

THE EFFECT OF WASHING PROCESSES ON THE ELECTROMAGNETIC SHIELDING OF KNITTED FABRICS

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ABSTRACT

Nowadays electromagnetic shielding is getting more importance due to the widely usage of electronics such as mobile phones, televisions etc. There are many studies on the electromagnetic shielding effects of the conductive textile structures. However there are no researches on the shielding effect of the fabrics after washing cycles and also there are no researches on the physical properties of these fabrics. For this reason, firstly some physical properties of conductive fabrics used for electromagnetic shielding is studied in this study. Furthermore, shielding properties of the fabrics after washing cycles are discussed.

Keywords: Knitted fabrics, Interlock fabric structure, Single jersey fabric structure, Electromagnetic shielding, Washing cycle.

ÖZET

Mobil telefonlar, televizyon gibi elektronik eşyaların yaygın olarak kullanımı sebebiyle elektromanyetik kalkanlama konusu günümüzde önem kazanmıştır. İletken tekstil yapılarının elektromanyetik kalkanlama etkisi hakkında yapılmış bir çok çalışma bulunmaktadır. Ancak bu kumaşların fiziksel özellikleri hakkında yapılmış çalışmalar çok azdır ve tekrarlı yıkamalar sonrasındaki elektromanyetik özellikleri hakkında yapılmış çalışmalara da rastlanmamıştır. Bu sebeple bu çalışmada ilk olarak iletken kumaşların bazı fiziksel özellikleri incelenecek ve daha sonra bu kumaşların yıkama sonrası elektromanyetik kalkanlama özellikleri tartışılacaktır.

Anahtar Sözcükler: Örme kumaş, İnterlok kumaş yapısı, Süprem kumaş yapısı, Elektromanyetik kalkanlama, Tekrarlı yıkama.

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1. INTRODUCTION

Accompanying the advances of science and technology, usage of electronic goods raises the levels of electromagnetic radiation which should cause the possible hazardous effects and jeopardizes people's health (1, 2, and 3). This results in growing interest to produce different materials which are used both for screening materials against the waves and insulating materials to prevent the leakage of radiation. They can be used as foil tapes with conductive adhesives, conductive coatings and conductive dyes etc. Conductive textiles; which can be knitted, woven or nonwoven fabrics are also produced to shield these electromagnetic waves.

There are many studies about knitted shielding textiles. Cheng and colleagues studied on the electromagnetic shielding properties of knitted fabrics (4, 5 and 6). In the first study, Cheng produced plain knitted, 1x1 rib and 1x2 rib knitted fabrics by using stainless steel (SS)/PES blended

yarns, SS/Stainless Steel Wire (SW)/PES and SW/PES core spun yarns in different blend ratios. He investigated the effects of yarn type and the blend ratio of the yarns on the electromagnetic shielding effectiveness (EMSE) (4).

In another study, Cheng et al. investigated the electromagnetic shielding properties of plain knitted and plain inlaid knitted composite structures. As a result of the research, the EMSE values of the plain inlaid knitted fabric composite laminates were measured higher than those of the plain knitted fabric composite laminates. It was observed that these values were increased as the fabric plies of the composites are increased (5).

In another study, Cheng et al. produced Cu/PP uncommingled yarns using different diameters of copper wire. Double plain, double plain inlaid, 1x1 rib and 1x2 rib composite laminates with eight plies of knitted fabrics were fabricated using these yarns. It was observed that the EMSE values of knitted composites were increased as the

amount of copper content was increased. They also expressed that; the EMSE of the laminates could be tailored by using higher amount of inlaid yarns (6).

Perulmaraj and Dasaradan produced different Cu/Co core yarns using different diameters of copper. Plain, rib and interlock fabrics were knitted using these yarns. The EMSE of these fabrics were measured. It was stated that the fabrics with higher tightness factor had good shielding effectiveness values than the fabrics with lower tightness values. The interlock knitted structures showed better EMSE values between 20 -18.000 MHz frequency range. They determined that with an increase of copper wire diameter, a decrease in shielding effectiveness was observed (7).

