SEPTEMBER 2019 M.Sc.Thesis in Textile Engineering NAZİFE TUĞBA ATLAS

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THE INVESTIGATION OF VARIOUS BEHAVIOUR OF COTTON FABRICS INCLUDING METALLIC YARN

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IN

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BY

NAZİFE TUĞBA ATLAS

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Supervisor

Prof. Dr. Cem GÜNEŞOĞLU

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Nazife Tuğba ATLAS

ABSTRACT

THE INVESTIGATION OF VARIOUS BEHAVIOUR OF COTTON FABRICS INCLUDING METAL YARN

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In recent years, as a result of the increased use of electronic devices, there has been an increase in the electromagnetic field emitted by these devices as well. Various technical shield fabrics are needed to protect people from the harmful effects of electromagnetic fields created by these devices. In this thesis, nine different conductive textile materials were produced from stainless steel wire (18-micron, 35-micron, 50-micron) as a conductive material and cotton yarn (Ne 50/1, Ne 60/1, Ne 70/1) as textile material. Cotton yarns and stainless-steel blend hybrid yarns are produced by hollow spindle method. These yarns have been knitted by a circular knitting machine to form a textile fabric. In addition, the control fabrics have been knitted from 100% cotton fabrics. These fabrics have been dyed with reactive dyes in laboratory type dyeing machines. Color differences, color strength, electrical surface resistance, washing and rubbing fastness and thermal conductivity of these fabrics have been evaluated and compared to control fabrics. ANOVA two-factor random analysis method has been used to see the effect of variable values (cotton yarn count and metal wire diameter) on the results. It has been determined that surface resistance would be reduced by adding metal wires to the fabric. In addition, it has been observed that color differences, color strength, abrasion resistance and thermal conductivity values increased as metal wire thickness increased in fabric content.

Key Words: Metal Wire, Hybrid Yarn, Conductivity, Shielding Effectiveness (SE)

ÖZET

METAL TEL İÇEREN PAMUKLU KUMAŞLARIN ÇEŞİTLİ DAVRANIŞLARININ İNCELENMESİ

ATLAS, Nazife Tuğba
Yüksek Lisans Tezi, Tekstil Mühendisliği
Danışman: Prof. Dr. Cem GÜNEŞOĞLU
Eylül 2019
48 sayfa

Son yıllarda, elektronik cihazların kullanımındaki artışın birsonucu olarak, bu cihazların yaydığı elektromanyetik alanda da artış meydana gelmiştir. İnsanları, bu cihazların yarattığı elektromanyetik alanların zararlı etkilerinden korumak için çeşitli teknik kalkan kumaşlarına ihtiyaç duyulmaktadır. Bu tezde, iletken bir malzeme olara kpaslanmaz çelik telden (18 mikron, 35 mikron, 50 mikron) ve tekstil malzemesi olarak pamuk ipliğinden (Ne50/1, Ne 60/1, Ne 70/1) dokuz farklı iletken tekstil malzemesi üretilmiştir. Pamuk iplik ve paslanmaz çelik karışım hibrit iplikler, içi oyuk iğ metodu ile üretilmiştir. Bu iplikler, bir tekstil kumaşı oluşturmak için yuvarlak örme makinesi ile örülmüştür. Bunun yanında, control kumaşları ise %100 pamuklu ipliklerden örülmüştür. Bu kumaşlar reaktif boyalarla laboratuvar tipi boyama makinelerinde boyanmıştır. Renk farklılıkları, renk mukavemeti, elektriksel yüzey direnci, yıkama ve sürtünme haslığı ve bu kumaşların ısıl iletkenliği değerlendirilmiş ve kontrol kumaşları ile karşılaştırılmıştır. Değişken değerlerin (pamuk ipliği sayısı ve metal tel çapı) sonuçlara etkisini daha iyi anlamak için ANOVA iki faktörlü rassal analiz yöntemi kullanılmıştır. Kumaşa metal tellerin eklenmesi ile yüzey direncinin azaltılacağı tespi tedilmiştir. Ayrıca, metal tel kalınlığı arttıkça renk farklılıkları, renk mukavemeti, aşınma direnci ve ısıl iletkenlik değerlerinin de artış gösterdiği görülmüştür.

AnahtarKelimeler: Metal Tel, Kompositİplik, İletkenlik, EkranlamaEtkinliğ

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LIST OF SYMBOLS

μT	Microtesla
Ω	Ohm

LIST OF ABBREVIATIONS

EMF	Electromagnetic Field
EMI	Electromagnetic Interference
SS	Stainless Steel
Kv	Kilovolts
A	Ampere
A/m	amperes per meter
µT	Microtesla
V/m	Volts per meter
Hz	Hertz
ELF	Extremely-Low Frequency
ICP	Conductive Polymers
MnZn	Manganese Zinc
PVD	Physical Vacuum Deposition
CVD	Chemical Vapor Deposition
EMSE	Electromagnetic shielding effectiveness
SE	Shielding effectiveness
RCS	Relative Color Strength

CHAPTER I

INTRODUCTION

1.1 Introduction

The use of the electronic devices in houses, industrial zones, health sector, and communication and automation sectors are being steadily increased recently.

The communication devices like smart phones, personal computers, television etc. are indispensable parts of our daily lives. The prevalent usage of those devices can easily be observed in any crowded public area (in airports, at the waiting halls, on a bus etc.). One can claim that at least half of the people in any public area will be seen at a glance as engaging with their smart phones. People are surrounded by digital stimuli. The exposure by digital screens is being increased day by day. Daily used small household devices had been started to be digital years ago but nowadays photo frames, books, notebooks, etc. are being digital as well. For sure, most of these devices make life easier for us. Nevertheless, their harmful effects on human health are also highlighted by many experts.

There are different views on the effects of Electromagnetic Field (EMF) on health. Existing research is not yet sufficient to strongly defend whether it is harmful.

On the other hand, the stated harmful effect of Electromagnetic Interference (EMI) applies not only to human health but also to the device. Any electrical and electronic equipment with varying voltages and currents, is seen as a source of EMI. This unwanted EMI may generate unwanted voltages and currents that may cause loss of performance in other devices. The victim equipment can be reached either by conduction or by electromagnetic radiation, or by both and that induce undesirable voltages and currents in it. [1]

Electromagnetic field shielding is necessary to prevent harmful effects of electromagnetic interference. EMF shielding prevents the harmful effects onsensitive electronics, avoids the health risks of human and other organisms, and decreases the environmental pollution. Generally metal sheet screens are used asshielding conductive materials. However, they are high in weight, inflexible in construction and costly. Therefore, to eliminate the disadvantages of metal sheetscreens, textile materials have been developed as shielding stuff. In order to utilize textile structure as EMF shield, conductive constituents should be added to textile materials. There are different ways of converting the textiles into conductive materials. Inherently conductive polymers can be used, carbon or metals can be added to the yarns (hybrid yarns), or the textile can be coated with conductive substances. [2] after all these applications, some comfort properties of textile may be adversely affected. Therefore, it is very important to decide the sufficient EMF shielding values of textile and its final usage area. Accordingly, the proportions of the used constituents must be decided, and the proper production methods must be established.

1.2 The Purpose of the Thesis

There are several methods to improve the fabric conductivity; incorporation of conductive fibers or yarns such as metallic yarns into the fabric is one of the mostly applied approaches. However, the metal yarn within the fabric may affect various properties like color, color fastness and comfort sensations. So, various behaviors of fabrics including metallic yarns should be investigated and any difference with the conventional fabrics should be assessed. For this purpose, hybrid yarns, the combination of 100% cotton yarn and stainless steel (SS) metallic yarn; will be used for knitted fabric production. The variations in the fineness of metallic yarn and cotton yarn number will determine the density of conductive metallic yarns within the fabric. Then the sample fabrics will be dyed in a laboratory dyeing machine and color strength; color efficiency comparing to 100% cotton fabric (control sample) of those fabrics, surface resistivity and thermal conductivity values will be measured with relevant instruments. On the other hand, the effect of metallic yarn density of the fabrics will also be evaluated and any correlation between color strength and thermal/electrical conductivity will be analyzed.

1.3 Electromagnetic Fields

EMF is an acronym for “electric and magnetic fields.” As explained by the National Institutes of Health, electric and magnetic fields (EMF) are “…invisible lines of force that surround any electrical device. Power lines, electrical wiring, and electrical equipment all produce EMF." EMF has two definite constituents: electric fields (created by electric voltage, measured in volts (V) or kilovolts (Kv)), and magnetic fields (created by electric current, measured in amperes (A) [3].

Electric fields are formed by differences in voltage. The higher voltage would cause the increase in electric field. Electric current is not necessary to form electric field. Because of this plugging a wire of a lamb into an outlet creates electric field even the lamb is switch off. As the supply voltage of a device rises, the resulting electric field also rises. Electric field strength decreases as it moves away from the source. Most conductive building materials shields electric fields to some extent. Electric field strength's unit is V/m [4].

Magnetic fields are formed when electric current flows. Magnetic field's magnitude depends on the current magnitude, the distance from the conductor and the shape into which the conductor is formed. The strength of the magnetic field is measured in amperes per meter (A/m). But scientist prefers to specify a related quantity, the flux density (in microtesla, μT) instead of (A/m). Gauss is also used as magnetic field strength' s unit. Higher current cause stronger magnetic field. As in the electric field, the magnetic field strength also decreases rapidly by distance. In contrast to electric field, the magnetic field can not be shielded by shielding materials [4].

Table 1.1 The specialities of the electric and magnetic field [5]

Electric Fields	Magnetic Fields
Electric fields increase by increasing voltage.	Magnetic fields increase by increasing current flows.
Their strength is measured inVolts per metre (V/m)	Their strength is measured in flux density (inmicrotesla (μT) or millitesla (mT) , amperes per meter (A/m).
An electric field can be occurred when a device is switched off.	Magnetic fields occurred only when the device is switched on
Field strength decreases withdistance from the source.	Field strength decreases with distance from the source.
Most building materials shield electric fields to some extent.	Magnetic fields are not attenuated by most materials.

1.3.1 The Basics of Frequency and Wavelength of the EMF

EM Radiation is formed by an electron's motion driven by the electric field. The movement creates fluctuating electric and magnetic fields which move at right angles to each other in a bundle of light energy called photon. Photons move in harmonic waves at the speed of light (186,282 miles per second). The waves can be determined and classified according to properties as frequency, wavelength or energy [6].

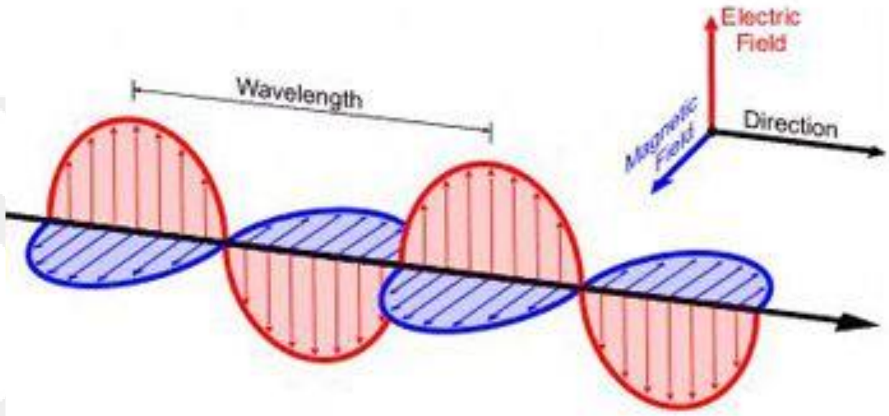


Figure 1.1 Schematic view of electromagnetic field

Electromagnetic waves are formed when an electric field (shown in red arrows) couples with a magnetic field (shown in blue arrows). Magnetic and electric fields of an electromagnetic wave are perpendicular to each other and to direction of the wave [6].

