UNIVERSITAT POLITÈCNICA DE VALÈNCIA

CAMPUS D'ALCOI

"THE STUDY OF THE ALTERATION OF TEXTILE PROPERTIES AFTER INSERTION OF CONDUCTIVE YARNS"

MEMORIA PRESENTADA POR:

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PROJECT'S SUMMARY

ENGLISH

The main objective of the project is to study the alteration in physical and conductive properties that knitted and woven fabrics undergo once conductive monofilament/multifilament threads have been inserted by means of embroidering.

To achive this, different textile substrates with different structures (knitted and woven structures) and weights, conductive yarns with different characteristics will be studied. All the samples obtained will be characterized in order to define the alteration of properties such as bending rigidity, surface roughness and tensile strength.

PALABRAS CLAVE: conductive textiles, properties, conductivity, knitted, woven, embroidery, yarns.

RESUMEN DEL PROYECTO

SPANISH

El objetivo principal del proyecto es estudiar la variación de propiedades físicas y conductoras que sufren tejidos de punto y calada una vez han sido insertados hilos de monofilamento/multifilamento conductivos mediante bordado.

Para ello se estudiarán distintos sustratos textiles de diversas estructuras (estructuras de punto y calada) y gramaje, hilos conductores de distintas características. Todas las muestras obtenidas serán caracterizadas con tal de definir la modificación de propiedades tales como rigidez a la flexión, rugosidad superficial y resistencia a la tracción.

PALABRAS CLAVE: textiles conductores, propiedades, conductividad, punto, calada, bordado, hilos.

RESUM DEL PROJECTE

VALENCIÀ

El objectiu principal del projecte és estudiar la variació de les propietats físiques i conductores que pateixen els teixits de punt i calada una vegada han segut insertats fils de monofilament/multifilament conductor mitjançant brodat.

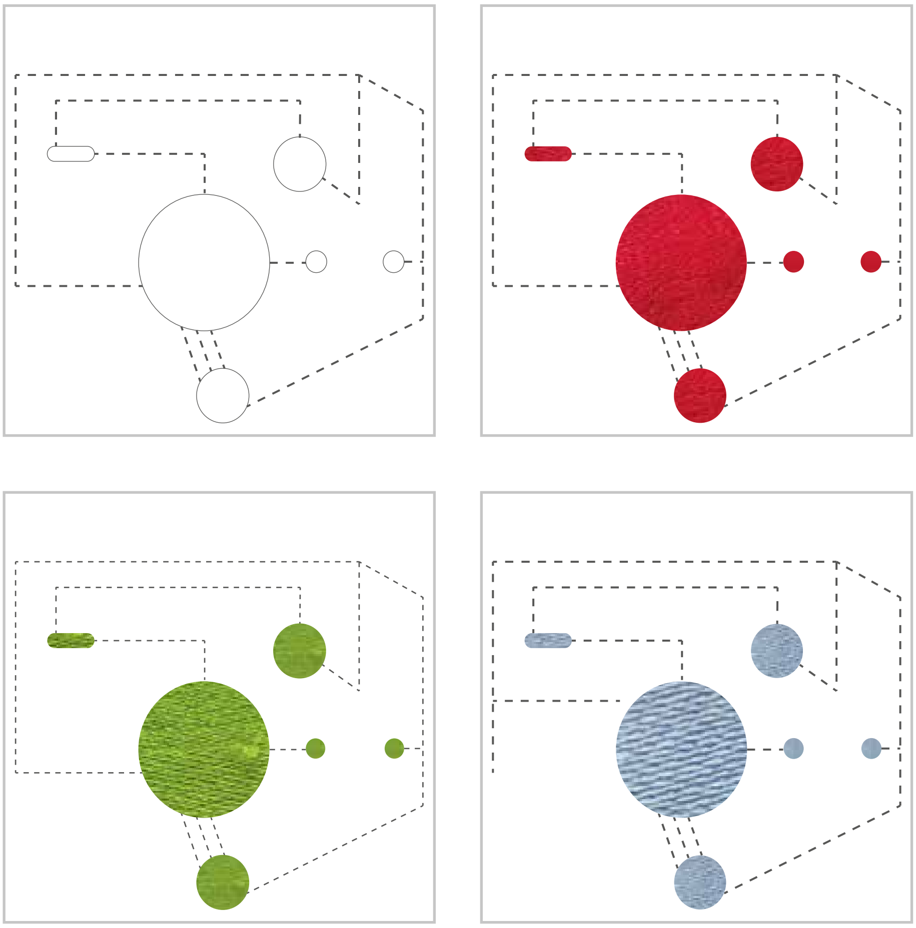
S'estudiaran diversos sustrats textils de diverses estructures (estructures de punt i calada) i el gramatge, fils conductors de distintes característiques. Totes les mostres obtingudes seran caracteritzades per tal de definir la modificació de les propietats com son la rigidessa a la flexió, rugositat superficial i resistència a la tracció.

PARAULES CLAU: tèxtils conductors, propietats, conductivitat, punt, calada, brodat, fils.

THE STUDY OF THE ALTERATION OF TEXTILE PROPERTIES AFTER THE INSERTION OF CONDUCTIVE YARNS

MÁSTER UNIVERSITARIO EN INGENIERÍA TEXTIL

REYES NAVAS FLORIT



MAYO, 2020

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CERTIFICATE OF FINAL PROJECT

Pr. DR.. (signatory) ___Dominique C. ADOLPHE___ from (host institution) _University of Haute-Alsace_______

HEREBY CERTIFIED THAT

Ms. (Student name) Reyes NAVAS FLORIT______________________________

from Universitat Politècnica de València. Campus d'Alcoi has developed a Final Project (300 hours) ______"The study of the alteration of textile properties after the insertion of conductive yarns"______(project tittle) at our organization from __24/09/2019_ to __12/02/2020_ .

The general evaluation of the projects has been _____very good_____ (in case of assessment).

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1. INTRODUCTION | THE PROJECT

The field of study to which this project belongs is intelligent textiles. First of all, it must know what it means when it talks about smart textiles. As indicated by the author Melissa Knothe Tate in her study "*Smart composite textiles and methods of forming*" [1] an intiligent material can be defined as one that includes a textile component and a material arranged by an additive manufacturing technique on the textile substrate based on an additive manufacturing pattern. This composite fabric must exhibit a variation in at least one of its mechanical, material or structural properties and/or show a change in at least one mechanical, material or structural property in response to at least one external stimulus.

The field of application of these intelligent textiles is very wide. This project focuses on the interconnection of sensors capable of monitoring people's vital signs. In this regard there is a dramatic growth in medical devices that use wireless technologies, some implanted and others used in the body, to monitor body functions and measure a range of physiological parameters. Some examples can be found in the book "*Smart textiles and their* applications" [2] such as devices implanted with biosensors and actuators can control heart rhythms, control hypertension. . .

According to the book *"Smart textiles and their applications"* [2] these sensors can be classified into two types:

- ✓ Actives
- ✓ Pasives

Active sensors are those that require an external power source to convert the input into a usable output signal, while passive sensors are those that intrinsically provide their own energy or derive energy from the measured phenomenon at an electrical potential or useful current.

The authors Lina M Castano and Alison Flatau, in their study *"Smart fabric sensors and e-textile technologies"* [3] define fabrics that acquire sensory properties as smart fabric sensors (SFSs). These fabrics provide some functionality to measure or influence your application environment. They are also classified into three categories:

- ✓ SENSORS: Fabrics that acquire sensory properties of different physical nature, such as capacitive, resistive, optical and solar.

- ✓ ACTUATORS: Fabrics that are capable of acting on some aspect of their environment. Examples of this type of tissue are electroactive tissues and auxiliary tissues.

- ✓ BATTERIES AND POWER COLLECTION: Based on fabrics that use the kinetic energy or thermal energy of the carrier or its environment to generate electrical energy

Regarding the way to insert conductive lines in e-textiles, the following techniques have been established [3] by collecting information from several studies: manually attaching conventional wires or sewing conductive thread [4], replacing non-conductive fibers with conductive ones [5] machine embroidering of conductive thread [6], and printing rigid [7] and stretchable [8] conduction lines (i.e. inks, polymers) using macroelectronics [9] and microelectronics techniques [9]. Connections to data acquisition systems are achieved by either mechanical [10] or electrical attachment mechanisms [11].

The techniques set out in the previous section are explained in summary form below:

Manually attaching conventional wires or sewing conductive thread: this is the conventional manual sewing method. No special equipment is required. Note that the ends of these yarns can easily fray [12].

Image 1 – Conventional conductive yarn sewing. [12]

Replacing non-conductive fibers with conductive ones: conductive fibres can be obtained by various methods [13] such as depositing carbon or metallic coatings, incorporating hydrophilic comonomers and manufacturing stainless steel fibres.