Palamutçu et al. developed an electromagnetic shielding efficiency measurement set and tested its reliability within the circumstance of the produced electrical conductive plain knitted and plain woven fabrics (8).

Soyaslan et al. studied the electromagnetic shielding effectiveness of plain knitting, weft in-laid plain knitting, 1x1 rib and weft in-laid 1x1 rib fabrics by using the folded yarns obtained from Ne 20/2 cotton and copper wire with a diameter of 0.1 mm, 0.15 mm and 2x0.15 mm diameter. They investigated the effect of the fabric structure and the copper content on the shielding performance of knitted fabrics (9).

Ceken et al. studied the textile surfaces knitted with only bare conductive copper and stainless steel wires without using a wrapped or core conductive yarn to test the electromagnetic shielding properties of fabrics. Therefore, the knittability of the copper and stainless steel wires are tested. In this study, different types of knitted structures (plain knit structure, rib knit structure, full cardigan etc.) were produced. Then the electromagnetic shielding effectiveness of these fabrics is examined (10).

Ortlek et al. studied the electromagnetic shielding effectiveness of various knitted structures made of Siro core-spun cotton yarns containing stainless steel wire. Test results showed that fabrics knitted from Siro corespun hybrid yarns containing SS wire have shielding efficiency of 10 dB or higher. The existence of elastane in the single jersey fabric structure did not have any significant influence on shielding efficiency. The loop density change in the rib knitted fabrics effect the SE values at lower frequencies (11).

Ortlek et al. investigated electromagnetic and shielding properties of single jersey fabrics produced from conductive hybrid yarns. As a result of this study, it was found that SE value of the knitted fabrics having SS wire higher than that of without SS yarns (12).

Ceken et al. studied textile surfaces knitted with conductive copper/PAC and stainless steel wires/PAC and also core yarns produced by using conductive yarns to test the electromagnetic shielding properties of the knitted fabrics (cross miss 1x1 plain knit, lacoste, interlock and double pique structures). They concluded that the knitted structure of the fabrics affect the EMSE and fabrics knitted using both needle beds of the knitting machine with higher amounts of conductive yarns and unit weights could not provide the targeted improvement in the EMSE values with respect to the fabrics produced on a single needle bed of the knitting machine (13).

Ortlek et al. studied the electromagnetic shielding effectiveness of various weft-knitted fabrics made of hybrid yarns considering the anisotropy of the structures. Conductive hybrid yarns having stainless steel wire were knitted as plain knit, pique knit and double-knit structures. The EMSE measurements of the fabrics were performed by using the anechoic chamber method. The results show that EMSE depends on the orientation of the fibers within the structure regarding the direction of the electrical field in addition to parameters such as metal content, loop length and frequency (14).

Bedeloglu studied the effect of knitted fabric structure and wire diameter in EMSE and some other physical properties of hybrid knitted fabrics. The SS wire/PAC yarns were used to produce plain and rib knitted fabrics. As a result of this study, rib fabrics exhibited better EMSE values than plain fabrics. Fabrics using two-folded yarns exhibited better EMSE values. Fabrics produced with thinner wire exhibited higher EMSE values (15).

Hwang et al. produced conductive yarns using stainless steel wires and bamboo charcoal roving. On a 14-gauge flat bed knitting machine, they produced plain knit fabrics. Then they obtained different lamination layers in order to obtain highest EMSE degrees. As a result of this study, they concluded that EMSE of the fabrics increases with an increase in stainless steel content and number of lamination layers (16).

Tezel et al. investigated the EMSE of thin and lightweight knitted fabrics that are suitable for casual wear like t-shirts. Metal/cotton conductive composite yarns are produced by a yarn doubling technique, involving stainless steel wires or copper wires in order to knit single jersey fabrics. Coaxial transmission line and free space measurement techniques are used for the EMSE measurements. They concluded that single jerseys knitted fabrics have EMSE ability for the electric field polarization in the same direction as the main direction of the conductive metal wires. If the electric field polarization is perpendicular to the direction of the conductive metal wires, fabrics do not show EMSE ability. In other words, there is some conductivity in vertical direction (wale direction) of the fabrics because of some contact of the metal wires. Fabrics with two-ply fine cotton yarns have higher EMSE values than the fabrics with one-ply cotton yarn of the same yarn count (17).