A wavelength is the distance between two sequential peaks of wave. This distance is measured in meter (m). Frequency is the amount of waves that creates in the determined length of the time. It is generally determined by number of wave cycles per second or hertz (Hz). Therefore, frequency and wavelength are interconnected variables; the higher the frequency the shorter the wavelength[6].

1.4 Electromagnetic Frequency Ranges

1.4.1 Static Magnetic Fields

Static magnetic fields do not change in direction and strength over time. Their frequency is 0 Hz. Static magnetic fields pull the metallic objects. Also, in the universe Earth's magnetic field apply a force between South and North naturally. With this feature of the world we can run compasses. Electricity in the form of direct current creates static magnetic fields. The aluminum production, some subway systems can be some examples of the artificial static magnetic field [7,8].

1.4.2 Extremely-Low Frequency Fields

Extremely low frequency (ELF) fields indicate electromagnetic fields which frequencies below 300 Hz. Household appliances and wirings, alternating currents transported in power lines are the sources of the extremely low frequencies. Railway, welding machines, power plants are also other sources of the Extremely low frequencies [8].

1.4.3 Intermediate Frequency Fields

Intermediate Frequency Fields include the frequencies between 300 Hz to 100 kHz. Equipment creating intermediate frequency fields are growing in recent years. Radio transmitters, anti-theft devices, compact fluorescent lamps, television and computer screens are some of the sources of the intermediate frequency fields. Some medical operations as electrosurgery creates intermediate frequency fields [8].

1.4.4 Radio Frequency Fields

Radio Frequency is electromagnetic fields frequency between 100 kHz and 300 GHz. Devices creating radio frequency are used very common in daily lives. Local wireless, radio transmission towers, mobile phones, microwave ovens, medical scanners are some of the sources of radio frequency [8].

1.5 Electromagnetic Shielding

Specialists and researchers still discuss the harmful effects of electromagnetic field on human health and ecosystem. Also, electromagnetic interference affects the other device's performances and working efficiencies [9]. Because of all these oppressive effects of the electromagnetic field, shielding processes and materials are becoming very important issues to study.

Electromagnetic shielding is trying to reduce the field in the space by blocking the fields with barriers made of conductive materials. Generally, it is applied to distinguishing electrical devices from the environment, enclosures, distinguishing wires from the surroundings. The materials which guard ecosystem, peoples or electrical devices from dangerous electromagnetic field is named shield. Basically, shields are used according to two principles; one of them is to protect an area from external sources, and the other is to prevent undesired emission of electromagnetic energy dispersed by interior sources [10].

When electromagnetic rays move through an object or a medium, they affect each other. This interaction can be analyzed in three points at below:

1.5.1 Absorption Loss

When electromagnetic rays strike to the shield material, it forces charge in the shield to vibrate at the same frequency as itself. Because of this force some of the energy turns into heat form. This loss can be called as absorption loss [10].

1.5.2 Attenuation due to Reflection

If electromagnetic waves strike to conductive material as metal some of the waves will be reflected. These types of losses can be called reflection loses [10].

1.5.3 Attenuation due to Re-reflection

Some of the waves are re-reflected sequentially in the shielding materials and these types of losses can be called as re-reflection losses [10].

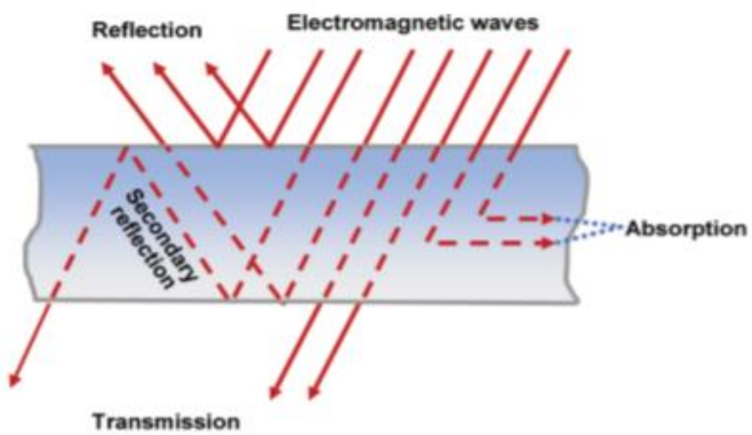


Figure 1.2 Schematic view of the electromagnetic shielding mechanism.

1.6 Shielding Effectiveness

Shielding principle is based on the attenuation of the electromagnetic field. Shielding effectiveness expresses to difference between an electromagnetic signal's intensity before shielding and its intensity after shielding. It is measured in decibels (dB).

1.7 Electromagnetic Shield Textiles

It is almost accepted that Electromagnetic waves are dangerous for living organism and ecosystem. When an organism is exposed to electromagnetic wave continuously, heat is released by the oscillation of the molecules. Also, according to some research, EM waves may affect the proper functioning of the human body slowing down the renewal of the DNA and RNA cells, and this can cause to some diseases as leukemia, some skin disease, and depression. Beside these, electromagnetic waves can affect medical devices such as pacemakers which can cause extremely important bad results. Consequently, shielding of these electromagnetic waves is an important and urgent demand [10,12]. Metallic materials and metallic coated plastics are the most common shielding materials and they are good conductors. But they are not flexible enough to use in some area. Also, they can expand in the higher temperature. They are heavy, expensive; to shape these materials is not easy. These materials cannot meet expectation to prevent from this unwanted electromagnetic field. In order to find optimum electromagnetic shielding methods which meet both proper electromagnetic shielding effect and the specification with mandatory characteristics according to end use, researchers are trying to improve new materials and production methods. Electromagnetic field sources and frequencies that we exposed are very variable, so shielding is becoming very complicated and formidable task. One of the best alternatives to the shielding material is textile-based materials that are flexible, cheaper, light weight, better comfort (for garment), easy care. But textile materials that is not applied any process is not conductive enough; even natural fibers are not conductive materials. Therefore, they do not exhibit electromagnetic shielding.

Textile materials can be turned into conductive materials in order to act as an electromagnetic shield by using aluminum, conductive polymers, copper, stainless steel, metallic filler or coating with different manufacturing methods. Metal fillers can be added to the polymers during the melt spinning and wet spinning of synthetic fibers. Micro powders (graphite and ferromagnetic), carbon nanotubes, carbon nanofibers or alternative inorganic compounds can be used as fillers. Textile surface and yarns can be coated by conductive agents [13, 14].

There are lots of methods to make the textile materials as electromagnetic shield materials. We can summarize these methods in 4 main headings as follows:

1.7.1 Composite Yarn Fabrics

Generally composite yarns are produced to compensate for the weak points of one fiber with the strong properties of the other. Good comfort properties can be obtained by textile natural fiber, and strength and electromagnetic shield property can be obtained by conductive material as metal wire. Some common methods to produce these hybrid yarns are as follows:

1.7.1.1 Hollow Spindle Twisting

The hollow spindle spinning system consist of drafting unit, a hollow spindle which is located at a pirn of filament, a built unit and take up rollers. A roving feeding from drafting unit is pulled with filament from the pirn together to hollow spindle and false twisted by the pin type twister [15]. This method is cheaper and faster according to conventional ring spinning system. Fancy and wrap yarns can be produced between 15and 1500 tex yarn count from all types of man-made and natural fibers.

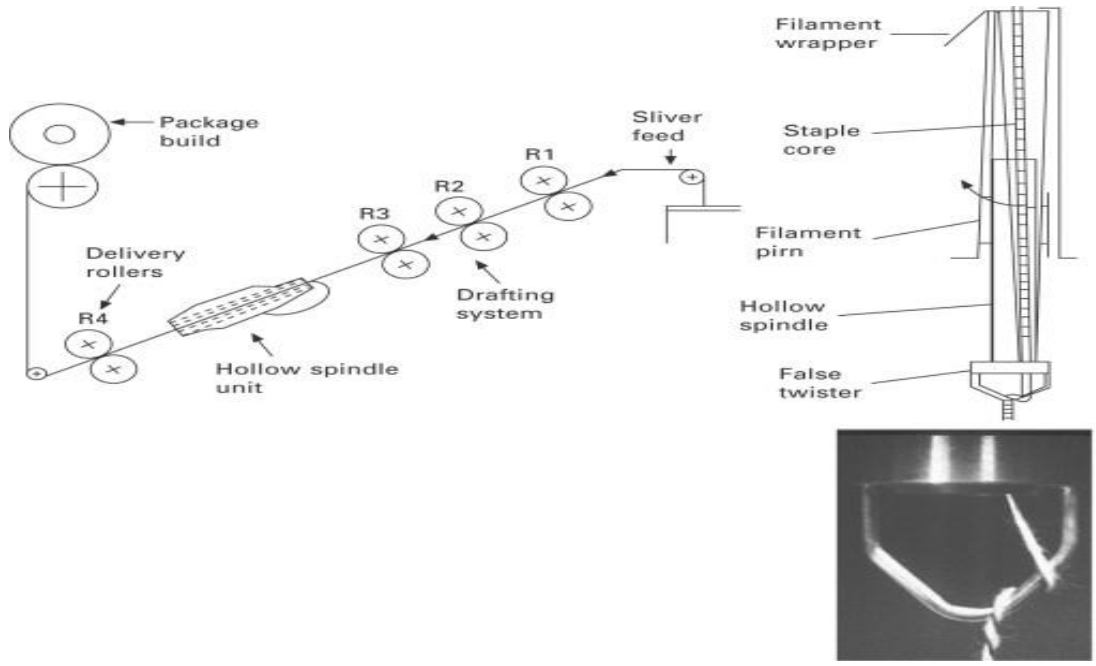


Figure 1.3 Schematic illustration of the hollow spindle machine [15]

1.7.1.2 Friction Spinning

The longitudinal view of a friction spun yarn is similar to the ring spun yarn than an open-end yarn. But the structure of this yarn is totally different from both of the oriented yarn. Core has twisted fibers which are distributed randomly on the yarn axis. Sheath fibers loosely bundled are wrapped helically around the core [16].

These types of yarns are bulky and low tensile strength. Manufacturing cost and labor cost is low, and the production rate is high.