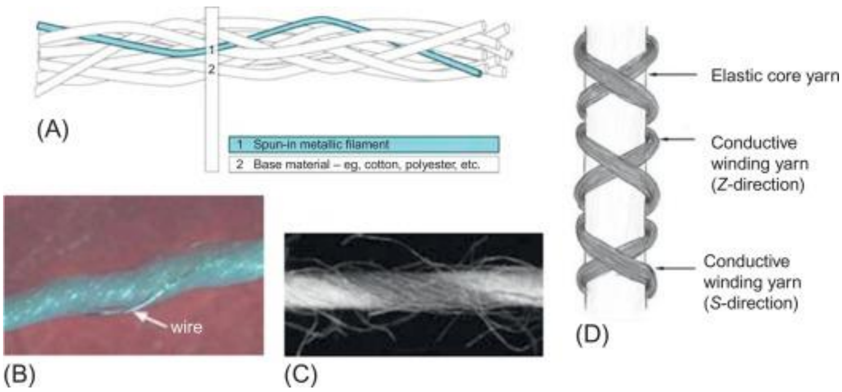


Image 2 – Non conductive fibers with conductive ones [13]

Machine embroidering of conductive thread: these are embroidery machines that allow embroidery with this type of conductive threads. It is important to choose the type of machine and the type of conductive thread to be used since not all machines or all conductive threads allow this type of embroidery.

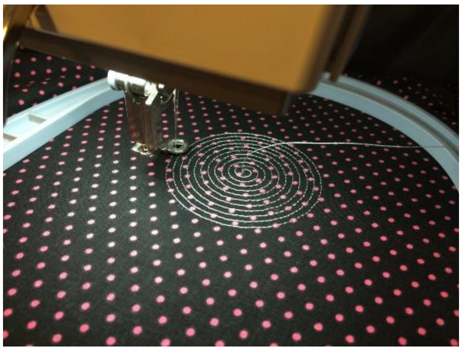


Image 3 – Machine embroidering of conductive yarn

Printing rigid: these are screen printing processes using conductive ink with the aim of creating complex electronic circuits in textile garments [7].

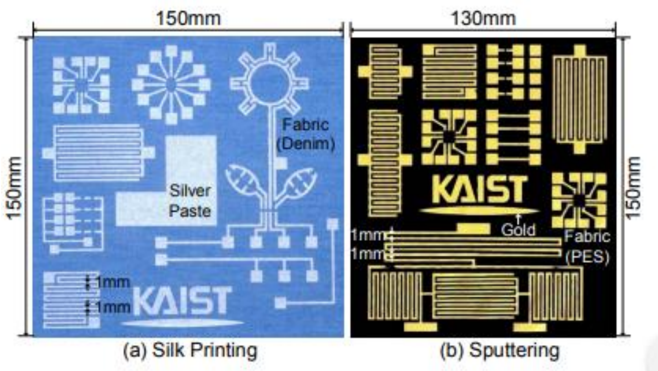


Image 4 – Fabric circuit board [7]

Conduction lines (i.e. inks, polymers) using macroelectronics [9] and microelectronics techniques [9]: microelectronics is based on the study and manufacture of very small electronic designs and components. As the name suggests, inks are used to create these conductive lines using microelectronic and macroelectronic creation methods.

Similarly, with the help of information from other studies some examples of the connection techniques of the FSSs [3] are: soldering and wire bonding [13], conductive epoxy [14], machine-printed line [15], conductive polymer [16], lamination [17]. . .

Textile circuits are defined [3] as methods and techniques used to obtain circuits on fabric substrates or to obtain circuit boards on fabric. There are many options for the manufacture of textile circuits.

In this project, the fabric circuit manufacturing technique chosen is embroidery circuits (conductive yarn sewn into fabric).

It has a thread sewn into the fabric. Its main advantages [4] are that it has a lot of flexibility, but its main disadvantage [4] is that it needs to be elaborated.

The authors Wilson S and Ling R, in their report “Fabrics and garments as sensors: a research update" [18] describe how research on sensors in fabrics designed to interact with the human body has not taken into account how it should be, properties of the structure and of the garments such as elasticity or rigidity to flexion with those related to performance such as cleaning, storage. . .

These authors [18] emphasize the importance of these factors to be taken into account for these intelligent fabrics to be used effectively. Structural stability facilitates the functionality of the tissues and influences their use. It is necessary to convert the conventional properties of clothing and garment fabrics.

The object of this project is study the integration of a actives sensor network into the fabric and interconected with conductive yarns. **The main idea is to know how this integration of sensors and the insertion of conductive yarns could be affect to the fabric’s properties.**

So, the tecnological progress in the fabric’s field is evident. For that, by means of this studies it pretens know if it could be possible the creation of a new network sensor design that presents a combination of flexibility, ergonomy, integration and autonomy.

2. OBJECTIVE | THE PROJECT

The project aims to study the influence, and consequently the possible modification of the mechanical properties produced by different conductive yarns on various textile structures.

To accomplish this a mechanism has been developed to embroider through flexible electronic modules using conductive yarn, thus creating an interconnection with other modules like sensors, batteries, textile keyboards,

As many technologies (micro technologies, telecommunication, low-power design, new textiles, and flexible sensors) are now available, new user-friendly devices can be developed to enhance the comfort and security of the client.

The project will cover the following aspects:

- On the one hand the creation of a design to create a simulation of sensor interconnection thus creating a prototype of how a circuit could be embroidered on a textile structure.

- On the other hand, the study of the possible variations of the mechanical properties of the studied textile structures.

The following steps have been followed in order to achieve the project's objective:

- ✓ Different textile structures have been chosen to carry out the study. Two woven structures and two knnited structures. With different compositions and different ligaments.

- ✓ Three conductive yarns were chosen to be inserted in the prototypes. Two of them will be multifilament stainless steel yarns and the third is a monofilament with conductive covered. All three with different conductive capacity.

- ✓ Design a possible sensor network prototype embroidered into textil estructures and interconnected by conductive yarns.

- ✓ Study of the mechanical properties of fabrics without thread insertion using Kawabata Evaluation System.

- ✓ Creation of the prototypes with embroidered textile sensors by means of an embroidery machine and the interconnection of them with the chosen conductive threads and inserting them into the fabric with the help of a straight sewing machine.

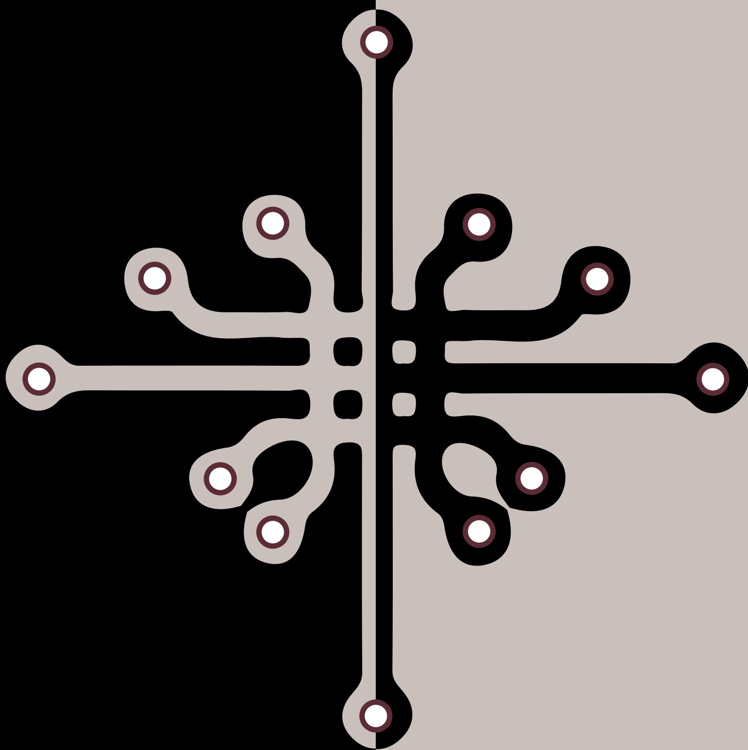
- ✓ Study of the mechanical properties of fabrics with insertion of conductive threads using the Kawabata Evaluation System.

- ✓ Finally study the results with a statiscal program called “R Commander” to get conclusions about all the project.

3. BULLETIN TECHNOLOGY WATCH | SMART TEXTILES

TEXTILE
SECTOR

CONDUCTIVE YARNS AND THEIR APPLICATIONS



BULLETIN
TECHNOLOGY WATCH

SMART
TEXTILES

REYES NAVAS FLORIT

DATE RANGE 2000-2020

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INTRODUCTION

This bulletin technology whatch will present a research of information gathered over the past twenty years on intelligent textiles, more specifically conductive yarns.