In this paper, it was aimed to study the textile surfaces knitted with stainless steel/ cotton yarns to test the electromagnetic shielding properties of fabrics before washing and after washing cycles and some physical properties of these fabrics are also investigated.

2. MATERIALS AND METHOD

2.1 Production of Knitted Fabrics

40 Ne %20/%80 stainless steel/Co yarns are used to produce knitted fabrics. The linear resistance of these yarns is 90 ohm/cm.

Knitted fabrics were produced on circular knitting machines (E18). The knitting notations of the fabrics were given in Figure 1. To produce single jersey structure, conductive and 44 dtex elastomeric yarns were fed together in every course.

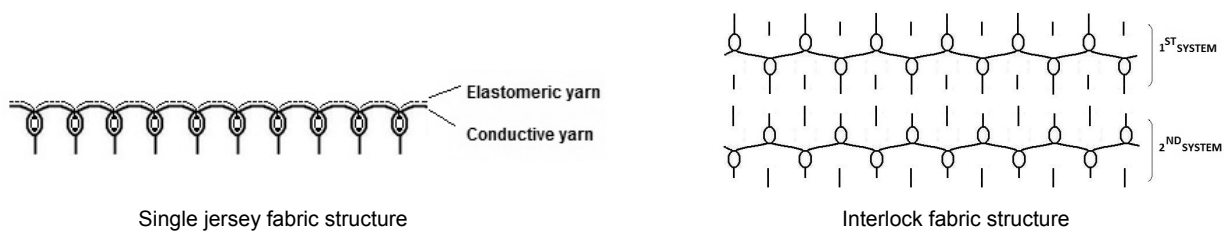


Figure1. Knitting notation of the fabrics

2.2. Measurements of Physical Properties of Knitted Fabrics

The measured physical properties and the standards for these measurements were given in Table 1.

Table 1. Tested Physical Properties and Standards for these measurements

The Name of The Physical Test	Name of The Standards
Loop length	TS EN 14970
Course and wales densities	TS EN 14971
Thickness	TS 7128 EN ISO 5084
Aerial density	TS 251
Air permeability	TS 391 EN ISO 9237
Pilling	TS EN ISO 12945-2

Before measurements, all samples were conditioned at standard atmospheric conditions ($20 \pm 2^\circ\text{C}$ and $65 \pm 2\%$ RH).

Aerial density values were calculated using a precision balance. Air permeability tests were measured with FX 3300 TexTest Instruments Air Permeability Tester III.

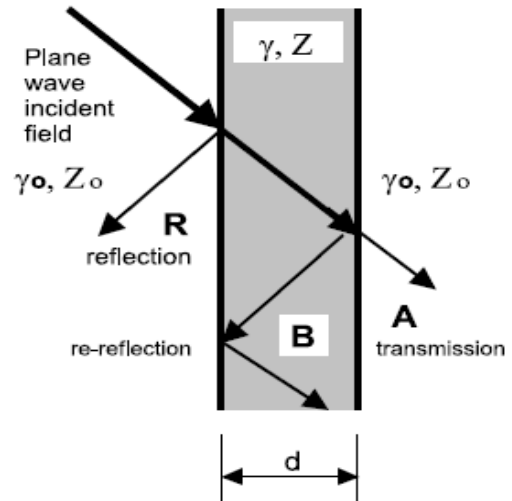
Pilling evaluations were performed on the Martindale Abrasion and Pilling Tester. The surface of tested fabrics was evaluated and the grade of pilling is assigned by comparing the process samples with EMPA standard pilling photographs under standard lighting conditions. These photographs consist of five grades ordered from a severely pilled sample to a nearly pilled sample (Grade 5: No or very little pilling, Grade 1: Strong pilling formation). Moreover, the surface images of the fabric samples before and after pilling process were taken using stereo microscope to get easier evaluation.