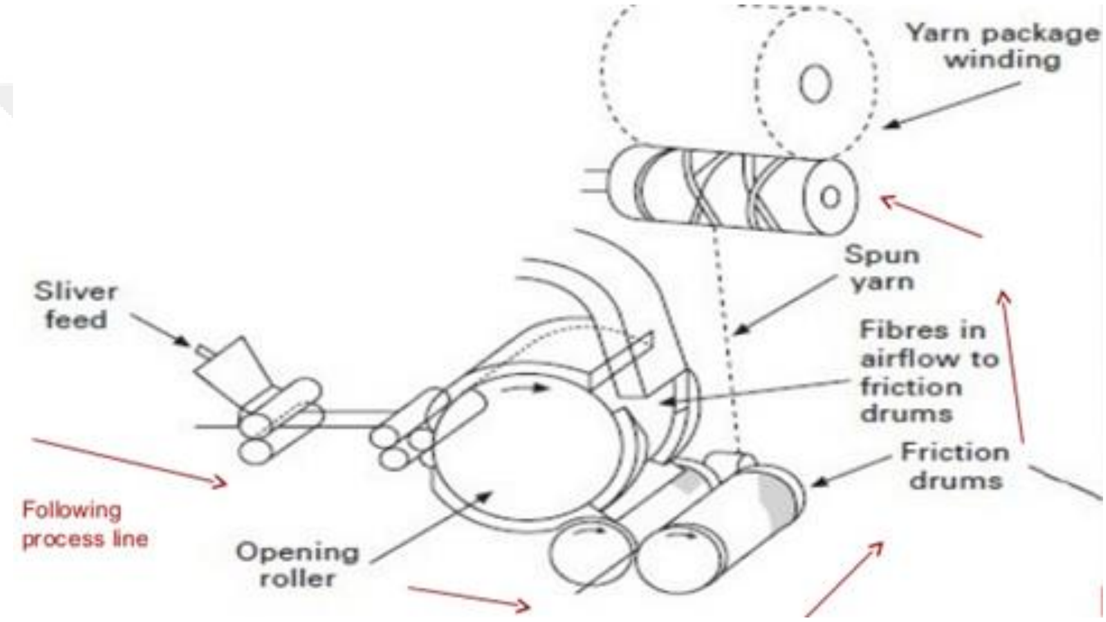


Figure 1.4 Schematic View of Friction Spinning [17]

1.7.1.3 Ply Twisting

Ply-twisting is the twisting process of two or more yarns together. Generally, two yarns single twisted in the same direction combined together by ply twisting in the opposite direction in order to prevent wale spirality. This twisting method is used to prevent pilling in the garment, to make the yarns fancy yarns, to enrich technical properties of the component yarns.

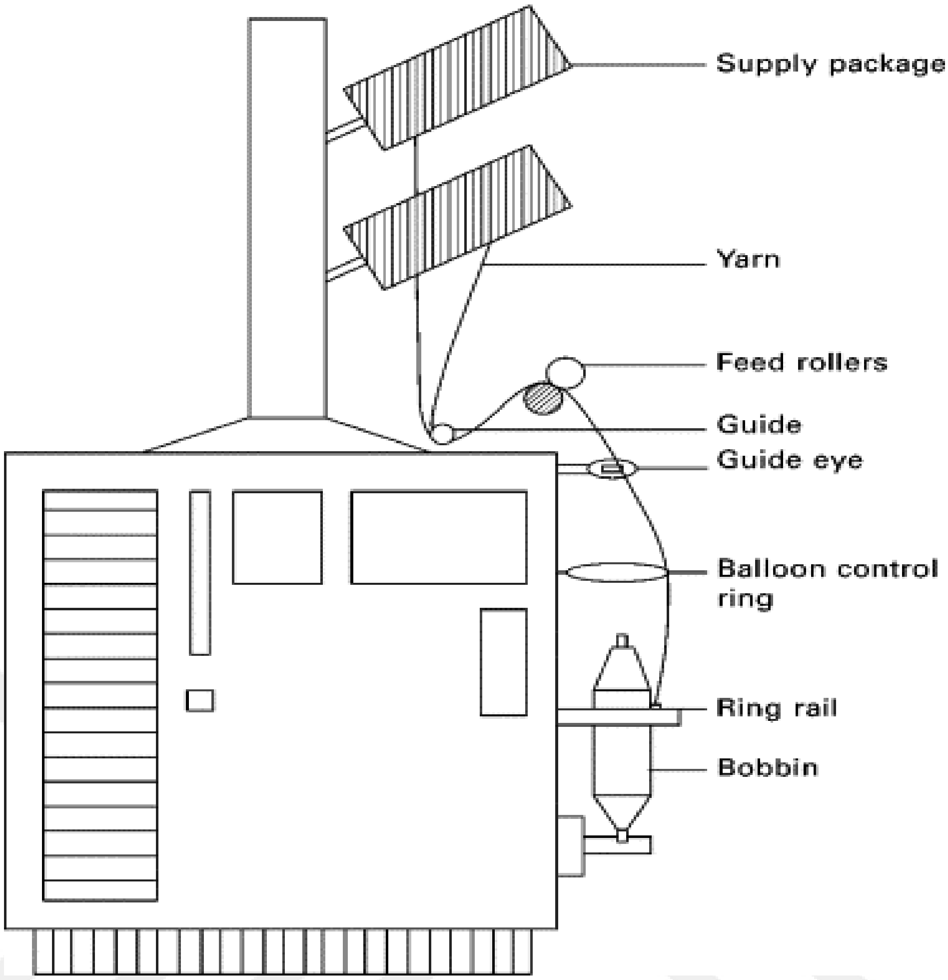


Figure 1.5 Schematic View of Plying Twisting Machine

Appropriate textile fabric can be produced that meet specific application requirement by using these hybrid or composite yarns. These yarns can be knitted or woven in different ways [18,19]. Fabrics can be produced in jacquard or ordinary handloom [20]. Some different effect can be obtained also by weft or warp knitting. The structural properties of knitted and woven fabric as loop length, end density metal fraction affects the performance of the fabric. Some studies mentioned that SE (shielding effectiveness) of the composite fabrics could be arranged by adjusting the metal content ratio, the metal grid geometry and size, changing composite yarn structure [21,22,23]. When metal ratio increase in the shielding fabric, EMSE (electromagnetic shielding effectiveness) is increased [21,24]. Core yarn fabric's EMSE value is higher than plied and covered yarn's. 1/1 plain woven yarn's EMSE value is higher than 3/1 twill and 2/2 plain weave's [25]. The estimations show that tighter fabrics and high conductive yarns have great reflection coefficient almost equal to metal foils [26].

1.7.2 Nonwoven Fabrics

In addition to knitted and woven fabrics, non-woven fabrics provide new features to add the final product and are developed rapidly with new technologies. Conductive fibers or materials can be added to the batt formation at thermal and needle punched method, and during extrusion at spun bonded nonwovens. Absorption property of Conductive polymers and carbon fiber are relatively high, Reflective property of metallic components is relatively high [27]. Hence, the mixture of the two materials provides a remarkable shielding capability. Coating with conductive polymers as metal particles Polypyrrole, nonwoven fabric can be made conductive. Impregnation carbon to the nonwoven fabric makes the fabric excellent shielding material. If the conductive fiber ratio in the nonwoven fabrics is increased the EMSE value will increase also [9]. It has been found that electromagnetic shielding increases linearly with increasing frequency in nonwoven fabrics [30]. Mobile phone envelopes, clothes' interlining and barriers in buildings can be produced by conductive nonwoven materials.

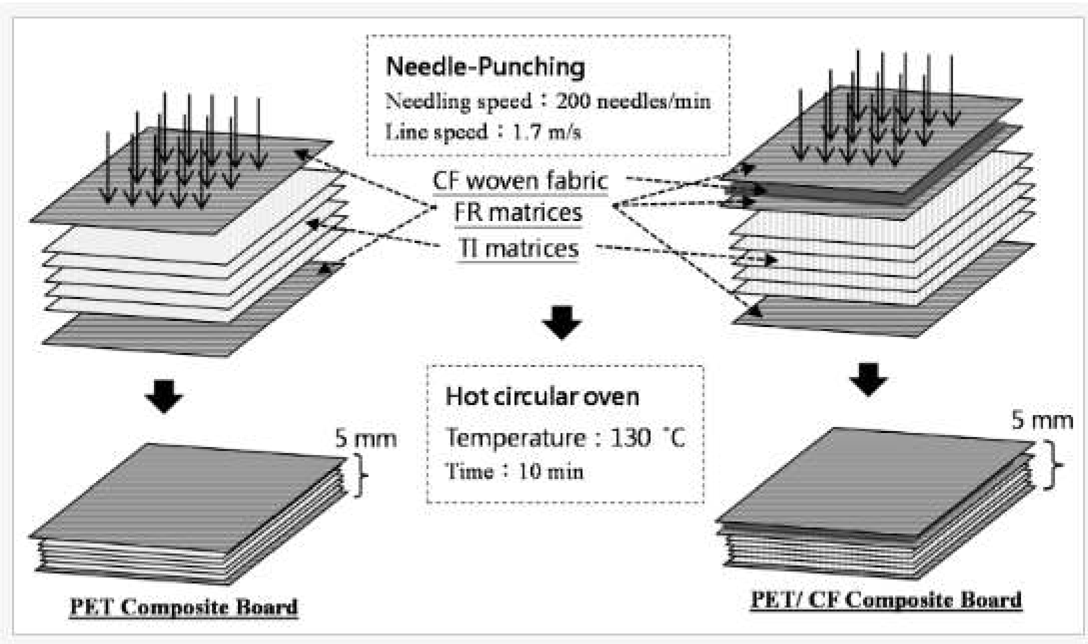


Figure 1.6 The Illustration of thermal insulative and electromagnetic shielding nonwoven composite boards [29]

1.7.3 Polymer-based Composites

Macromolecular polymer materials are developed in 1970s and gradually substituted metals because of their high strength, corrosion resistance, toughness and light weights [31]. Conducting polymers can exhibit good electromagnetic shielding effectiveness by good absorption features unlike carbon and metals which materials have good reflective property [32]. For this reason, it is preferred for secret and camouflage applications of the army.

1.7.3.1 Structural Polymer-based Composites

Conductive polymer comprises linear conjugated π electron system that is conductive by free migration of carriers in polymer. Conductive polymer (ICP) is composed of some polymers having conjugate π bonds. These polymers (ICP) are developed by doping electrochemical or chemical thus the conductivity is improved. The first developed conductive polymer is Polyacetylene is doped with arsenic. The conductivity of polymer has almost reached the same level as the conductivity of copper. Polyaniline is the best choice for use as an electromagnetic shielding because it has good electrical conductivity and can be easily synthesized among other conductive polymers [31, 33].

1.7.3.2 Composite Polymer-based Electromagnetic Shielding Composite Materials

Polymer - Metal Composite

Polymer – Metal composites have high corrosion resistance, low weight, low cost of production method. Electromagnetic shielding properties can be adjusted according to the end use area by changing filler type, content and structure. Because of these advantages, polymer metal composites are widely used in electromagnetic shielding [34].

Polymers and metal fiber or powder are blended until the metal content reach a certain level to create a composite material which has shielding property. Silver is a very good conductor but is very expensive. So, it is used only some special area. Nickel is cheaper and a good conductor. Also, Stainless steel, copper, iron and other metal fiber can be used as electromagnetic shielding material [31].

Metal Oxide –Polymer Matrix Composite

Ferrite, zinc oxide, tin oxide, titanium oxide are the main metal oxide fillers. Metal oxide polymer composites have good stability and small density. So, they can used in the production of transparent plastic [31].

Carbon-based Polymer Composites

The composite of carbon and polymers has low price, high corrosion resistance, low density and easy settlement properties. But surface comprise multiple polar substances and this cause to difficult disperse. Carbon based polymer composite materials can be used for the low electromagnetic field. They are semiconductor. Conductivity of carbon-based material is less than metal fillers. By copper plating or nickel plating the conductivity can be increased [31].