Due to the enormous dimensions of the field of search, it has been decided to focus the aforementioned on conductive yarns, fabrics and garments, procurement processes and applications.

The bulletin contaisn scientific articles related to the topic as well as patents and graphs where you can observe the trend presented by the study of intelligent fabrics (conductive yarns) regarding the last twenty years.

SEARCH METHODS

"SMART TEXTILES: CONDUCTIVE YARNS AND THEIR APPLICATIONS"

KEY WORDS: *Smart, E-textile, Conductive, Electricity, Textile, Application, Yarn, Modify, Sensors, Devices, Material, Mechanism, Circuite, Embroidery, Clothing, Properties, Processes, Woven, Knitted, Wereable, Technical.*

OPERATORS BOOLEANOS: *[conductive and yarn] [smart and conductive and garment] [smart and garment] [conductive and yarn and garment] [devices and garment] [smart and conductive and fabric] [conductive and fabric] [method and conductive and garment] [method and conductive and yarn] [method and conductive and fabric] [embroidery and conductive and yarn] [sewing and conductive and yarn] [conductive and yarn and application] [function and conductive and textile] [function and conductive and yarn] [function and conductive and fabric] [impact and smart and textile] [enviroment and conductive and yarn].*

RESEARCH SOURCES: *Thesaurus, Google Scholar, EUIPO, LENS, PatentScope, TextileWorld, TechnicalTextile, CORDIS, Espacenet.*

E-Textiles For Wearability: Review Of Integration Technologies

The field of study of smart textiles is becoming larger and more interesting. The idea of smart textiles in the past was a futuristic and hard to get products. Currently these types of textile products are presented in the market with a high added value, far from the conventional and providing value and functionality to the customer in order to meet their needs

One of the main applications of these smart textiles is smart clothing. To achieve a union of technology and garment whose main characteristic is functionality and comfort.

The most feasible way to achieve this type of garment is the interconnection of sensors through transmission lines [19]. These lines consist of wires integrated into the fabric itself forming "a textile transmission line"; capable of successfully interconnecting devices. The most common integration methods are: woven, knitted, sewn, e-broidery and printed structures.

Conductive Yarns And Their Use in Technical Textiles

Fibers and threads have been of great interest in the last decade with respect to smart textiles. The most common methods for obtaining wires can be summarized in [20]: adding carbon or metals in different forms sucha wires, particles or fibres. Using inherently conductive polymers. And coating with conductive substances.

The main applications of conductive textiles can be: intelligent clothing, transport of electrical signals, heating and protection against electromagnetic interference and electrostatic discharges.

Smart Textiles Offer Development Opportunities In Medical, Health Application

As mentioned above, the field of application of Smart textiles is quite broad. In this case, the focus is on medical and health applications. The market for sensors is developing very rapidly and many companies are emerging to support the development of these e-textiles.

One example is San Francisco-based health technology company Siren, which introduced Neurofabric TM [21], a sock and foot monitoring system for diabetics that features microsensors integrated directly into the fabric.

Another example is the development of printed graphite sensors by Bonbouton [21], a manufacturer of low-cost graphite temperature sensors, so that they can be used for leather temperature control.

Finally, Emglare [21], based in San Francisco, presented smart clothing designed with sensors to monitor heart beats, as well as the electrical activity of the heart through electrocardiography (ECG).

Bally Ribbon Mills Announces E-WEBBINGS® E-textile Product Base For Electronic Intercommunicative Technology

Another proposal, for example, is that of Bally Ribbon Mills (BRM) [22], a designer in the sector, which presents its E-WEBBINGS® electronic textiles. This is a wide variety of woven fabrics obtained using different types of fibres and conductive elements capable of adapting electronic and digital components in their structure.

Investigation Into Electromagnetic Shielding Efficiency Of Conductive Knitted Fabrics

This application is very interesting. Nowadays, the constant use of electronic devices (telephones, tablets, computers. . .) is indisputable. Because of this, it is increasingly important to develop technologies capable of shielding the electromagnetic waves that these devices emit.

Dr. Bahadur Goonesh Kumar, Dr. S Rosunee and Dr. M Bradshaw propose in their study [23] a combination of wires in textile structures to serve as protective equipment against these electromagnetic waves.

Prospective Impacts Of Electronic Textiles on Recycling and Disposal

Nowadays, one of the fields that is most under investigation is the recycling of textiles (recycling of textile fibres, processes for obtaining recycled fibres...)

Like many high-tech products, electronic textiles may evolve to become a mass market in the future, with large quantities of difficult-to-recycle product being discarded. This therefore means a great loss of waste.

The authors Andreas R. Kohler, Lorenz M. Hilty, and Conny Bakker investigate the possible end-of-life implications of this textile-integrated e-waste [24].

They carry out a study creating three possible scenarios. Each one with a textile electronic product (firefighter suit, ECG shirt, Outdoor jacket) and a different market sector (niche, sectoral, mass). They also estimate an approximate number of users, units per user, the lifetime of each product and the characterization of each product (weight and the weight of the components that are integrated).

They conclude, following the study, that these products may cause problems in the future because: these products will be used en masse and may give rise to large waste streams. It will be difficult to collect and recycle old electronic textiles through temporary recycling schemes.

This product recycling factor must be taken into account. These electronic textiles contain some substances that can be dangerous to the environment and health level in the recycling and disposal processes.

Trend presented by the study of conductive yarns and conductive fabrics in the textile sector due to to the number of publications in the last 20 years [25]. It can be seen that there is a quite considerable increase in studies published between approximately 2017-2019. It can see too how the trend line increases as the years go by. At present, as the year has not yet been completed, the number of published works is still low.

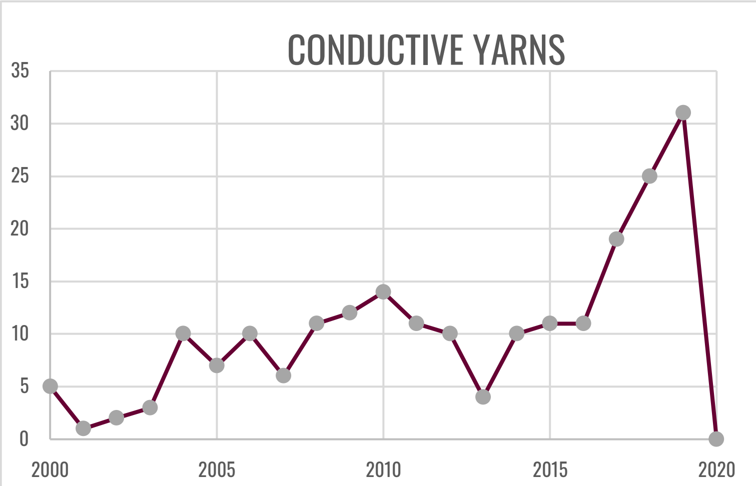


Image 5 – Conductive yarns trend 200-2020

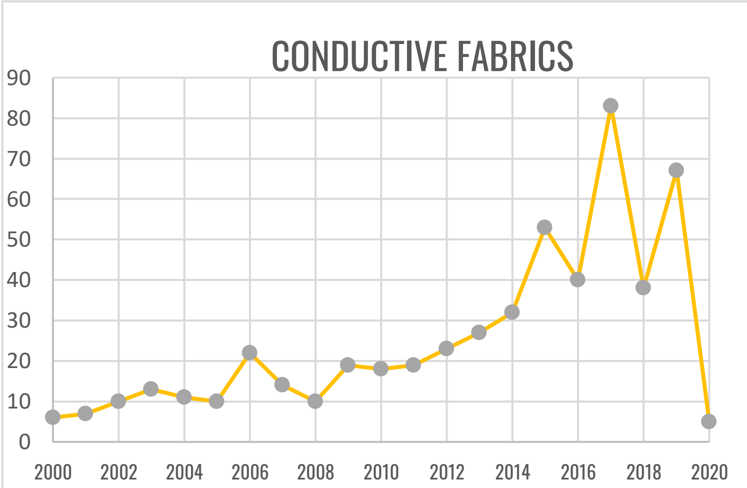


Image 6 – Conductive fabric trend 200-2020

These graphics represent the percentage of publications of studies in the last twenty years concerning the conductivity property in garment and methods of obtaining conductive fabrics and conductive yarns [25]. It can be seen that there is a large number of works published in recent years on conductive threads in fabrics (52%) and in processes for obtaining conductive fabrics (74%). Research into intelligent conductive garments and its procurement processes has not been so important as the others in the last twenty years.