2.3. Measurement of Electromagnetic Shielding Effectiveness

In shielding methodology, the signal strength in the media depends on several parameters related with material properties such as electric and magnetic behavior, conductance on the surface and in the volume, material thickness and system structure. Figure 2 shows signal propagation on a layer of shielding material (18).

The Shielding Efficiency (SE) term explains the level of prevention. The shielding efficiency, SE, describes the performance of the shield and it is defined in Equation 1 (19):

$$SE_p = 10 \cdot \log_{10} \frac{\text{incident power density}}{\text{transmitted power density}} = 10 \log \frac{P_I}{P_T} \quad (1)$$



where:

- γ, γ_0 - propagation constants
- Z, Z_0 - characteristic impedance of the medium
- d - thickness of the shield.

Figure 2. Wave Transmission on a thin layer of media (18)

The two power densities in this ratio are the measured powers before and after the shield is placed (19).

In this study, free space measurement technique was used in order to determine shielding efficiency of stainless steel/Co knitted fabrics. Fundamental measurement method was based on the signal attenuation of the two sides of fabric material located on far field zones of transmitter and receiver antennas. The ratio of total amount of transmitted signal strength over total incident signal strength determines SE term related with material properties given above.

The measurement setup is shown in Figure 3 and also the practical measurement setup is shown in Figure 4. A spectrum analyzer, Anritsu MS2711D with the option of transmission measurement, was used for the tests. In order to prevent the unwanted signals, absorbers were used around the testing area (Figure 4.). Initially, the reference signal collected without the shielding material at all frequencies. Afterwards, the stainless steel/cotton knitted fabrics were attached on the foam layer which is placed between receiver and transmitter equipments. Finally, the signals obtained from both states were compared.

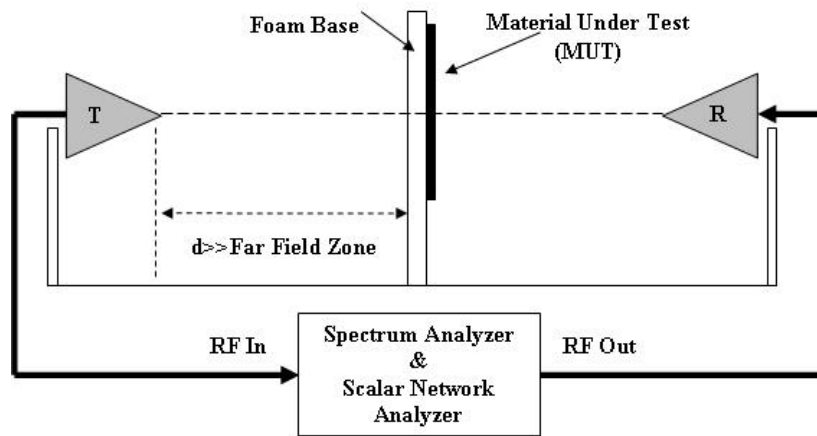


Figure 3. The measurement setup

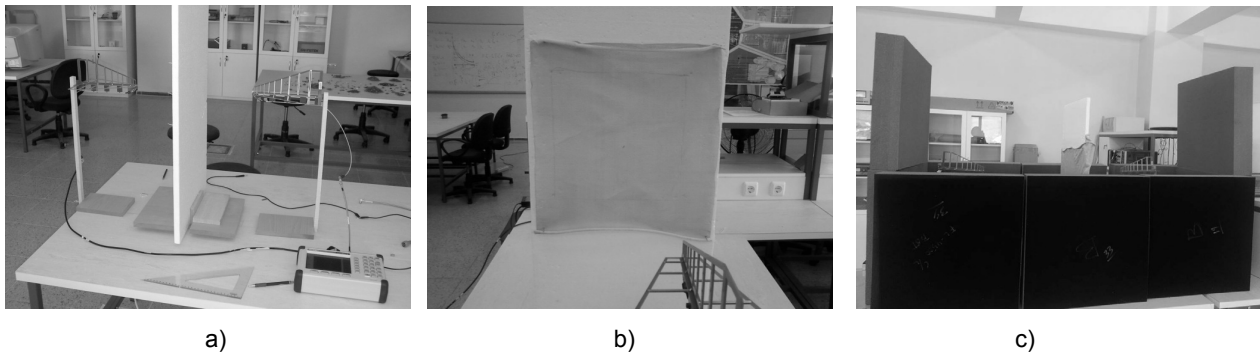


Figure 4. Practical measurement setup a) The measurement setup, b) Placement of the fabric on the foam layer, c) Placement of the absorbers around the testing area