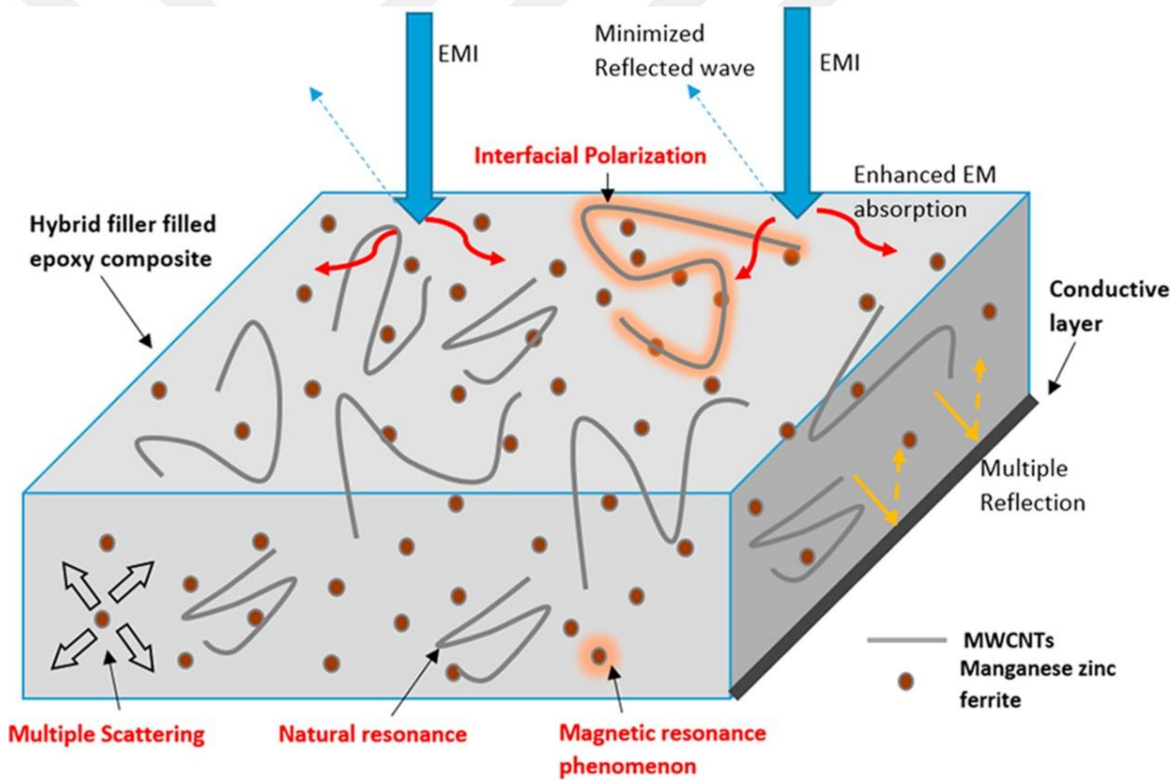


Figure 1.7 The illustration of the shielding mechanism of carbon nanotubemanganese zinc ferrite (MnZn ferrite) fillers [35].

1.7.4 Coated Textiles

Textile surfaces can be coated with conductive materials by some various methods in order to convert nonconductive material to conductive fabrics. The methods are explained briefly as follows:

1.7.4.1 Coating and Printing

Metallic fillers are integrated into a polymeric career. Then this material is coated on the fabric by using dip coating, transfer, foam coating, knife-over-roll coating foam coating methods. Roll printing, ink jet printing, silk- screen printing can be given as examples of the printing techniques [36].

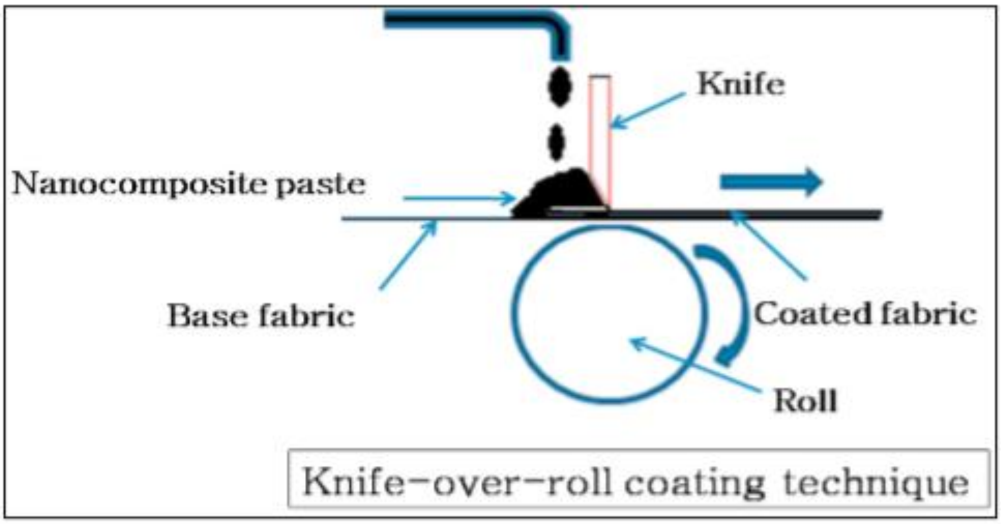


Figure 1.8 Illustration of Knife-over-roll Coating Technique[37]

1.7.4.2 Physical Vacuum Deposition (PVD)

The fabric is located in a vacuum chamber which is comprising the solid metal. Evaporation of the solid material occurs by vacuum at high temperature occurs. This vapor is transported to the fabric in vacuum. With the help of the cooled drum, the steam condenses and forms a thin layer [36].

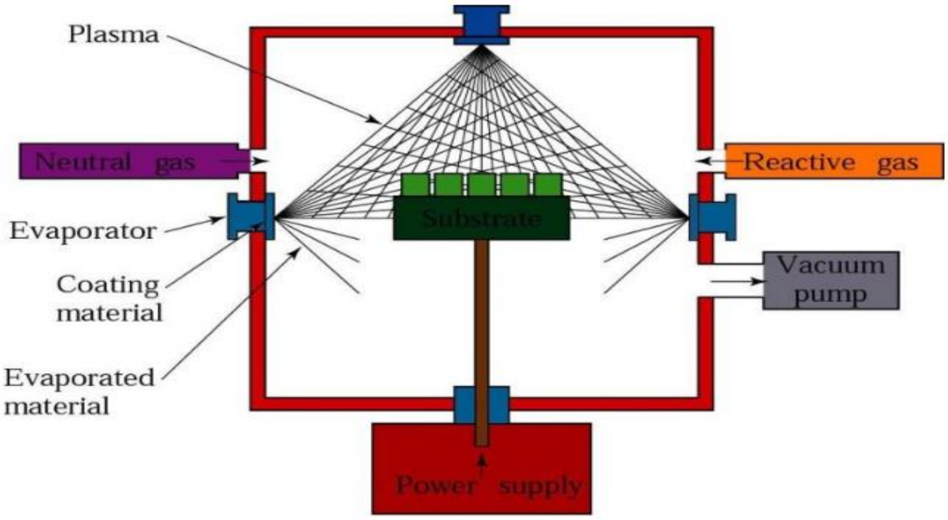


Figure 1.9 Schematic View of Physical Vacuum Method [38]

1.7.4.3 Chemical vapor deposition (CVD)

This method is used for reactant gaseous chemicals reactions occur on heated fabrics. The principle is based on pyrolytic decomposition of gaseous chemicals on the fabric to produce a coating of a solid reaction product.

1.7.4.4 Sputter Coating/Plating

This method contains a vacuum chamber have in it an inert gas, argon. A cathode is placed at to chamber as coating material's source. And there is also an anodeholding the surface to be coated. Potential electric is applied to these electrodes current flow and a glow discharge is occurred because of the motion of electrons. The argon gas is ionized by the electrons and accelerated through the cathode. This accelerated gas displaces atoms from cathode by collisions. These displaced atoms condense on fabric and createsa thin layer [36].

1.7.4.6 Electroless plating

In order to crate a conductive fabrics by electroless plaiting there is no need to supply electrons; the coating process is performed by chemical reaction. The fabric is immersed a bath line. There are some stages to applied before coating process, These pretreatments applications are as follows:

Pre-cleaning is performed in order to obtain required properties of the fabric. Accordingly the performance of this process is increased .

Sensitisation process, ensures the nonconductive materials catalysing before coating. This provide fabrics as a catalyst for the accumulation of coating materials.

Activation process is applied to the substrate to provide coating material deposition. Actually this process is serving the same purpose with sensitisation. Differently in this stage an activator solution is used.

After all these pretreatments the deposition as a main process is performed. The activated substrate is immersed to the coating materials bath and coated at appropriate temperature. At the end post treatment is applied to the final product to achieve the desired properties. [A].

Electroless plaiting is performed not only textile fabrics but also in yarns and even to the garment. And the other advantage that provide uniform coating and superior conductivity [33].

CHAPTER II

LITERATURE REVIEW

In this thesis nine different conductive fabrics had been prepared with 50/1, 60/, 70/1 Ne cotton yarn and 18-micron, 35-micron and 50-micron stainless steel wire. Cotton yarns and metal wires are twisted by hollow spindle method and obtained hybrid yarns. These yarns are knitted by circular knitting machine and conductive fabrics were obtained. The fabrics were dyed in laboratory type dyeing machine. Color strength, abrasion resistance, washing and rubbing fastness, thermal conductivity of the fabrics were measured, and color difference was calculated. Surface electrical resistivity was measured and correlation between conductivity degree and yarn counts and metal wire thinness are analyzed. Metallic yarn density of the fabrics was evaluated, and correlation between physical and mechanical properties and electrical conductivity were analyzed. There is not enough study to shows the effect of the metal wires on the colors of the textile materials in the literature. Similar studies in the literature were investigated to contribute to this thesis (see below)

Onar, N. et al. (2009) studied electrical, structural and electromagnetic properties of textile fabrics coated with Polypyrrole and polyaniline. Chemical oxidative polymerization method was used to coat cotton fabrics. UV Protection, Electromagnetic shielding efficiency, colorfastness of the samples is measured. Uv Protection of both samples coated with Polyprole and polyaniline had been found excellent. Tensile strength of the Poypyrrole coated fabric was increased and polyaniline coated fabric was decreased. Also it is reported that there is no significant difference of the resistance values and electromagnetic properties between the fabrics coated with Polyaniline and Polypryrole [39].

Perumalraj, R et al. (2007) produced some different woven fabrics (plain and twill) from hybrid yarns consist of copper wire core and cotton sheath. They observed that electromagnetic shielding effectiveness increased with an increase of finer yarn count cover factors, warp/ weft density and conductive fabric layers. They also found that shielding efficiency decreased when the metal wire diameter increased [40].

Manasoglu, G. et al. (2019) tried to develop thermal and electrically conductive textile fabrics. They coated woven fabrics with different nano grapheme powders at different concentration ratio. They used knife over roll technique for coating. They analyzed abrasion resistance mass per unit area, bending rigidity, thickness electrical resistivity and thermal conductivity of coated fabrics. By grapheme coating electrical conductivity property is were increased. It is observed that thermal conductivity increased gradually with increasing graphene concentration [41].

Roh, J. S. Et al. (2008) produced hybrid yarns from metal fiber and polyester fiber by hollow spindle method. Metal composite yarns were inserted in determined interval in to the plan weave fabric structures. Various open grid structures were obtained. It was observed that the geometry and grid size effect the electromagnetic shielding effectiveness degree. Fabrics with looser grids showed better EMSE in the medium frequency. Fabrics with closer grid(square shaped) showed the best EMSE in the high and low frequency [42].

Ortlek, H. G et al. (2010) investigated the whiteness and color properties of the fabrics containing metal. Hybrid yarns were produced from the metal wire (20 and 35 micron) by siro, ring and compact core spun yarn. And this yarns were knitted to single jersey fabrics. They noticed that the spinning method did not affect the Tw or K/S values. But the best whiteness properties were observed in the siro spun yarn. This result was thought to be due to the excellent coating ability of the siro yarn [43].