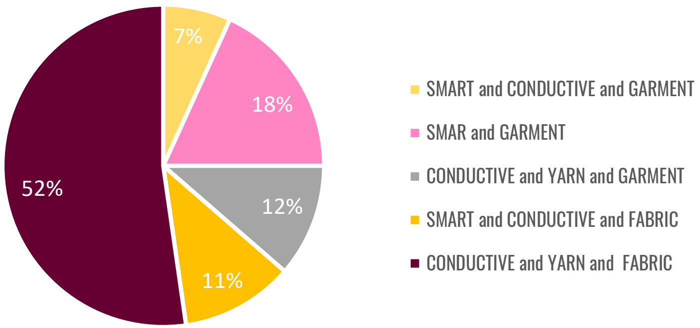


Image 7 – Publication percent about smart fabrics and garment in the last twenty years

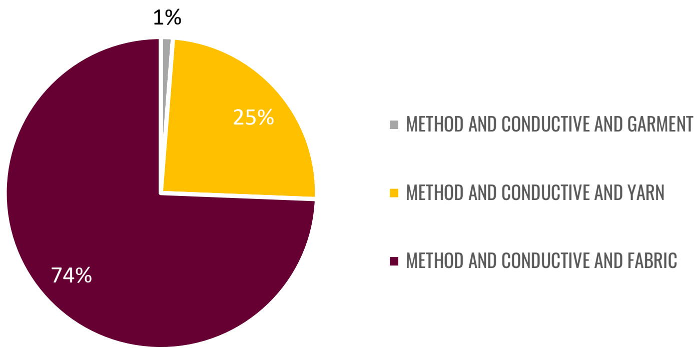


Image 8 – Publication percent about method to get conductive garment, fabric and yarnsin the last twenty years

PUBLICATION NUMBER US2007/0059524
APPLICANT KUNFER TEXTILWERKE GMBH [DE]
COUNTRY GERMANY

TITLE: ELECTRICALLY CONDUCTIVE, ELASTICALLY STRETCHABLE HYBRID YARN, METHOD FOR MANUFACTURE THEREOF AND TEXTILE PRODUCT WITH A HYBRYD YARN OF THIS KINF

SUMMARY:
The present invention concerns the creation of an elastic hybrid thread. Its core consists of an elastic filament surrounded by a shell of electrically conductive fibres.

Thus creating an improvement in its technical properties and obtained by a simple manufacturing process.

PUBLICATION NUMBER CN108611719
APPLICANT XINXIANG BEIFANG FIBER CO LTD
COUNTRY CHINA

TITLE: PERMANENT FLAME - RETARDANT CONDUCTIVE YARN

SUMMARY:
The invention presents a flame-retardant yarn. This flame retardant yarn is composed of a mixture of aramid and stainless steel fibres. This wire is easy to manufacture, featuring high efficiency, good electrical conductivity and high weather resistance.

PUBLICATION NUMBER CN102505231
APPLICANT SHAOXING COUNTY HENGMEI FANCY SILK CO LTD; SHAOXING SHULILE TEXTILE PRODUCT CO
COUNTRY CHINA

TITLE: BAMBOO FIBER, COOLMAX FIBER AND CONDUCTIVE FIBER BLENDED YARN AND METHOD FOR PRODUCING SAME

SUMMARY:
The invention presents a bamboo fiber, a coolmax fiber and a mixed conductive fiber, as well as the method for obtaining it. These three fibres have their own characteristics and advantages that make them complement each other very well. This technical yarn is soft to the touch and resistant to washing. It can be used to make sports knitwear, underpants. . .

PUBLICATION NUMBER CN107268131
APPLICANT DANYANG SPORTS GOODS CO LTD
COUNTRY CHINA

TITLE: CONDUCTIVE SILVER-FIBER TWISTED YARN FOR FABRIC OF FENCING SPORT METAL GARMENT

SUMMARY:
The present invention concerns the creation of sportswear for fencing from silver-conducting fiber braided yarns. The conductive silver fibre is a braided thread obtained by twisting a first thread of conductive silver fibres with a second one of elastic fibres (both have the same fineness). The fabric that is created from these yarns, and therefore the garments, reduce an fatigue physical consumption and improve performance.

PUBLICATION NUMBER US20100105992A1
APPLICANT RITSUMEIKAN TRUST; OKAMOTO CORP
COUNTRY UNITED STATES

TITLE: PRESSURE-SENSITIVE CONDUCTIVE YARN AND BIOLOGICAL INFORMATION-MEASURING GARMENT

SUMMARY:
The invention presents the possibility of creating medical garments able of collecting biological information. These garments are created with pressure-sensitive wires capable of detecting information about the patient (functioning as an electrode). The yarn is composed of an elastic central thread surrounded by a mixed composition of conductive and non-conductive fibres.

PUBLICATION NUMBER US8771831B2
APPLICANT THE UNITED STATES OF AMERICA AS REPRESENTED BY THE SECRETARY OF THE ARMY, WASHINGTON, DC (US)
COUNTRY UNITED STATES

TITLE: MULTI-FUNCTIONAL YARNS AND FABRICS HAVING ANTI-MICROBIAL, ANTI-STATIC AND ANTI-ODOR CHARACTERISTICS

SUMMARY:
The invention presents fabrics with antistatic, anti-odour and anti-microbial properties. The yarn that create these fabrics is composed of several predetermined fibers. They are formed by incorporating three different fibre groups. Fibers with these properties (a nti-microbial, anti-odor and anti-static) are fibers with a metallic coating. Other fibers that may also be useful are meta-aramid fibers, para-aramid fibers...

PUBLICATION NUMBER	CN110528276
APPLICANT	BEST PACIFIC TEXTILE LTD
COUNTRY	CHINA

TITLE: METHOD FOR PREPARING CONDUCTIVE YARN BY MEANS OF VACUUM THERMAL EVAPORATION TECHNOLOGY

SUMMARY:

The present invention explains a method of vacuum evaporation for obtaining conductive yarns. This method consists of pre-treating a wire and placing that wire into a vacuum chamber of a vacuum evaporation winding coating machine for coating, making the metal evaporate on the surface of the pre-treated yarn, thus creating a metallic film around the yarn. The yarn obtained has good conductive properties, flexibility and surface smoothness.

PUBLICATION NUMBER	KR20120034026
APPLICANT	SAM GWANG DYEING CO LTD
COUNTRY	SOUTH KOREA

TITLE: PROCESS OF MULTI FUNCTIONAL FINISHING METHOD FOR CONDUCTIVE TEXTILES HAVING MULTI LAYER CONDUCTIVE YARN

SUMMARY:

This invention focuses on obtaining functionality that prevents wrinkles and maintains the dimensional stability of the shape. To this purpose, it presents a method for processing a conductive fabric made up of different layers of conductive threads. In this method there is a stage of dyeing the fabric with reactive dye, another stage of padding with a solution containing 30-50g/l water-repellent (along with more compounds), water and drying, and a final stage of padding with an antistatic solution and curing. The conductor wire is composed of several layers: copper, covered with nylon wire and cotton or wool thread.

PUBLICATION NUMBER	CN109137464
APPLICANT	UNIV SHANGHAI ENG SCIENCE
COUNTRY	CHINA

TITLE: CONDUCTIVE WASHABLE GRAPHENE/SILVER COMPOSITE COTTON FABRIC AND PREPARATION METHOD THEREOF

SUMMARY:

The invention refers particularly to a cotton fabric composed of washable conductive graphite/silver. The washable graphite/silver composite cotton conductive fabric comprises a cotton fabric matrix, a graphite layer (nano-leaves) attached to the cotton fabric matrix, and a silver (particles) film attached to the graphite layer. This method has the following steps: plasma treatmen of the cotton fabric, bind and reduce the graphite oxide and finally a magnetrón cathodic spraying to obtain the washable graphene/silver composite cotton fabric. The conductivity and washability of the composite cotton fabric are greatly improved, the quality of the cotton fabric is improved, the application field is expanded, and the commercial value is increased.

PUBLICATION NUMBER	CN107700010
APPLICANT	UNIV JIANGNAN
COUNTRY	CHINA

TITLE: INTELLIGENT CONDUCTIVE YARN FOR MONITORING HUMAN BODY ACTIVITIES, APPLICATION AND PREPARATION METHOD THEREOF

SUMMARY:
The present invention focuses on an smart yarn capable of controlling the activities of the human body. To create the yarn, a magnetron spray method is used to deposit metallic nanoparticles on a yarn that has an elastic core. This yarn has the advantages of being obtained through a simple, low-cost and industrially reproducible process. As a future application it is expected to be used in clothing for the control of human activities in athletes or elderly people.

