-Y2Y2-P-P-P-P-P-Y2Y2Y2-P-P-P-P-P
F9	Plain weave	Polyester filament (150D)	Y3-P-P-P-P-P-Y3Y3-P-P-P-P-P-Y3Y3Y3-P-P-P-P-P
F10	Plain weave	Polyester filament (150D)	YD1-P-P-P-P-P-YD1YD1-P-P-P-P-P-YD1YD1YD1-P-P-P-P-P
F11	Plain weave	Polyester filament (150D)	YD2-P-P-P-P-P-YD2YD2-P-P-P-P-P-YD2YD2YD2-P-P-P-P-P
F12	Plain weave	Polyester filament (150D)	YD3-P-P-P-P-P-YD3YD3-P-P-P-P-P-YD3YD3YD3-P-P-P-P-P
F13	Plain weave	Polyester : SS blended yarn	Y1-P-P-P-P-P-Y1Y1-P-P-P-P-P-Y1Y1Y1-P-P-P-P-P
F14	Plain weave	Polyester : SS blended yarn	Y2-P-P-P-P-P-Y2Y2-P-P-P-P-P-Y2Y2Y2-P-P-P-P-P
F15	Plain weave	Polyester : SS blended yarn	Y3-P-P-P-P-P-Y3Y3-P-P-P-P-P-Y3Y3Y3-P-P-P-P-P
F16	Plain weave	Polyester : SS blended yarn	YD1-P-P-P-P-P-YD1YD1-P-P-P-P-P-YD1YD1YD1-P-P-P-P-P
F17	Plain weave	Polyester : SS blended yarn	YD2-P-P-P-P-P-YD2YD2-P-P-P-P-P-YD2YD2YD2-P-P-P-P-P
F18	Plain weave	Polyester : SS blended yarn	YD3-P-P-P-P-P-YD3YD3-P-P-P-P-P-YD3YD3YD3-P-P-P-P-P
F19	Cell type	P-P-PS-PS-P-P-PS-PS (2 polyester filament and 2 blended yarn)	Y1 +YD1 Y2+YD2
F20	Plain weave	P-P-PS-PS-P-P-PS-PS (2 polyester filament and 2 blended yarn)	Y3 YD3

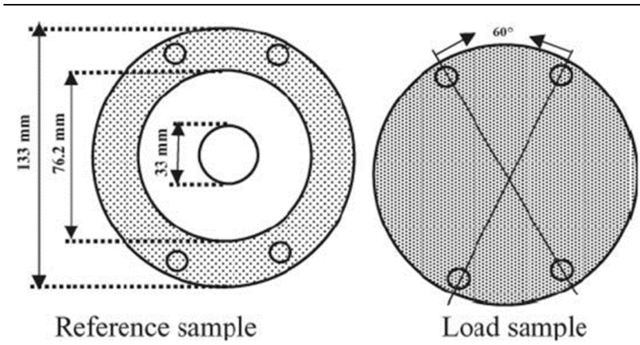

Fig. 3 — Sample holder and required specimens as per ASTM D4935-99 (ref. 1)

Effect of Thread Pattern on Shielding Behaviour of Plain Weave Fabrics

The shielding behaviour of plain woven fabrics having nonconductive polyester filament in warp and conductive yarn in weft direction is shown in Fig. 4(b). The effect of conductive fibre content in the weft direction of the sample on SE has also been analysed. The samples F7-F9 show insignificant difference in shielding behaviour despite the sheath polyester fibre content varies in the fabric. When the metal content is increased in doubled SS blended yarn fabric, the shielding effectiveness of the fabric samples is also increased.

The samples F10-F12 show the higher shielding effectiveness of -32 dB at 0.6 GHz. Compared to cell type fabrics, the plain samples show lower shielding effectiveness. This is mainly attributed to two reasons. First, the plain weave fabrics (F10-F12) has nonconductive polyester filament in the warp direction. Hence, the conductive grid could not be formed as the conductive yarn, present only in one direction. This reduces the shielding effectiveness of plain weave samples. Second, the conductive threads are introduced for every 6 picks in the fabric, as shown in the Table 2. This results in formation of large grid opening in the fabric. Hence, it doesn’t increase the shielding behaviour of plain fabrics much when conductive fibre content is increased (F10-F12), as compared to cell type fabrics (F4-F6).

In addition, there is no conductive component in the warp direction of the fabric. However, if conductive fibre is used in warp direction, the change in shielding effectiveness is observed. Figure 5 shows the shielding behaviour of plain fabrics (F13-F16)