Engin, F. Z., &Usta, I. (2014) has studied on the electromagnetic shielding effectiveness of the polyester woven fabric polymerized by aniline in different concentrated (0.5 M, 0.8 M, 1.2 M). Also, reflection and absorption characteristics and tensile strength of the fabric observed. It was observed that tensile strength of the fabrics had been increased as the monomer concentration increased. 0.5 concentration of treated fabric showed the highest conductivity value. The fabric which is treated with 0.8 M aniline had the best shielding effect.

Afzali, A et al (2010) studied on shielding effectiveness of the cotton fabrics which treated Cu-Ni-P alloy by the electroless plating method. Also, mechanical and physical properties were evaluated after coating. Coated and uncoated material's fabric thickness fabric shrinkage, percentage of elongation, weight change, bending rigidity and color change were measured and compared. The weight and the thickness of the coated fabrics were increased significantly. Generally, the mechanical properties of the coated fabric were better. Shielding effectiveness of the coated fabric met the expectations [45].

Bedeloglu, A. (2013) has examined the physical and comfort properties of the fabrics which were produced from hybrid yarns cotton –acrylic and / stainless steel metallic wire. And also, electromagnetic shielding effectiveness was evaluated. Metallic wire's diameters were 0,035 and 0,050 mm. Hybrid yarns were produced by hollow spindle method and these yarns were woven in plain and twill structure. The results showed that metallic wire increased the pilling resistance and thermal resistance, of the fabric. Plain weaves generally exhibited higher EMSE value compared to twill weaves [46].

Sarkar, K et al. (2017) produced conductive cotton fabric from various type woven fabric (plain, satin and twill) which are coated with macro structure carbon clusters by the knife-over-roll coating technique. The highest EMSE value is succeed by satin coated carbon black.

The maximum reflected portion of the electromagnetic interference shielding is observed when the satin designed fabric is used as base fabric. The EMISE of the coated fabrics is proportionally increased with increases in the areal density, thread density, and thickness. EMSE was increased gradually with increasing thickness of the fabric and thread density [37].

Ozen, M. S et al (2013) studied on shielding effectiveness of the needle punched nonwoven fabrics. Conductive fabrics were produced from stainless steel/polyester fiber at a certain ratio and bonded by needle punching method. And it was found that, as metal content ratio increased EMSE value had increased. The material met the expectations and showed 90% shielding properties at high frequencies, 85% at medium frequencies and 80% at low frequencies [9].

Palanisamy, S. et al. (2018) had researched extensively of 32 types conductive materials and seven nonconductive material's EMSE values and air permeabilities.

Some conductive materials had been chosen as silver, stainless steel copper, carbon, aluminum and polypyrrole are coating materials or used for hybrid yarn. These conductive materials are combined with synthetic textile fiber (pan, polyester, polyamide) in woven, knitted and nonwoven structure. Some main results were found as follows: The composite fabrics which include metal fiber or metal coating showed a very good shielding effect and also, they were air permeable enough. The aluminum foil had also good shielding effectiveness but was not air permeable. Bulky nonwoven structures which were coated by conductive polymers had low shielding effectiveness [47].

CHAPTER III

MATERIALS AND METHODS

3.1 Material

In this project, the production of cotton knitted fabrics containing metal wire was achieved by feeding the bobbins obtained by twisting the metal wire / cotton yarn in the hybrid yarn structure to the knitting machine. There are two sources of variation for hybrid yarn production:

3.1.1 Metal Wire Fineness

316L austenitic grade 0.018, 0.035 and 0.050 mm thin stainless Steel (SS) metal wires were used.

3.1.2 Cotton Yarn Number

The metal wires with each fineness were twisted with a twist of 300 T/m to have the knitting torsion with the Ne 50/1, Ne 60/1 and Ne 70/1 cotton yarns, respectively. Figure 3.1 shows the metal wire / cotton yarn structure used in this project.

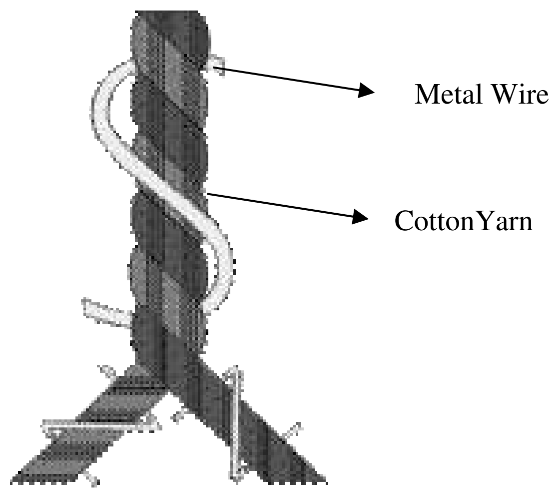


Figure 3.1 Hybrid yarn obtained by twisting metal wire/cotton yarn together

3.2 Method

3.2.1 Yarn Production

In the production of metal-containing hybrid yarns, hollow spindle twisting method was used. The hollow spindle twisting method is shown in Figure 3.2. The structuraldetails of the hybrid yarns used in the study are summarized in Table 3.1. The images of the produced 9 different metal-containing hybrid yarns (obtained by 45 times magnification under the microscope) are shown in Figure 3.2.

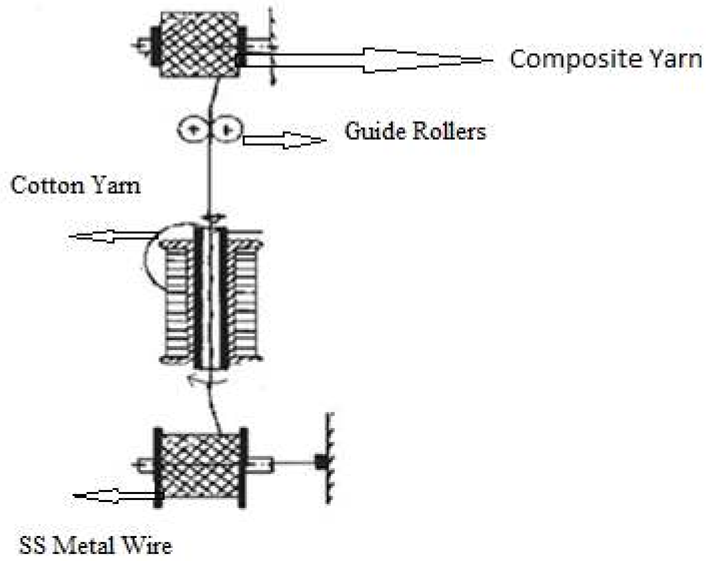


Figure 3.2 The hollow spindle twisting method

Table 3.1 Properties of hybrid yarns used in the study

The Code of Hybrid Yarn	The Count of Hybrid Yarn	The Diameter of Metal (count)	The Cotton Yarn (count)
5000	Ne 50	--------	Ne 50/1
5018	Ne 45.4	18 mic. (Ne 118)	Ne 50/1
5035	Ne 33.1	35 mic. (Ne 77)	Ne 50/1
5050	Ne 23.1	50 mic. (Ne 38)	Ne 50/1
6000	Ne 60	--------	Ne 60/1
6018	Ne 35.5	18 mic. (Ne 118)	Ne 60/1
6035	Ne 29.7	35 mic. (Ne 77)	Ne 60/1
6050	Ne 20.8	50 mic. (Ne 38)	Ne 60/1
7000	Ne 70	--------	Ne 70/1

7018	Ne 47.8	18 mic. (Ne 118)	Ne 70/1
7035	Ne 35.2	35 mic. (Ne 77)	Ne 70/1
7050	Ne 24.9	50 mic. (Ne 38)	Ne 70/1

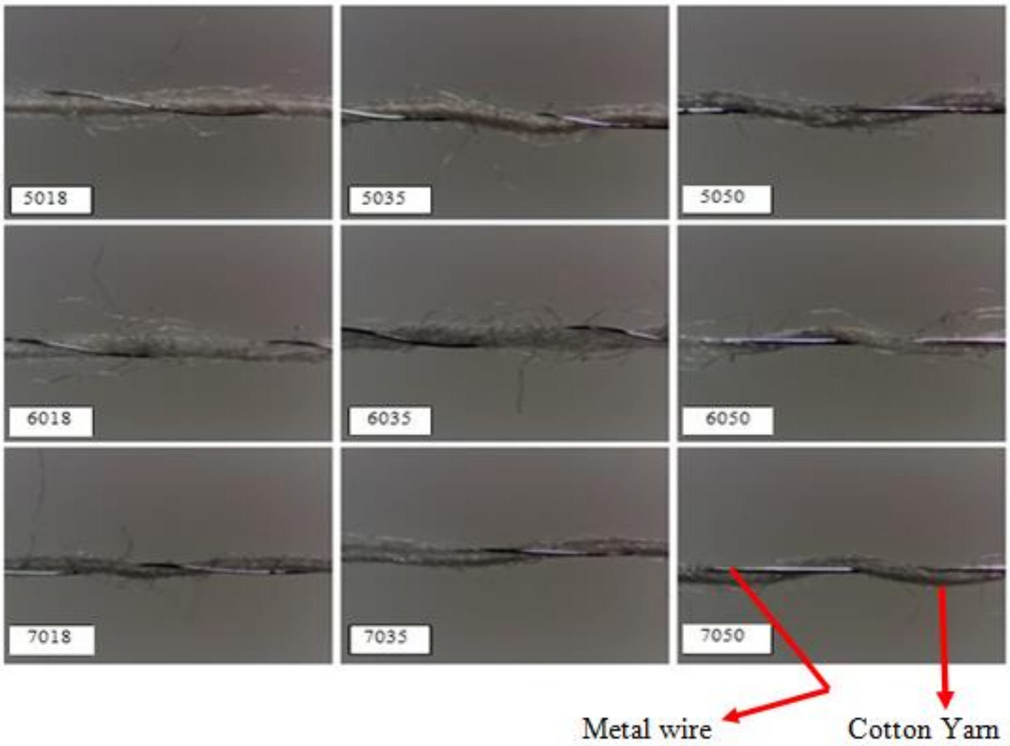


Figure 3.3 The images of the metal-containing hybrid yarns obtained by 45-times magnification

3.2.2 Fabric Production

SDL Atlas circular knitting machine in Gaziantep University Textile Engineering Department was used to bring 100% cotton and cotton-metal wire blended hybrid yarns to knitted fabric structure. (SDL Atlas Quickknit, 3.5 Pus, 22Gauge). There are 241 needles on the machine and 22 needles per inch. Machine diameter is 3.5 inches. The images of the knitted fabrics that produced in this study (obtained by 45 times magnification under the microscope) are shown in Figure 3.4.