The measurements are realized within a band of 750 MHz to 3000 MHz. GSM 900, GSM 1800 and several ISM bands which can be used for personal purposes are exist in this spectrum.

2.4. Washing Processes

All of the fabric samples were washed and dried several times according to the experimental setup which is given in Figure 5. Washing process were carried out in a domestic washing machine at $40^{\circ}\text{C} \pm 3^{\circ}\text{C}$ for 30 minute using 4 gr/l detergent according to TS EN ISO 6330. After each washing cycle, fabrics were laid in the free form for 48 hours on a flat surface to dry. After the 5th washing cycle the electromagnetic shielding effectiveness of the fabrics are measured.

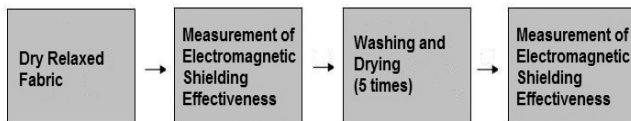


Figure 5. Stages of EMSE measurements and washing and drying process

RESULTS AND DISCUSSION

The measured physical properties of the conductive knitted fabrics are given in Table 2.

Air permeability is affected by different parameters such as fiber fineness, and cross-sections, yarn manufacturing

techniques, twist, hairiness, yarn packaging, fabric weave structure, thickness, aerial, and volume densities (15). When the air permeability of the single jersey and interlock fabric is investigated, it is seen that the air permeability of single jersey fabrics are higher than that of interlock fabrics due to the highest knitted fabric tightness of jersey structure. When the fabric tightness gets looser, this structure is more permeable to air owing to their higher porosity (20, 21). In the single jersey structure, elastomeric yarns exist in every row and also it was proved that air permeability of spandex-containing fabrics was lower (22)

Table 2. Some physical properties of conductive knitted fabrics

PROPERTIES OF FABRICS	FABRIC STRUCTURES	
	SINGLE JERSEY	INTERLOCK
Course per cm	20	17
Wales per cm	18	11
Loop length (loop/mm)	3,393	3,34
Aerial density (g/m^2)	227	230
Thickness (mm)	0,58	1,23
Air permeability (mm/sn)	415	1617
Pilling grades	3	2

Pilling is a common problem namely in knitted fabrics and can be defined as the formation of the entanglements of loose fibers on the surface of a fabric (23). When the single jersey and the interlock fabrics are compared, it can be seen that single jersey fabric structures have better pilling grades than interlock fabric structures (Table 2, Figure 6). This is

due to the fabric tightness and the fibers protruding from the fabric surface can easily form pills in loose knitted fabrics than in tight knitted fabrics (24) also the elastomeric yarn affects the pilling formation.

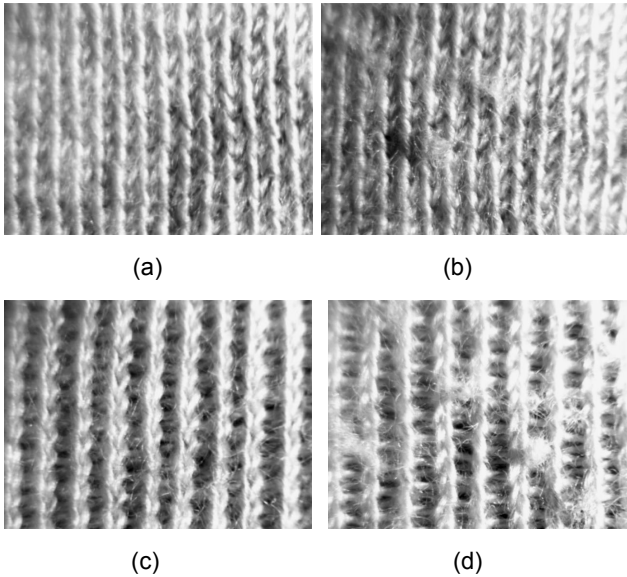


Figure 6. Single jersey (a-Before pilling, b- after pilling) and interlock (c-Before pilling, d-after pilling) fabrics