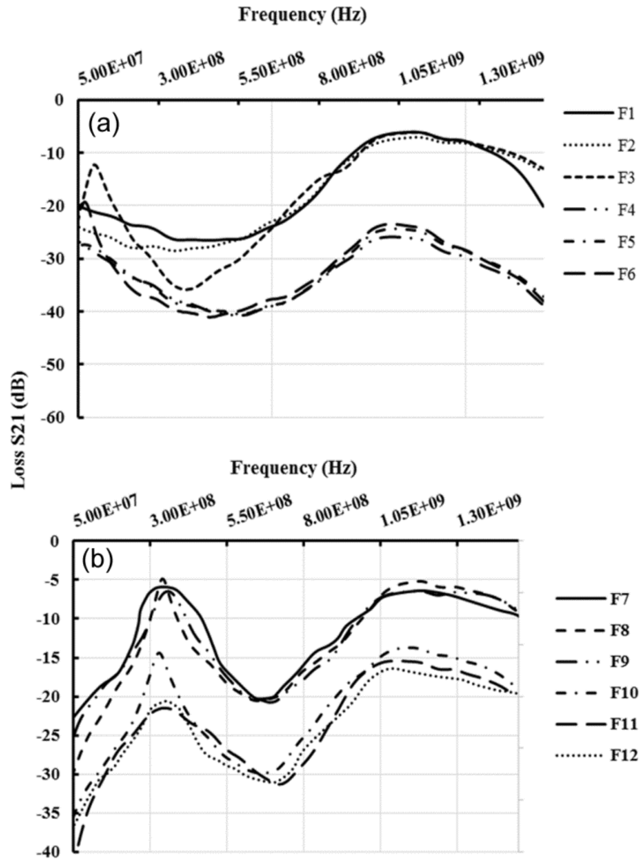

Fig. 4 — Shielding behaviour of different fabrics (a) cell type and (b) plain fabric with different thread patterns

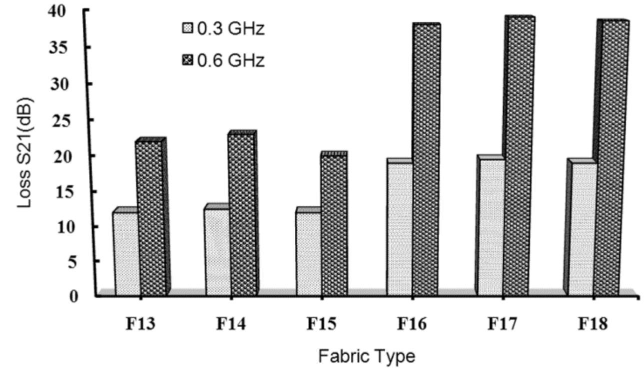

Fig. 5 — Shielding behaviour of plain fabrics at different frequencies

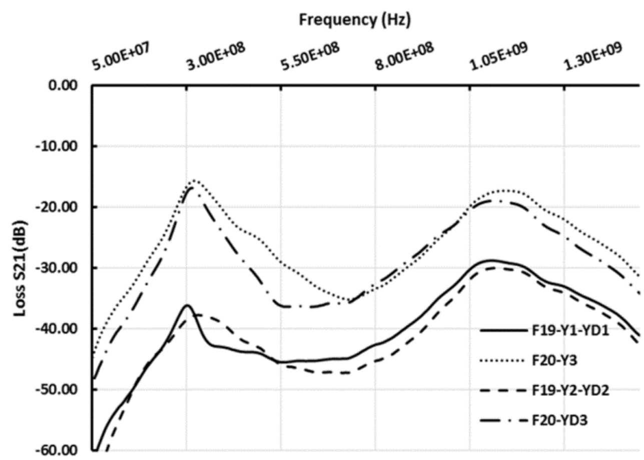

Fig. 6 — Comparison of shielding behaviour of plain and cell type fabrics

containing the conductive yarns in warp and weft directions (F13-F18). As can be seen, there is not much difference in shielding effectiveness of fabric observed, despite the sheath polyester fibre content increases (F13-F15). However, an increase in core SS content improves the SE of fabrics, as seen in samples F16-F18. This is due to the formation of strong conductive grids as the metal fibre content in the weft way increases. Similarly, effect of incident frequency on shielding effectiveness of fabric is also studied. As the frequency increases from 0.3 GHz to 0.6 GHz the shielding effectiveness of the fabric is increased. This is due to formation of effective conductive network by the fabric. However, further increase in frequency reduces the overall shielding effectiveness of the fabric due to skin depth effect[11].

Comparing the Shielding Effectiveness of Plain and Cell Type Weave Fabrics

The cell type and plain fabric structures have been developed with same conductive fibre content in warp and weft directions of fabric (F19 & F20) as shown in Table 2. The shielding effectiveness of these fabrics have been compared and the results are shown in Fig. 6. As can be seen, cell type fabric exhibits better shielding effectiveness than the fabric with plain weave structure. This is due to better shielding effect of cell type fabrics than the plain fabric. In addition, as the metal content is increased in the fabric, i.e F19-Y1 to F19-YD1 by using the doubled SS yarn in core of the yarn, the shielding effectiveness of the fabric is also increased (Fig. 6). The similar trend is also observed for plain weave fabric. Hence, cell type fabric could be used as effective shielding fabric.

The inferences drawn by this study are given hereunder:

- An increase in sheath polyester content in the yarn changes the overall shielding effectiveness of the fabric. However, an increase in core SS content of the yarn increases the shielding effectiveness of the fabric, irrespective of the fabric structure.

- When conductive yarns are introduced in one direction, the fabric shows lower shielding effectiveness. If the conductive yarns are present in warp and weft directions, the fabric shows higher shielding effectiveness.
- The increase in incident frequency initially increases the shielding effectiveness of fabric and then the SE of the fabric is decreased. As the frequency increases from 0.3 GHz to 0.6 GHz, the shielding effectiveness increases due to formation of effective conductive network by the fabric. Beyond 0.6 GHz, the shielding effectiveness decreases due to skin effect.
- When the conductive yarns are introduced in both directions of the fabric and the grid formed by the fabric is small, the cell type fabric shows the higher shielding effectiveness of -48 dB as compared to plain fabric with SE -35 dB at 0.7 GHz.
- In addition, the increasing metal content in the larger grid fabric does not improve the shielding effectiveness of the fabric. Hence, the developed fabric could be used as shielding cloth and electrostatic discharge fabric in various industrial applications.

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