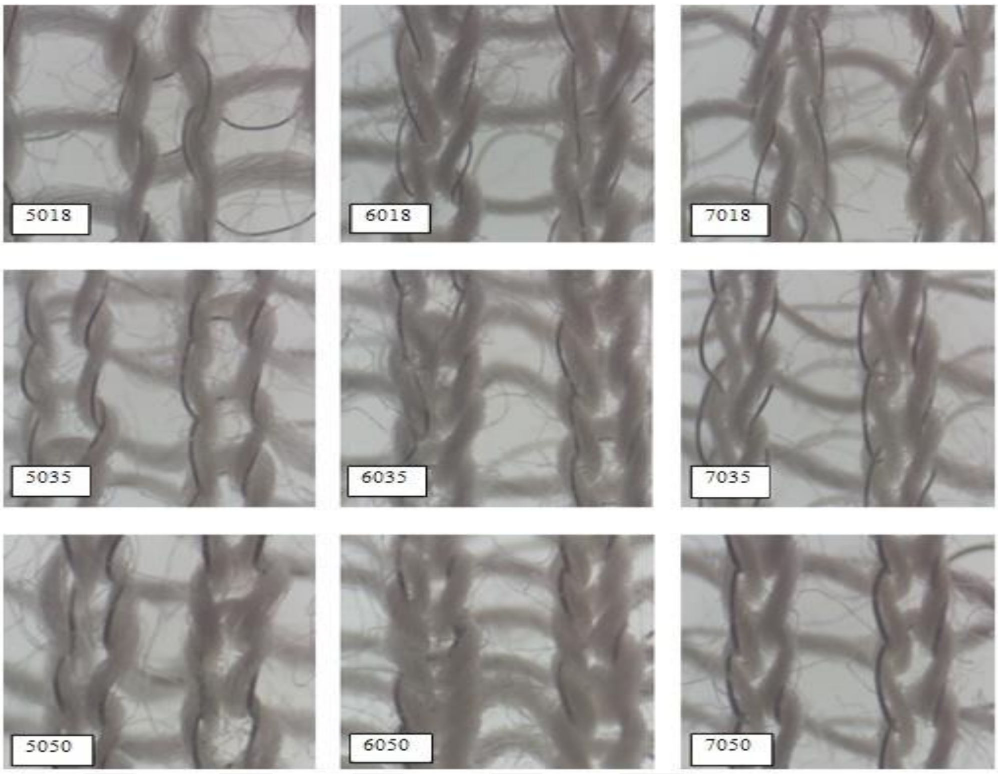


Figure 3.4 The images of the produced fabrics obtained by 45-times magnification

Table 3.2 The structural details of sample fabrics

Fabric Code	**Fabric Thickness (mm)**	**Fabric Weight (gr/m²)**	**Fabric Density (g/cm³)**	**Row / cm**
5000	0.301	67.221	0.224	10 x 25
5018	0.546	106.582	0.195	10 x 25
5035	0.572	113.255	0.197	10 x 25
5050	0.868	221.881	0.255	10 x 25
6000	0.262	59.168	0.225	10 x 25
6018	0.472	77.045	0.163	10 x 25
6035	0.54	109.092	0.202	10 x 25
6050	0.848	190.833	0.225	10 x 25
7000	0.252	56.556	0.224	10 x 25
7018	0.378	80.554	0.213	10 x 25
7035	0.516	110.998	0.215	10 x 25
7050	0.836	177.532	0.212	10 x 25

3.2.3 Fabric Dyeing

Fabric samples were pretreated in laboratory dyeing machines and dyed in blue, red and yellow colors to correspond to three different regions of the color space according to the prescription shown in Table 3.3 and the dyeing diagram shown in Figure 3.5.

Table 3.3 Dyeing recipe

1% Dyestuff
(Blue: Reactive blue C.I. 61211)
(Yellow: Reactive yellow C.I. 18972)
(Red: Reactive red s)
40 g/L Salt
10 g/L Caustic Soda
Liquor Ratio 100:1

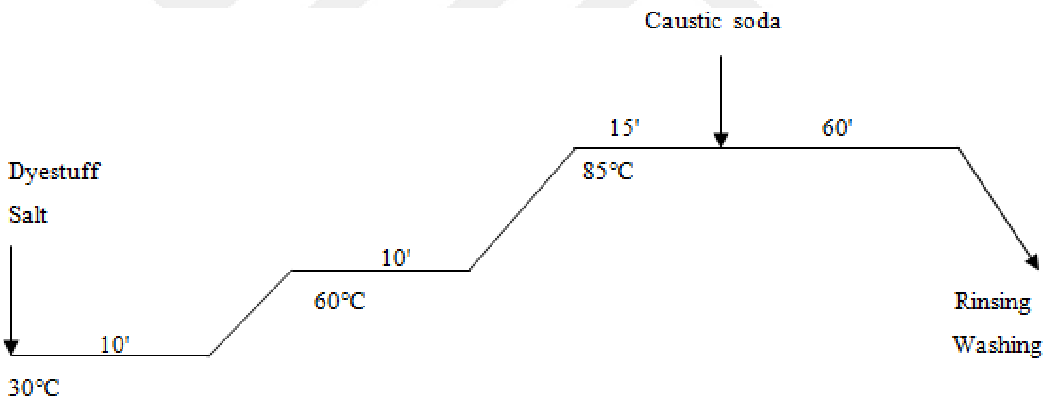


Figure 3.5 Dyeing diagram used in project. Heating speed 1,5 °C / min

3.3 Performed Tests to the Fabrics

3.3.1 Color Measurements

Color and color differences evaluations were carried out under D65/10 illuminant and according to the AATCC 173 standards and D/0 measurement geometry by using reflectance spectrophotometer (Colorquest II) in Gaziantep University Textile Engineering Department. In these measurements, CIELab color differences between fabric samples without metal wire (produced from 5000, 6000 and 7000 coded yarns) and samples containing metal wire were calculated and reported as ΔE. In the calculations, 5000, 6000 and 7000 coded fabrics were defined as reference fabrics and those containing metal wires were defined as test fabrics.

The color and color difference assessment in the CIELab color space according to AATCC 173 is based on the amount of light reflected from the standard illuminator in the visible region (400-700 nm wavelength range). Effects that change the amount of light reflected from the colored surface cause the color difference.

Within the scope of the project, the reflection value (R) at the wavelength where the minimum reflection (maximum absorption) from the sample fabric is measured is taken as reference. From this value (R), the K / S value (Equation 1) which allows evaluating the color strength was found by using the Kubelka-Munk equation. And, from these values, the Relative Color Strength (RCS) values between the control and test fabrics (Equation 2) were calculated:

$$\mathrm{K/S} = \frac{(1-R)^2}{2R} \quad (3.1)$$

$$\text{Relative Color Strength (\%)} = \frac{(K/S)_{sample}}{(K/S)_{control}} \times 100 \quad (3.2)$$

3.3.2 Fastness Tests

Washing and rubbing fastness of fabric samples were measured according to AATCC 8CC2001 and AATCC 61–2001 standards, respectively.

3.3.3 Abrasion Resistance Tests

The abrasion resistance values of the samples were evaluated according to ASTM D 4966 standard by using Nu Martindale device in Gaziantep University Textile Engineering Department.

3.3.4 Surface Resistivity Measurements of the Fabrics

Surface electrical resistivity measurements of fabric samples were made according to ASTM-F-150 standard with CharlesWater 99105 Surface Resistance Meter which was purchased within the scope of this project. In this measurement, the probes of the device are placed on the sample in a linear line with "*s*" distance between them (Figure 3.6). When the electrical potential between probes is V (10 V), the electric current (I) from the fabric is determined and the resistivity value (ρ) is calculated as in Equation 3:

$$\rho = \frac{V \times 2\pi}{I \times \left(\frac{1}{s}\right)} \qquad (3.3)$$

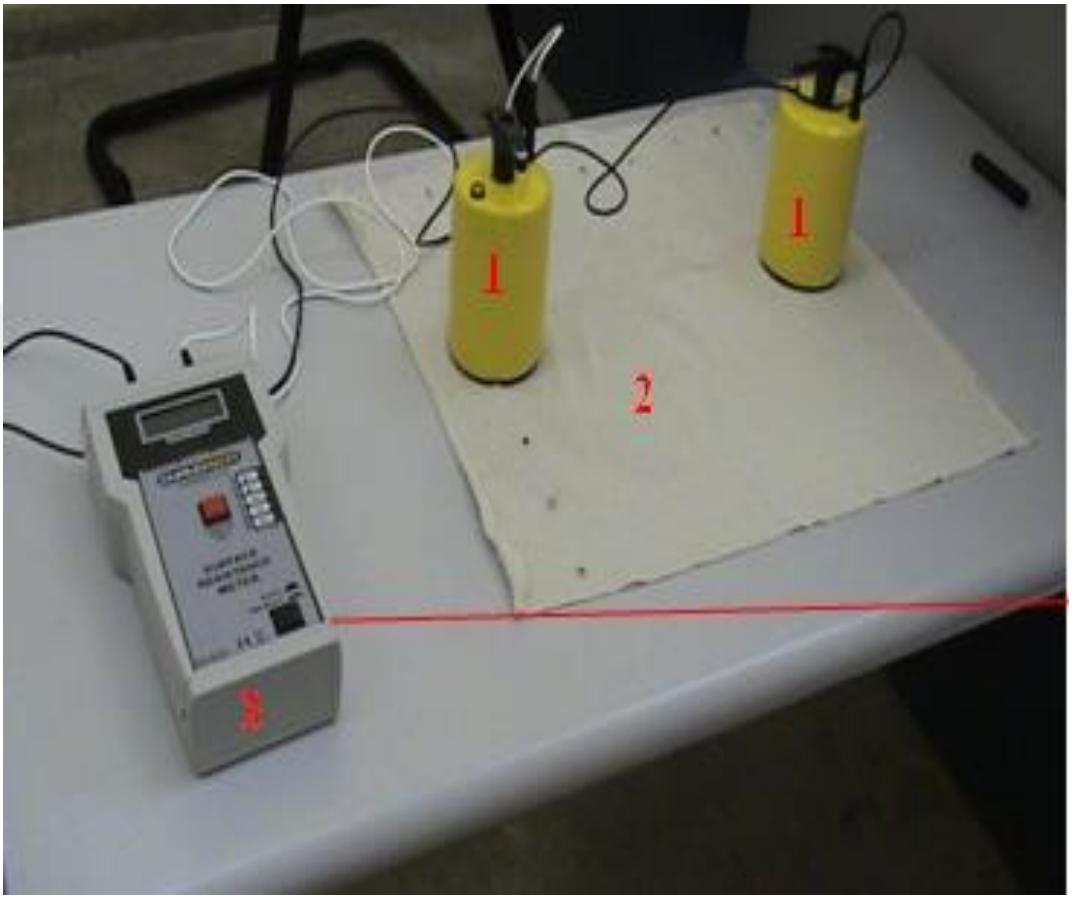


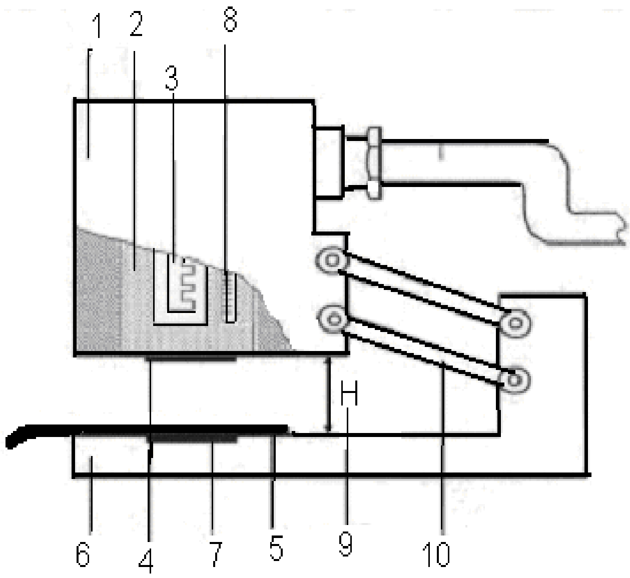
Figure 3.6 CharlesWater 99105 surface resistance meter

The surface resistivity measurement starts by placing the probes (1) on the fabric sample (2). When the potential difference between the probes is set to 10 V, the resistance value (in Ω) is read from the screen of instrument (3) and converted to the resistivity value by Equation 3.