In Figures 7-10, the electromagnetic shielding values of single jersey and interlock fabrics before and after washing processes are given.

In Figure 7, it is observed that the highest EMSE value of single jersey fabrics before and after washing cycles is at 1361 MHz as 28 db. Especially the EMSE values are higher than 15 dB in the frequencies between 1206 and 1700 MHz. After 1700 MHz, the EMSE values vary between 10-15 dB.

When the EMSE values after washing cycles are examined, it is seen that the EMSE values are lower than the values measured before washing between 700- 1735 MHz frequencies. The average of these values is lower than 10 dB. There are slight differences in between 1735 MHz and 2310 MHz. In 2425 MHz and between 2770 MHz and 2885 MHz the EMSE values are lower than 10 dB. The difference in the low and medium frequency band before and after washing cycles could be explained due to the changes and the deformation in the fabric structure, which affect the dimensional parameters in the knitted fabric.

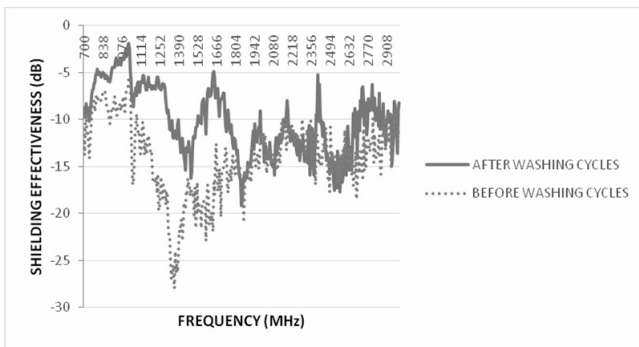


Figure 7. Measured EMSE values of single jersey fabrics (Horizontal measurement)

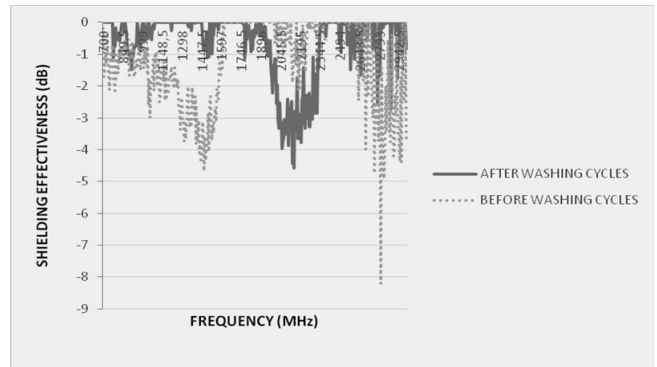


Figure 8. Measured EMSE values of single jersey fabrics (Vertical measurement)

In Figure 9, it is seen that the EMSE values of interlock fabrics are very low at the low frequency bands before and after washing cycles. The highest EMSE value is obtained in 1533 MHz as 25 MHz before washing cycles. Especially the values are higher than 15 dB in the frequency range between 1786 and 2100 MHz. But in this frequency range, these values obtained after washing cycles are slightly higher than that of obtained before washing. As it is known, interlock fabric has more balanced structure and after washing cycles there are little changes in the dimensional properties of these structures. So it can be concluded that, the shielding efficiency of the interlock fabric is improved in the medium frequency range slightly after washing processes due to the dimensional changes.

In the highest frequency bands, the EMSE values are higher than 10 dB before and after washing, it was almost 12 dB.