PUBLICATION NUMBER	KR20150109915
APPLICANT	GANGSERO [KR]
COUNTRY	SOUTH KOREA

TITLE: FLEXIBLE PRINTED CONDUCTIVE FABRIC WITH DAMAGE PREVENTION FUNCTION

SUMMARY:
This invention presents a conductive fabric which has a damage prevention function (absorbs and dampens an applied load) to protect heating parts from breakage. It also reduces the thickness of a printing layer of the heating area to improve electric stability and flexibility, and improving productivity and reducing the manufacturing costs. The conductive fabric includes a planar-structured base layer; a heating layer formed on the surface of the base layer, and formed with a conductive material or a mixture of a conductive material and a binder.

PUBLICATION NUMBER	KR20100012593
APPLICANT	SNU R&DB FOUNDANTION [KR]
COUNTRY	SOUTH KOREA

TITLE: ELECTRICALLY CONDUCTIVE METAL COMPOSITE EMBROIDERY YARN AND EMBROIDERED CIRCUIT USING THEREOF

SUMMARY:
This invention features an electrically conductive metal composite yarn for embroidery and an embroidery circuit to be applicable in smart textiles. This can be used as signal transmission and power supply lines. This circuit is embroidered by a metal composite yarn on a substrate of dielectric fabric.

All-Organic Devices In Textiles for Wereable Electronics

This is a project coordinated by the University of Exeter in the United Kingdom and funded by the European Union. The project [26], following progress in the field of intelligent textiles with regard to the integration of electrical components, raises the possibility of incorporating technological elements into fabrics. It aims to create such electronic devices directly on textile fibres that can be woven into textile substrates. They use two types of electronic devices: field effect transistors and speakers. They focus on the use of unconventional materials in electronics, particularly graphene and its derivatives. These materials are flexible, elastic and transparent.

The aim is the development, with this project, of completely new applications for electronics, integrated into our everyday clothes.

Micro Fabrication Production Technology for MEMS On New Emerging Smart Textiles/Flexibles

This is another project funded by the European Union, this time carried out by the University of Southampton in the United Kingdom. In this case, the project [27] focuses on flexible materials in the form of intelligent fabrics or textiles capable of detecting stimuli and reacting or adapting to them by default. To this end, the project studies micromanufacturing using customized printing processes, cost-effective active functions. This will result in an economical, easy-to-design, flexible and fast solution for the manufacture of multi-functional textiles/smart garments applicable in a multi-sectoral manner.

Inkjet printing processes will be used for them, as these processes include many advantages such as low cost, short development time and ability to deposit a wide range of materials. All new printed inks will be electrically activated sensors and actuators and we will use standard electronic devices for energy supply/storage, signal processing and communications that offer low prices and mass production.

Feasibility Study Of Yarns and Fabrics With Annexed Electronic Functions

This project is carried out by the Universita Degli Studi Di Cagliari (Italy).

This project [28] focuses on the feasibility study of textile circuits created from electronically functionalized yarn, and the study of the electronic behaviour of the fabric which will be determined by the electronic properties of the yarn as well as the topology of the fabric.

This research idea has important benefits in several fields such as biomedicine, telecommunications, sports performance monitoring, remotely controllable electronic systems. . .

Therefore, the evaluation consists of the following steps: the evaluation of materials and technologies to make a yarn with electronic properties, the evaluation of the appropriate electronic model for the yarn and finally the investigation of possible topologies (how many yarns will be used, 3D structures for fabrics...).

Contactless Sensors For Body Monitoring Incorporated In Textiles

This project [29] carried out by Philips Electronics Nederland BV (The Netherlands) focuses on the possibility of treating musculoskeletal disorders (such as low back pain) by creating a system in which different non-contact sensors are incorporated into textiles for use in the continuous monitoring of individuals.

The integration of these sensors in the textile is a very logical option because we live in continuous contact with clothing, upholstery. . .

These sensors are textile electrodes that pick up electrical signals from the muscle and heart. The miniature sensor electronics are connected to a textile substrate containing the wire structures necessary for the transmission of data and electrical power.

The aim is to create a feasibility prototype in the form of a vest, which contains a set of these integrated sensors capable of monitoring the muscular activity and psychological stress state of the person who is wearing it.

Developing Stretchable Conductive Fibres and their Implementations in Wearable Electronics

Coordinated by Istanbul Teknik Universitesi (Turkey), this project [30] focuses on being able to find a solution that leaves aside the rigid and uncomfortable character and obtain elastic conductive materials that can be woven into fabrics, washable and breathable. For this purpose, research is carried out using silver nanowires and spandex fibre. They are applied in different environments and prototypes are created based on health monitoring systems and electro muscle stimulation technologies.

The aim is to achieve an advanced material that will cause competitiveness in Europe with respect to the wearonics field.

Multifunctional Fibre Nano Composites

This project was developed by the IMDEA MATERIALS FOUNDATION (Spain).

There is also a rather interesting field of study, high-performance mechanical fibres.

This study [31] focuses on the development of fibre-reinforced polymer composites with high performance mechanical properties, electrical and thermal conductivity superior to those of carbon fibre composite.

These compounds will be produced using a process based on macroscopic carbon nanotube fibres, a new high-performance fibre with mechanical properties.

The structure of nanocomposites adapts to different scales, from nano to macro, to maximize multi-functionality. The adaptation is achieved by controlling the following parameters: type of nanotubes, fiber architecture and fiber-matrix interaction.

Image 9 – Fabric circuit board [26]

Image 10 – Fabric circuit board [27]

Image 11 – Fabric circuit board [30]

Image 12 – Fabric circuit board [31]

4. EXPERIMENTAL PART

4.1 EXPERIMENTAL PART | MATERIALS

First of all, to develope all this experimental part it has been used the following materials:

REFERENCES	Composition	Structure	Ligament	Weight(gr/m^2)
1º PROTOTYPE	100% cotton	Knitting fabric.	Plain Knit	150-165
2º PROTOTYPE	95% cotton – 5% elastane.	Knitting fabric.	Plain Knit	220
3º PROTOTYPE	Polyester- cotton	Woven frabric.	Plain Weave	100
4º PROTOTYPE	100% cotton	Woven fabric	Twill	210

Table 1 – Table of characterization of the studied prototypes.

- Scissors.
- Ruler.
- Non woven fabric.
- Conductive yarns:

It's going to be inserted three different conductive yarn, one for each different color:

REFERENCES	Composition	Monofilament/Multifilament	Colour	Ω
1º CONDUCTIVE YARN	Stainless steel	Multifilament	RED	24
2º CONDUCTIVE YARN	Stainless steel	Multifilament	BLUE	32.8
3º CONDUCTIVE YARN	Polymer core with a conductive covered	Monofilament.	GREEN	230

Table 2 – Table of characterization of the studied conductive yarns.

Image 13 – Conductive yarns

All of them are made with stainless steel with the object to do all the washing machine process without problems with the conductive yarns. The objetctive of this experimental part is to reach conclusions and find out how the insertion of conductive yarns into textile could modify the properties of the textile stuedied.

4.2 EXPERIMENTAL PART | METODS

This project is related to the project I've made to finish my degree. The idea was to implement children's hospital pyjamas throughout the integration of a sensor or a sensors network with the purpose of getting the patient's vital signs registration.

To carry out all this experimental part it has been decided to study two knitting fabric with different compositions (these types of fabric are the most used to fabric adult's and childen's pyjamas). Also, to get a comparative part it has been decided to study two more fabrics, in this case are woven fabrics (plain fabric) with the purpose of getting comparative results between the woven and knitting fabric properties variatons.

The experimental part follows the next steps:

4.2.1 Study the properties of each fabric before inserting the conductivity yarns with KAWABATA Evaluation System:

The first step of all is study the properties of each fabric before inserting the conductivity yarns. This step is so important to have an idea about how are the properties of each fabric and with that, then do a good comparation with the results and see if there are any variation or not.

The fabric properties that are going to be studied are the following:

- Surface properties.
- Compression properties.
- Bending properties.
- Share properties.
- Tensile properties.

4.2.2 Design an example of a possible sensors network wich is integrated in the fabric and interconected through a conductive yarn:

The aim of this project is to design an example of a possible sensors network wich is integrated in the fabric and interconected through a conductive yarn. This design should get the combination of flexibility, ergonomy, integration and autonomy.

After having done a market study about sensors (ANNEX 1) which could be interconected and a research to know which of them are more viable to interconect with conductive yarn and insert in the fabrics it has been discovered these type of sensors whose name are "LilyPad Arduino Sensors".