3.3.5 Thermal Conductivity Measurements of the fabrics

Thermal conductivity measurements of sample fabrics were made in the Czech Republic by Alambeta (Sensora/Czech Republic) device based on ISO EN 31092 standard. The simplified scheme of Alambeta is given in Figure 3.7 [24]. The device's measuring head (1) comprises a metal block (2) which is heated to 32 ° C to simulate body temperature by means of electric heater (3). The temperature is controlled by a thermometer (8) connected to the regulator. In the lower part of the heated block there is a heat flow sensor (4).

When the measuring head is in the opening H, the fabric sample (5) is placed on the heat flow sensor and the measuring head is closed. Weight is attached to the movement mechanism (10) such that the measuring head exerts pressure between 100 and 1000 Pa on the fabric. The motion sensor (7) controls that the measuring head is in proper contact with the fabric. After the measuring head is closed, heat flow begins from the metal block to the sample, the sample surface temperature changes suddenly, and the device measures the thermal characteristics by subtracting the heat flow curve during this time.



1. MeasureHead
2. Metal block
3. Elektricheater
4. Heatflowsensor
5. Test fabric
6. The lowest part of mea-seure head
7. Sensor
8. Resistance
9. Ascending distance of head before measure-ment
10. Theascending-mechanismofmeasure-head

Figure 3. 7 The simplified scheme of ALAMBETA device

ANOVA, a two-factor random variance analysis method, was used to evaluate the data obtained from the measurements. There are two factors selected; metal wire fineness and cotton yarn count. The first factor, metal wire fineness has 4 factor levels (0, 18, 35, 50-micron metal wire), the other factor, cotton yarn count has 3 factor levels (Ne 50/1, Ne 60/1, Ne 70/1 cotton yarn count). Analysis of variance was performed by COSTAT statistical program. The Fs (F statistic) value obtained by variance analysis was compared with Ft (F table) which is found for type I error $\alpha = 0.05$. Also, the expected variance (MS) and p-probability values obtained by analysis of variance indicate the severity of the factor level. When Fs> Ft, SNK (Student-Newman-Keuls) test results showed there are differences between factor levels. Factor levels are grouped with letters according to the mean of all values; It was assumed that there was no statistical difference between the factor levels grouped with the same letter.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1. Surface Resistivity Measurement Results of Fabrics

The surface resistivity measurement results of the fabrics produced within the scope of the project are shown in Table 3.1. The results in Ω.cm are the averages of three measurements for each fabric type and the in brackets are% CV values.

Table 4.1 Surface resistivity measurement values (Ω.cm)

Cotton yarn count (Ne) in the fabric	Fineness of metal wire in fabric (Micron)			
	--	18	35	50
50 /1	8,9 x 10^{12} (3,2)	2,6 x 10^{8} (4,5)	6,5 x 10^{6} (3,5)	5,2 x 10^{7} (1,3)
60/1	6,9 x 10^{12} (4,6)	6,1 x 10^{7} (3,2)	4,6 x 10^{5} (4,5)	1,6 x 10^{6} (4,5)
70/1	5,2 x 10^{12} (3,9)	2,9 x 10^{7} (2,1)	2,4 x 10^{5} (2,5)	7,1 x 10^{6} (1,5)

The results in Table 4.1 showed that the resistivity values of cotton fabrics can be reduced between 10^4 and 10^6 (the electrical conductivity can be increased) by the addition of metal wire. The lowest resistivity value (highest electrical conductivity) was measured with knitted fabric coded 7035 (Ne 70/1 yarn and 35-micron metal wire containing hybrid yarn). It has been possible to achieve higher conductivity values as the cotton yarn fineness increased (as yarn count increased). Conductivity values were found to be lower in samples containing 50-micron metal wire fineness than samples having 35-micron metal wire fineness. This can be explained by the fact that 50-micron metal wire leads to a higher increase in fabric thickness (Table 3.2.); because it is known that surface thickness is the source of variation for the resistivity value of the surface

4.2 Color Difference and Color Yield Evaluation of Fabrics After Dyeing

After dyeing, the CIELab color difference values (ΔE) of the fabric containing metal wire produced for this study compared to control samples containing 100%cotton are shown in Table 4.2. The results showed that there was a color difference outside the acceptable limit (ΔE ≥ 1.2) with the addition of metal wire. According to the results, the distinct color difference values were obtained in different color space regions. The results showed that as the thickness of the metal wire increased, the color difference increased as well. It has also shown that higher color difference will be seen with the yellow-red (hot series colors) coloring process on fabrics containing metal wire.

Table 4.2 CIELab color difference values calculated after dyeing of fabrics with a) blue b) red c) yellow dyestuff (ΔE)

Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (a)**		
	18	35	50
50 /1	2,98	5,65	9,43
60/1	4,20	7,20	10,37
70/1	4,56	7,93	11,37

Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (b)**		
	18	35	50
50 /1	8,34	10,03	11,01
60/1	11,15	12,55	12,68
70/1	10,34	13,18	16,98

Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (c)**		
	18	35	50
50 /1	9,89	12,44	13,11
60/1	11,34	14,64	14,93
70/1	13,35	18,16	25,13

The K/S and Relative Color Strength values of dyed fabrics are shown in Table 4.3. The results in Table 4.3 show that the addition of metal wire resulted with the increase in K/S value (color yield) in all three colors and the fabrics are dyed darker in the presence of metal wire. According to these results, the existence of metal wire decreased cotton yarn ratio so this might cause to absorb more dyestuff. Mass percentage of cotton in the sample fabrics was measured and the relationship between mass percentage of cotton and RCS values were analyzed. In the evaluation of the values in Table 4.3 and Table 4.4, in the thicker yarns (Ne 50/1) decreasing ratio of cotton is more effective on RCS. In the sample fabrics which are knitted by 50/1 yarn, RCS values were slightly more than the fabrics knitted from 70/1 and 60/1 yarns.As metal wire thickness increased, Relative Color Strength values of fabrics increased too

Table 4.3 The calculated K/S and Relative Color Strength (%) values after dying the fabric with a) blue color at 620 nm b) red color at 520 nm c) yellow color 440 nm

Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (a)**							
	--		18		35		50	
	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)
50 /1	5,64	100,00	6,32	112,06	7,32	129,78	8,96	158,86
60/1	6,81	100,00	7,62	111,89	8,05	118,20	9,14	134,21
70/1	6,94	100,00	8,00	115,27	8,56	123,34	9,23	132,99
Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (b)**							
	--		18		35		50	
	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)
50 /1	5,11	100,00	6,21	121,53	7,23	141,49	8,89	173,97
60/1	6,79	100,00	7,06	103,98	8,39	123,56	9,92	146,09
70/1	5,52	100,00	7,12	128,99	7,80	141,30	9,62	174,27
Cotton yarn count (Ne)	**Fineness of metal wire in fabric (Micron) Color (c)**							
	--		18		35		50	
	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)	K/S	RCS(%)
50 /1	5,22	100,00	5,98	114,56	7,12	136,40	8,96	171,65

60/1	5,79	100,00	6,64	114,68	7,25	125,22	9,12	157,51
70/1	6,16	100,00	6,31	102,43	7,24	117,53	9,33	151,46

Table 4.4 The Relationship between mass Percentage of Cotton and RCS values of the sample fabric

	MassPercentageCotton	MassPercentage Metal Wire	RCS% (Blue)	RCS% (Red)	RCS% Yellow
5018	70	30	112,06	121,53	114,56
5035	60	40	129,78	141,49	136,4
5050	43	57	158,86	173,97	171,65
6018	66,29	33,71	111,89	103,98	114,68
6035	56,2	43,8	118,2	123,56	125,22
6050	38,77	61,23	134,21	146,09	157,51
7018	62,76	37,24	115,27	128,99	102,43
7035	52,38	47,62	123,34	141,3	117,53
7050	35,18	64,82	132,99	174,27	151,46

Table 4.5 Regression analysis of the Cotton mass percentage effects on the RCS % Values.

	RCS% (Blue)	RCS% (Red)	RCS% Yellow
R^2 50/1	0,999912693	0,999865407	0,999809916
R^2 60/1	0,991367316	0,987427397	0,982569716
R^2 70/1	0,991854512	0,986657577	0,994175572

ANOVA variance analysis was performed to evaluate the effect of metal wire addition on color difference and color strength after dyeing. The Fs (F statistics) values of color difference and color intensity according to ANOVA results are shown in Table 4.4. The Fs value of the color difference in Table 4.4 is greater than the value of the color strength. It showed that, in the dyeing of knitted fabrics, the effect of the addition of metal wire on the color difference was more severe than the color strength.

Table 4.6 Variance analysis table for color and color difference assessment

Source of Variance	Fs
Color Difference (ΔE)	180,401
Relative Color Strength (RCS)	127,463

4.3 The Evaluation of ColorFastness of FabricsAfterDyeing

The washing and rubbing fastness values of the fabrics are given in Table 4.5 - 4.10. The results show that the addition of metal wire does not lead to a significant changein the color fastness of cotton knitted fabrics at the end of all dye, but a point of reduction in rubbing fastness is observed when only 50-micron metal wire is used.

Table 4.7 Washing fastness of fabrics dyed with blue dyestuff (Evaluation of color staining after washing to different multifibre fabrics)

Fabric Code	Color Change	Color Staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
5000	4/5	5	5	5	4/5	5	5
5018	4	5	5	5	4/5	5	5
5035	4	5	5	5	4/5	5	5
5050	4	5	5	5	4/5	5	5
6000	4/5	5	5	5	4/5	5	4/5
6018	4/5	5	5	5	4/5	5	5
6035	4	5	4/5	5	4/5	5	5
6050	4	5	5	5	4/5	5	5
7000	4/5	5	5	5	4/5	5	5
7018	4	4/5	5	5	4/5	5	5
7035	4	5	5	5	4/5	5	5
7050	4	5	5	4/5	4/5	5	5

Table 4.8 Rubbing Fastness of fabrics dyed with blue dyestuff (Evaluation of color flow after rubbing on cotton multifibre fabric)

Fabric Code	Dry	Wet	Fabric Code	Dry	Wet	Fabric Code	Dry	Wet
5000	5	4/5	6000	5	4/5	7000	5	5
5018	5	4/5	6018	5	4/5	7018	4/5	4/5
5035	4/5	4	6035	5	4	7035	4/5	4
5050	4/5	4	6050	4/5	4	7050	4/5	4

Table 4.9 Washing fastness of fabrics dyed with red dyestuff (Evaluation of color flow after washing to different multifibre fabrics)

Fabric Code	Color Change	Color Staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
5000	4/5	5	5	5	4/5	5	5
5018	4/5	5	5	5	4/5	5	5
5035	4	5	5	5	4/5	5	5
5050	4	5	5	5	4/5	4/5	5
6000	5	5	5	5	4/5	5	4/5
6018	4/5	5	5	5	5	5	5
6035	4	4/5	4/5	5	4/5	5	5
6050	4	5	5	5	5	5	5
7000	4/5	5	5	5	4/5	5	5
7018	4/5	4/5	5	5	4/5	5	5
7035	4	5	5	5	5	5	5
7050	4	5	5	4/5	4/5	5	5

Table 4.10 Rubbing Fastness of fabrics dyed with red dyestuff (Evaluation of color flow after rubbing on cotton multifibre fabric)