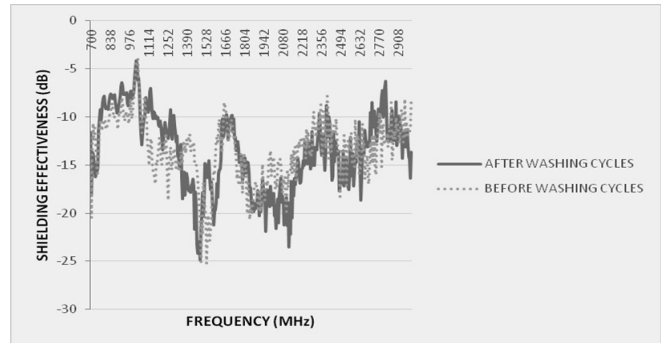


Figure 9. Measured EMSE values of interlock fabrics (Horizontal measurement)

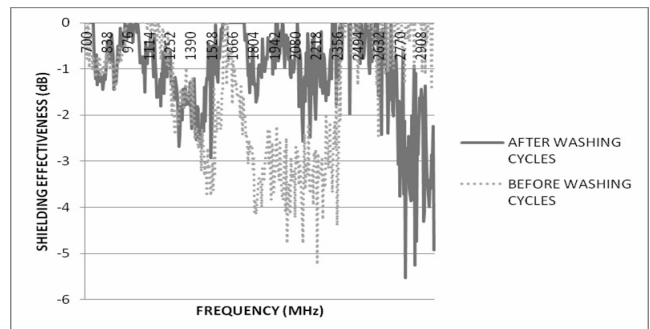


Figure 10. Measured EMSE values of interlock fabrics (Vertical measurement)

In vertical measurements, it is seen that there is not enough shielding effect, while the EMSE values are lower than 10 dB (Figure 8 and 10). In Figure 8, the EMSE values of the single jersey fabrics after washing cycles at the frequencies between 1907 and 2390 are higher than the EMSE values before washing. At the frequencies between 1162 and 1545 Mhz and after 2600 Mhz, the EMSE values of the single jersey fabrics before washing are higher than the EMSE values after washing cycles. In Figure 10, the EMSE values of the interlock fabrics before washing at the frequencies between 1666 and 2355 are higher than the EMSE values after washing cycles. At the frequencies after 2660 Mhz, the EMSE values of the single jersey fabrics after washing cycles are higher than the EMSE values before washing cycles.

When the values before washing processes are investigated in Figures 8 and 10, it can be seen that the EMSE values of single jersey fabric structure are higher than 10 dB after 1050 MHz. Especially shielding values between 1160 and 1660 MHz frequencies are averagely 19 dB. But in this frequency range, the EMSE values of interlock structure are lower than single jersey structure with an average of 15 dB.

When the values after washing processes are investigated in Figures 8 and 10, the interlock fabrics have better EMSE values than that of single jersey fabrics especially in low and medium frequency ranges. This could be due to the changes in the fabric structure of the single jersey fabrics after washing cycles.

CONCLUSIONS

In this study, it was aimed to study the textile surfaces knitted with stainless steel/ cotton yarns to test the electromagnetic shielding properties of fabrics before and after repeated washing processes and some physical properties of these fabrics are also investigated.

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As a conclusion;

- It is seen that the air permeability of single jersey fabrics are higher than that of interlock fabrics due to the highest knitted fabric tightness of jersey structure.
- It can be seen that single jersey fabric structures have better pilling grades than interlock fabric structures due to the fabric tightness and the elastomeric yarn in the fabric structure.
- In vertical measurements, it is seen that there is not enough shielding effect, while the EMSE values are lower than 10 dB.
- The EMSE values of single jersey structures before washing are higher than that of after washing in horizontal measurement.
- The EMSE values of interlock fabrics do not differ much after washing and this could be affected by the fabric structure in horizontal measurement.
- After washing processes, interlock fabrics have better EMSE values than that of single jersey fabrics especially in low and medium frequency ranges. This could be due to the changes in the fabric structure of the single jersey fabrics.

In the future studies, the physical properties and the effect of washing processes for different types of knitted fabrics can be investigated in order to examine EMSE characteristics.

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