The LilyPad system is a set of sewable electronic pieces designed to help us build soft, sewable, interactive e-textile projects. Using LilyPad pieces is a great way to experiment with electronics through the lens of crafting. Each LilyPad piece has large conductive sew tabs for easy sewing and a rounded shape so as not to snag fabric or cut thread. [19]

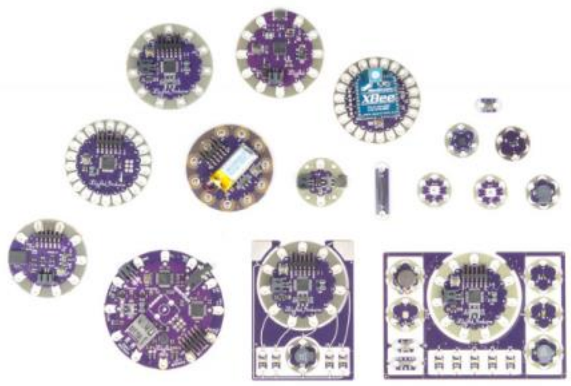


Image 14 – LilyPad sensors [19]

Once known which sensors could be used, the next step is knowing how these sensors could be interconected. At the LilyPad web there is a simple tutorial about how to get an easy network with these LilyPad sensor interconected.

The circuit designed in this project is similar to the one that appears in the tutorial but it’s a little more simple and easy, simplify networks ways and eliminate some sensors. The result is the following:

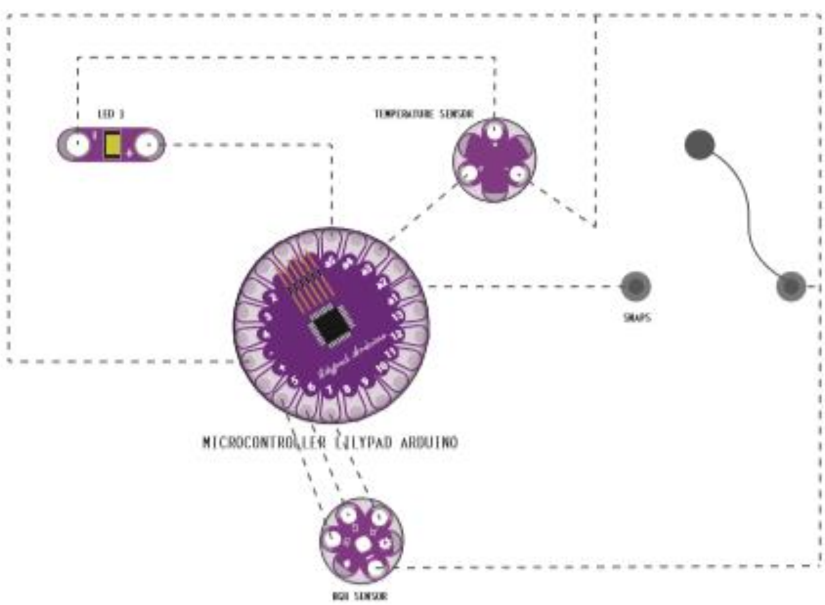


Image 15 – Circuit designed

4.2.3 Do the embroidery ("sensors") on the knitting fabrics:

To do that it use the DesignShop Commercial Embroidery Digitizing Software. Which this software this network it has done by the computer and then, with the Embroidery machine AMAYA XTS it gests the embroidery on the fabric. It made a little modifications on the network because it should cover the embroidery machine zone (18 cm of diameter).

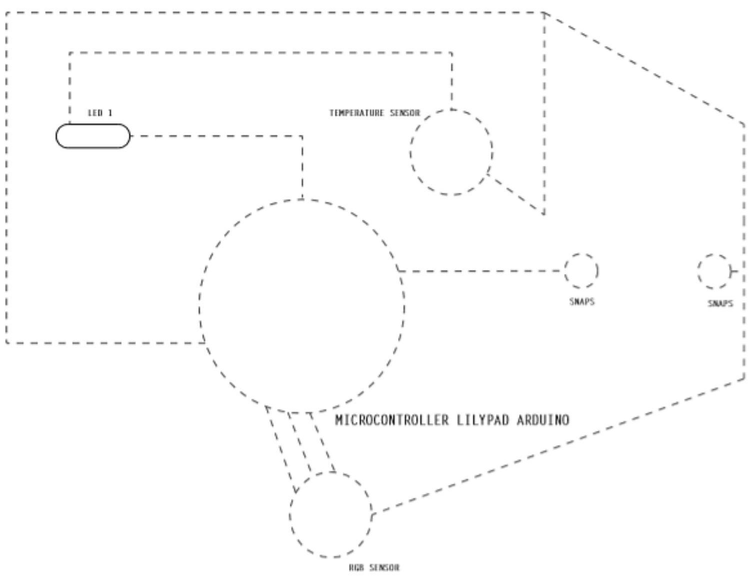


Image 16 – Definitive circuit designed for embroidery

Bellow are somo photos about how was the process to design all this circuit in the DesignShop Commercial Embroidery Digitizing Software:

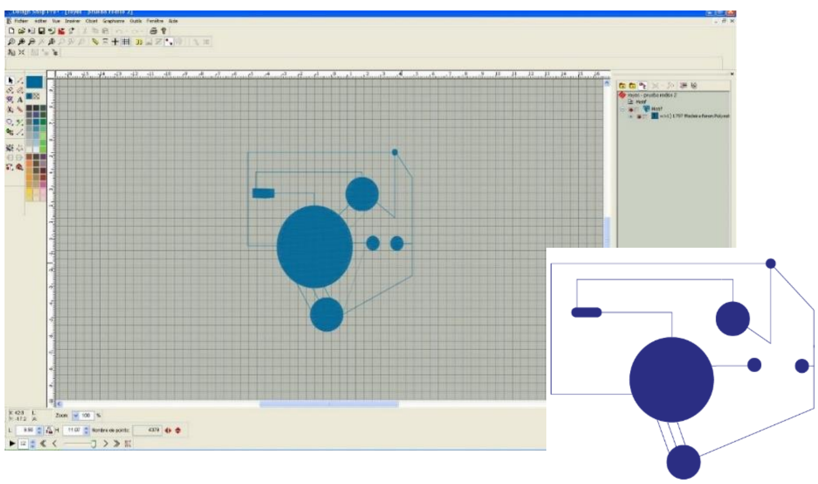


Image 17 – Circuit designed with DesignShop Commercial Embroidery Digitizing Software

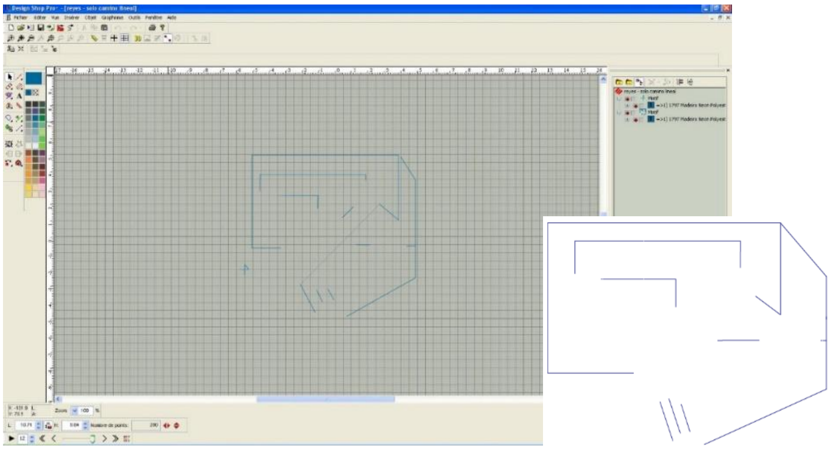


Image 18 – Yarns interconexion designed with DesignShop Commercial Embroidery Digitizing Software

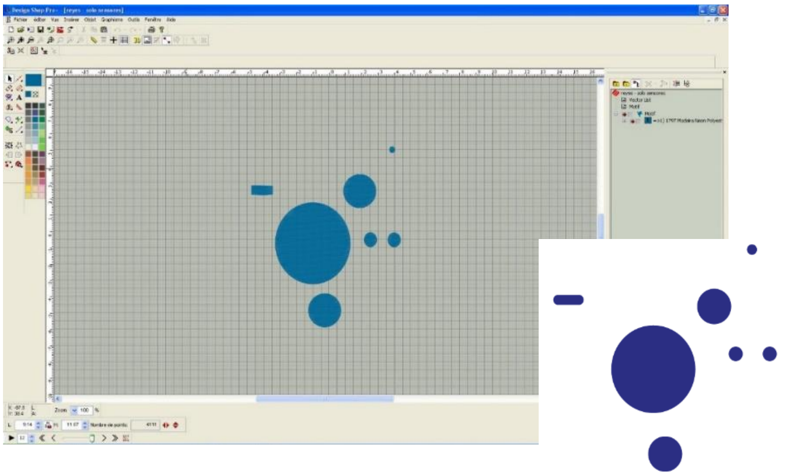


Image 19 – Sensors designed with DesignShop Commercial Embroidery Digitizing Software

To be able to do the embroidery on the knitting fabrics, which are so elastic, it should put a "support" fabric on the fabric which is being studied and then, these "support" fabric will be eliminated with a washing process.