Fabric Code	Dry	Wet	Fabric Code	Dry	Wet	Fabric Code	Dry	Wet

5000	5	4/5	6000	5	4/5	7000	5	5
5018	4/5	4/5	6018	5	4/5	7018	5	4/5
5035	4/5	4	6035	5	4/5	7035	4/5	4
5050	5	4	6050	4/5	4	7050	4/5	4

Table 4.11 Washing fastness of fabrics dyed with yellow dyestuff (Evaluation of color flow after washing to different multifibre fabrics)

Fabric Code	Color Change	Color Staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
5000	4/5	5	5	5	5	5	5
5018	4	5	5	5	4/5	5	5
5035	4	5	5	4/5	4/5	5	5
5050	4/5	5	5	5	4/5	5	5
6000	4/5	5	5	5	5	4/5	4/5
6018	5	5	5	5	4/5	5	5
6035	4	4/5	4/5	4/5	4/5	5	5
6050	4	5	5	4/5	4/5	5	5
7000	4/5	5	5	5	5	5	5
7018	4	4/5	4/5	5	5	5	5
7035	4	5	5	5	4/5	5	5
7050	4	5	5	4/5	4/5	5	5

Table 4.12 Rubbing fastness of fabrics dyed with yellow dyestuff (Evaluation of color flow after rubbing on cotton multifibre fabric)

Fabric Code	Dry	Wet	Fabric Code	Dry	Wet	Fabric Code	Dry	Wet
5000	5	4/5	6000	4/5	4/5	7000	5	5
5018	5	4/5	6018	5	5	7018	4/5	5
5035	4/5	4	6035	5	4/5	7035	5	4/5
5050	4/5	4	6050	4/5	4	7050	4/5	4

4.4 Evaluation of Abrasion Resistance of Fabrics

The abrasion resistance of the fabrics was evaluated by changing the mass loss in the samples rubbed under 9 kPa weight in Nu Martindale device. At the end of the abrasion cycles, the % reduction in the total mass of the samples indicates the badness of abrasion resistance of the fabric. The greater the % loss in mass, the worse abrasion resistance of the fabric. Table 4.11 shows the results for abrasion resistance assessment of the fabrics produced in this project. The results are the average of four repetitions.

Table 4.13 Abrasion resistance measurement results of fabrics (% mass losses)

Fabric Code	**Abrasion Cycle**			
	2500	**5000**	**7500**	**10000**
5000	3,88	5,23	6,91	9,38
5018	2,18	4,05	6,45	8,90
5035	0,99	2,37	4,86	6,37
5050	0,13	0,73	1,10	2,46
6000	0,03	0,97	4,80	8,68
6018	1,72	2,99	5,07	7,65
6035	1,48	3,17	4,40	7,02
6050	0,81	1,84	3,28	4,19
7000	1,36	2,46	3,78	6,09
7018	3,14	6,99	11,43	16,23
7035	0,82	4,39	9,87	15,57
7050	0,39	1,86	3,54	6,09

The results in Table 4.11 showed that the fabrics containing 50-micron metal wire exhibited higher abrasion resistance, although they were not evenly distributed due to the structural unevenness of the samples containing the metal wire. The results of the variance analysis (values after 5000 cycles) in which the abrasion resistance results were evaluated together (Table 4.12) provide more clear results. According to Table 4.12, the effects of cotton yarn count and metal wire thickness on wear resistance are almost equal (both sources of variance gave close expected variance (MS) values).

So, the effect of intersection of metal wire and cotton yarn is also statistically significant.

Table 4.14 Variance analysis of abrasion resistance of fabrics

Factors	MS	Fs	p
Type of Metal	9.071	26.245	0.0000 ***
Type of Cotton	9.412	27.233	0.0000 ***
The effect of metal x cotton intersects	8.739	25.286	0.0000 ***

The results of SNK test to see the effect of factor levels of metal wire and cotton yarn on the abrasion resistance of fabrics are shown in Table 4.13. The average mass loss results of the SNK test showed that the addition of 50-micron metal wire caused the lowest mass loss of all fabric types. It also showed that the fabrics which were knitted from the finest cotton yarn (Ne 70/1) gave the lowest abrasion resistance (highest mass loss) value. In the case of metal wire thickness, the effect was caused by 18-micron thick metal wire

Table 4.15 SNK analysis showing the effect of metal and cotton yarn counts on the abrasion resistance of fabrics

Factors	Factor Level	Avr. Mass Loss (%)	ns range
Type of Metal Wire	18 micron	4.054	a
	35 micron	3.065	b
	0 micron	2.617	b
	50 micron	1.637	c
Type of Cotton Yarn	Ne 70/1	3.861	a
	Ne 50/1	2.423	b
	Ne 60/1	2.246	b

4.5 The Evaluation of Thermal Conductivity Results of Fabrics

Thermal conductivity results of the knitted fabrics produced in the study (average of four measurements) are given in the graph in Figure 4.1

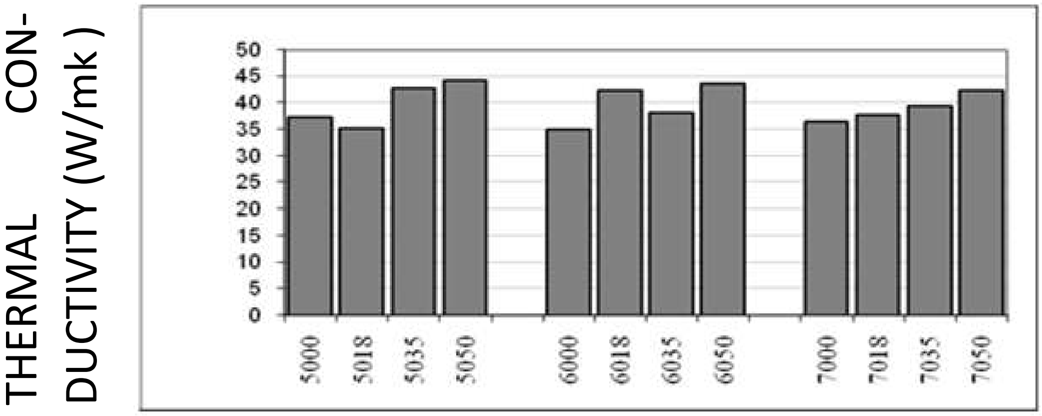


Figure 4.1 Thermal Conductivity Results

The results in Figure 4.1 show that as the thickness of the metal wire used increases the thermal conductivity values of all fabric types increases as well. It shows that samples using 50-micronSS wire give the highest thermal conductivity values. It is known that the thermal conductivity of stainless steel wires increases as the ambient temperature increases and has a higher thermal conductivity value than textile fibers at room temperature. The addition of metal wire led to an increase in the thermal conductivity values of the samples, even though it caused a lower density of fabric. The analysis of variance in which thermal conductivity results are evaluated is given in Table 4.14. In this table, the expected variance value (MS) of the metal wire fineness, taken as the source of variance, is higher than the variance value (MS) of the number of cotton yarns. This shows that the effect of the metal wire on the thermal conductivity value of the fabrics is stronger than the effect caused by the change in the cotton yarn count. The results for the metal wire type are statistically significant; the effect of intersection of metal wire and cotton yarn is also statistically significant. This result can be interpreted as follows: For fabrics containing metal wires, if the classification is to be made according to the thermal conductivity value, then fabrics containing 18, 35 or 50 microns SS should be classified in different grades. The comfort perceptions of these fabrics through thermal conductivity will be different from each other.

Table 4.16 Variance analysis of thermal conductivity values of fabrics

	MS	Fs	p
Type of Metal	84.005	49.724	0,000 ***
Type of Cotton Yarn	2,788	1.650	0,213 ns
The Effect of MetalxCotton Intersect	19,714	11.669	0,000 ***

The results of SNK test to see the effect of factor levels of metal wire and cotton yarn on thermal conductivity of fabrics are shown in Table 3.15. The average thermal conductivity results of the SNK test showed that the use of thicker metal wire (when the proportion of metal in the yarn increased) increased the thermal conductivity of the knitted fabric. In SNK test carried out for cotton yarn used in different numbers, it is seen that higher thermal conductivity values are obtained when thicker cotton yarn is used, although there is no statistical difference between them.

Table 4.17 SNK analysis showing the effect of metal and cotton yarn counts on thermal conductivity of fabrics

Factors	Factor Level	Thermal Conductivity (W/mK)	ns range
Type of Metal Wire	50 micron	43.533	a
	35 micron	40.199	b
	18 micron	38.467	c
	0 micron	36.300	d
Type of Cotton Yarn	Ne 50	39.975	a
	Ne 60	39.824	a
	Ne 70	39.075	a

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

In this study, surface resistivity (correlated with conductivity) and some physical properties of the conductive knitted fabrics produced from hybrid yarns are investigated. Hybrid yarns were produced from stainless steel wire (18-micron, 35-micron, 50-micron) as a conductive material and cotton yarn (50/1 Ne, 60/1 Ne, 70/1 Ne) as textile material. These fabrics are dyed three main colors (red, blue and yellow). Beside resistivity, color differences, color strength, abrasion resistance, washing and rubbing fastness, thermal conductivity of the fabrics were evaluated as well to determine the optimum value that meet shielding level, comfort and physical properties together.

It was found that the resistivity of the textile fabric was decreased between 10^4 and 10^6 which means the conductivity of the materials can be increased by adding metal content. The lowest resistivity and the highest conductivity were measured in 7035 fabric. The reason of this can be the fact that 50-micron metal wire leads to a higher increase in fabric thickness. Because it is known that surface thickness is the source of variation for the surface resistivity value.

Color differences of fabrics including the metal wire are founded out of tolerance ($\Delta E \geq 1.2$). The results showed that as the thickness of the metal wire increased, the color difference increased as well, also the highest differences are noticed on the hot colors (red and yellow). As metal wire thickness increase relative color strength increases too. As metal wire diameter increases all the fabrics get darker. This result showed that, when the metal wire proportion in the fabric increases the dye absorption of the cotton increases too. As the conclusion of ANOVA variance analysis, it was determined that in the dyeing of knitted fabrics, the effect of the addition of metal wire on color difference was more severe than the effect of color strength.No significant change arising out of metal wire addition was found in the washing and rubbing fastness results. Abrasion resistance increases as metal wire diameter increases. Also, the increase in cotton thickness has the similar effect on the abrasion resistance value.

The results in Figure 3.7 showed that as the thickness of the metal wire increases the thermal conductivity values of all fabric types increases as well. It showed that samples having50-micron SS wire gives the highest thermal conductivity values. It is known that the thermal conductivity of stainless steel wires increases as the ambient temperature increases and stainless steel has a higher thermal conductivity value than textile fibers at room temperature. The addition of metal wire led to an increase in the thermal conductivity of the samples, although it caused a lower fabric density.

According to SNK test, the effect of the metal wire on the thermal conductivity value of the fabrics is stronger than the effect caused by the change in the cotton yarn count. It was found that thermal conductivity increases as metal wire diameter increases. Also, as cotton thickness increases, the thermal conductivity increases too. However, the effect of this is not as strong as the effect of metal wires.

Producing electromagnetic shielding textile is a very complicated issue. Because there are lots of factors that affect the shielding efficiency and comfort properties. When shielding properties of textile fabric increases the comfort properties tend to decrease. Furthermore, we have to think about the effects of the electromagnetic field frequency on shielding effectiveness. This study provides insight about some comfort and physical properties of electromagnetic shielding textile. Based on this study, more physical tests should be performed in different media to improve superior electromagnetic shielding material.

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