Image 20 – Steps for preparing the embroidery

Image 21 – Steps for preparing the embroidery

The first idea was to do all the network sensors designed with the embroidery machine. These idea was dismissed because, after trying to do some attempt about that it was imposible to do. The conductive yarn was broken all the attempt it tried to do.

So once these idea was dismissed, it decided to embroidery only the geometric shapes which represented the sensors of the network designed. Each of the shapes was embroideried with a different color. The reason was differentiate each conductive yarn with each color. After all it designed three different circuits, which incluided different conductive yarn each one and all of them represented wich a different color.

RED CIRCUIT: stainless steel multifilament conductive yarn.

BLUE CIRCUIT: stainless steel multifilament conductive yarn. (With a different torsion).

GREEN CIRCUIT: monofilament synthetic yarn with conductive material.

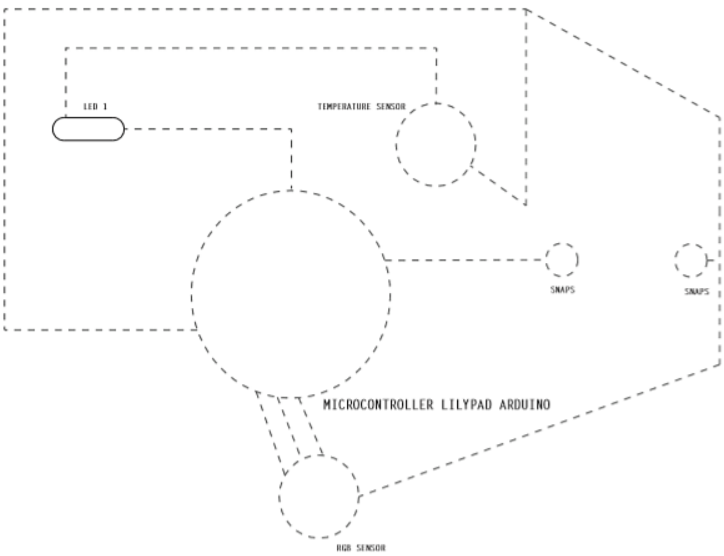


Image 22 – Embroidery circuit simulation

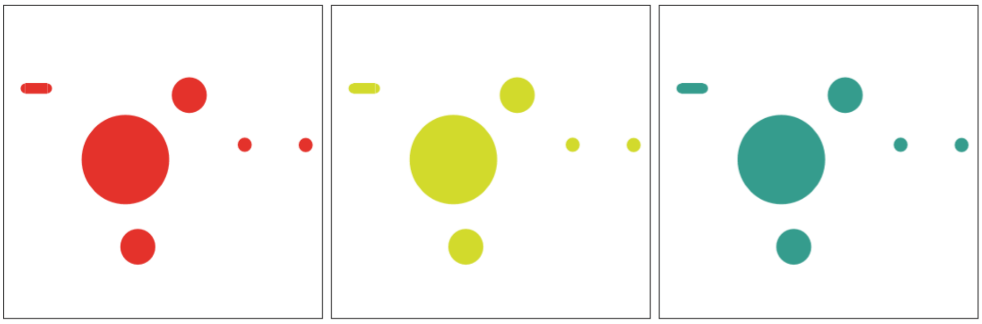


Image 23 – Embroidery circuit simulation in three different colours

Image 24 – Embroidery machine AMAYA XTS

Image 25 – Prototypes with embroidered sensor simulation

4.2.4 Get the insertion of the different conductive yarn:

When it has the sensors shapes embroideried the next step is getting the insertion of the different conductive yarns which will be used to do the projectl.

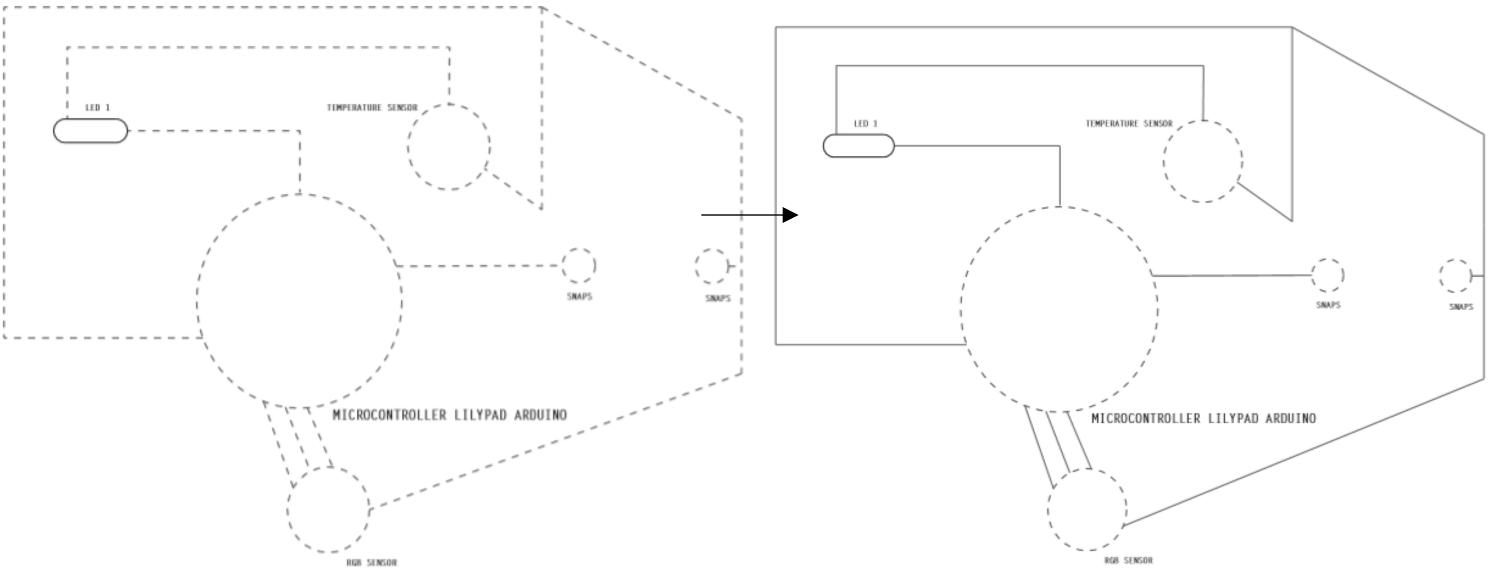


Image 26 – Yarns interconexion designed

The first step of this part was measure the conductivty of each yarn. I was done with a multimeter. This measure give it an idea about how conductive is each yarn.

Image 27 – Measurements made with the voltmeter

After dismissed the idea about do the “conductive way” of each circuit with the embroidery machine, the conductive yarn will be incluided in the fabrics with a rectilinear sewing machine. So it going to sew this “conductive way” step by step. The result is the following:

Image 28 – Conductive thread sewing process with straight machine

4.2.5 Study the properties of each fabric after inserting the conductivity yarns with KAWABATA Evaluation System:

Once it has the “sensors shapes” embroideried and the insertion of the conductive yarns done in all the prototypes the last step is do all the KAWABATA Evaluation System to get the results and verify if these knitting and woven fabrics suffers some variations in the properties of these.

The fabric properties that are going to be studied are the followin. <u>This methods don’t follow any normative. This is a Japanese method and when you buy all the devices they bring you some recomendations and steps to follow to do all the evaluations.</u>

Furthermore, with each kawabata evaluation system, this metod will study the following parameters:

- SURFACE TESTER:
    - MIU: coeffient of friction.
    - MMD: fluctuation (variation).
    - SMD: geometric roughness.
- COMPRESSION TESTER:
    - WC: compression susceptibility.
    - RC: compressional resilence.
- BENDING TESTER:
    - B: bending rigidity.
    - 2HB: capacity of recovery to the bending effort.
- TENSILE TESTER:
    - RT: tensile resilence.
    - WT: stretching capacity.
    - LT: traction stiffness.
- SHEAR TESTER:
    - G: shear stiffness.
    - 2HG: capacity of recovery to the shear esffort.

In this metod (KAWABATA EVALUATION SYSTEM) the sides of the fabric (front and back) and the yarns direction (WEFT and WARP) will be so important, and each tester will be studied different:

- In SURFACE TESTER, the properties must be studied according to the direction of the yarns and on both sides of the fabric.

- In COMPRESSION TESTER, the properties must be studied on the front side of the fabric.

- In BENDING TESTER,the properties must be studied on the front side of the fabric according to the directions of the yarns.

- In **TENSILE** and **SHEAR TESTER**: the properties must be studied on the front side of the fabric according to the directions of the yarns

KAWABATA EVALUATION SYSTEM | **SURFACE TESTER**

Image 29 – SURFACE TESTER

KAWABATA EVALUATION SYSTEM | **COMPRESSION TESTER**

Image 30 – COMPRESSION TESTER

KAWABATA EVALUATION SYSTEM | **BENDING TESTER**

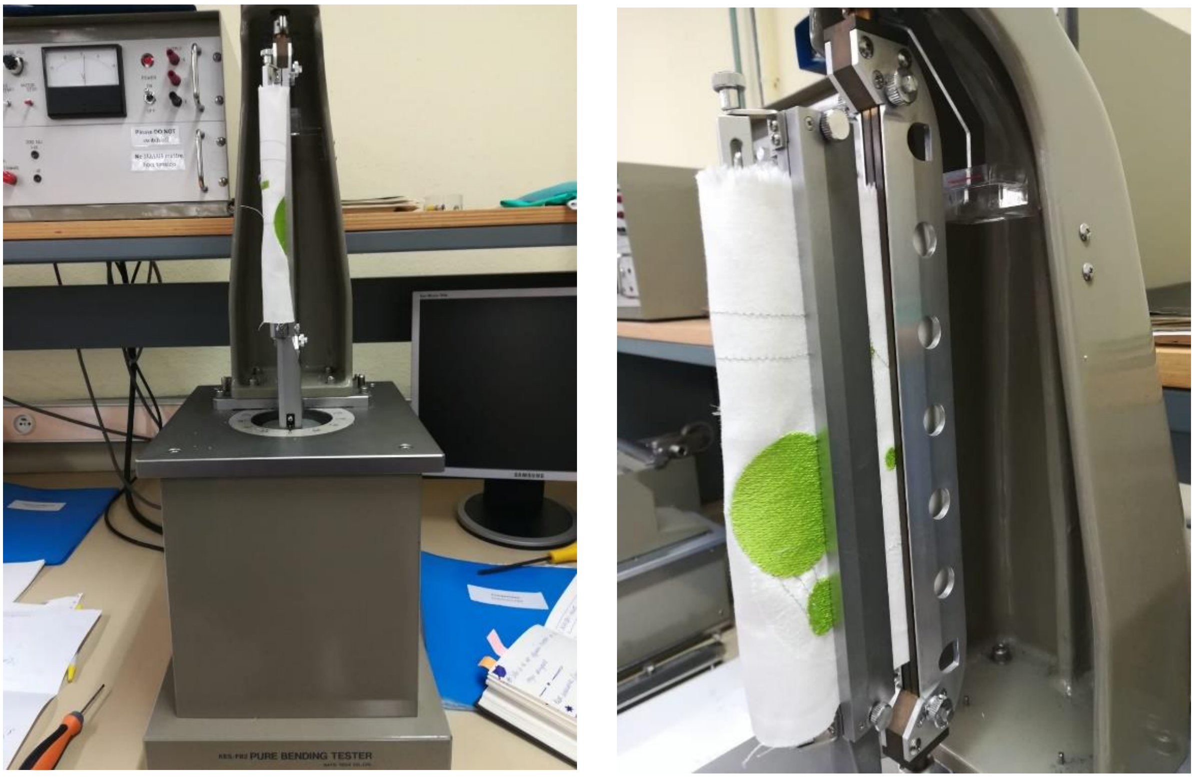


Image 31 – BENDING TESTER

KAWABATA EVALUATION SYSTEM | **TENSILE AND SHEAR TESTER**

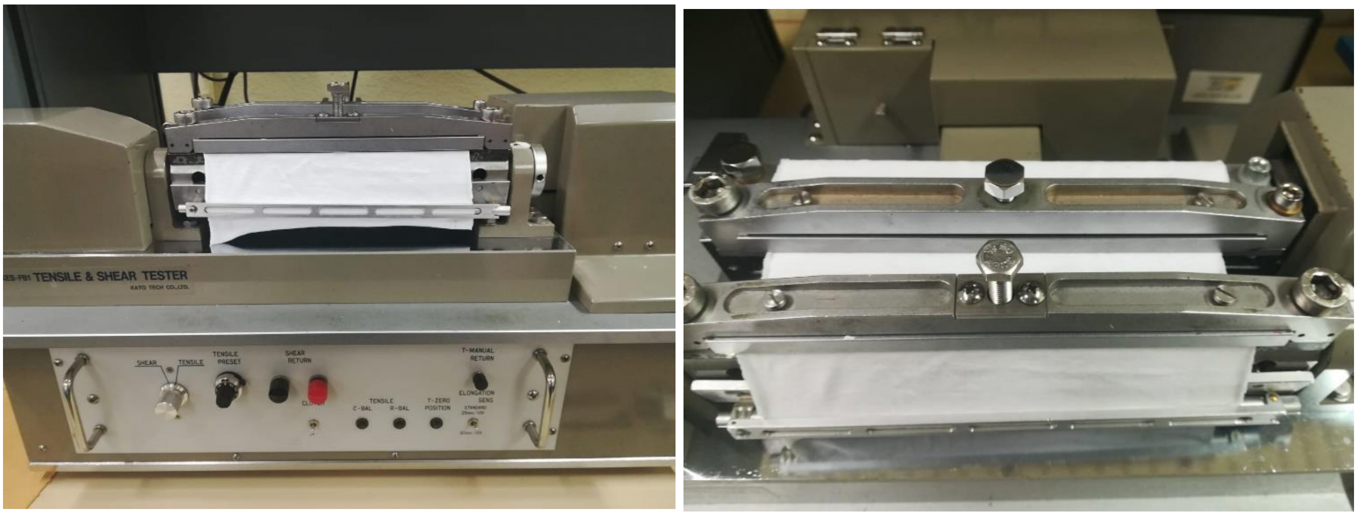


Image 32 – TENSILE & SHEAR TESTER

4.2.6 Get the final results and conclusions doing a statistical study (R Commander).

When the KAWABATA evaluation system have done, it obteined a lot of results. That's happened because there are, for each kind of fabric, four different prototipes to study.

Once it has been evaluated all the prototypes and it has been obteined correct results about all the parameters (some testers had to be repeted) the amount of final results obtined was 412 results.

A statiscal study it's necessary to analyze a large number of results because it gives to us a more visual response using graphics to explain in the correct way all the results and do the study more understandable.

So it created a experimental design with the statiscal program "R Commander". To do this, for each experimental design, it should be determined some factors and response variables. Factors are thouse parameters that make the results change and the response variable are all the results it obtenined in each Kawabata tester.

<table>
<tr><th colspan="4">FACTORS</th><th>RESPONSE VARIABLES</th></tr>
<tr><td colspan="4">YARN'S DIRECTION (IN FABRICS)</td><td>SURFACE TESTER</td></tr>
<tr><td colspan="2">"WARP"
LONGITUDINAL DIRECTION</td><td colspan="2">"WEFT"
TRANSVERSAL DIRECTION</td><td>MIU,MMD,SMD</td></tr>
<tr><td colspan="4">MATERIAL</td><td>COMPRESSION TESTER</td></tr>
<tr><td>"A"
COTTON- ELASTANE</td><td>"B"
COTTON (WOVEN)</td><td>"C"
COTTON
(KNITTING)</td><td>"D"
COTTON-POLYESTER</td><td>WC,RC</td></tr>
<tr><td colspan="4">YARNS</td><td>BENDING TESTER</td></tr>
<tr><td rowspan="3">"1"
WIITHOUT CONDUCTIVE YARN</td><td rowspan="3">"2"
BLUE-
MULTIFILAMENT
STAINLESS STEEL</td><td rowspan="3">"3"
RED-
MULTIFILAMENT
STAINLESS STEEL</td><td rowspan="3">"4"
GREEN-
MONOFILAMENT
WITH CONDUCTIVE
COVERED</td><td>B,2HB</td></tr>
<tr><td>SHEAR TESTER</td></tr>
<tr><td>G,2HG</td></tr>
<tr><td colspan="4">SIDES</td><td>TENSILE TESTER</td></tr>
<tr><td colspan="2">"A"
FRONT</td><td colspan="2">"B"
BACK</td><td>LT,WT,RT</td></tr>
</table>

Table 3 – Table of factors and response variables

The factors chosen for each experiment design and the output variables are explained below:

1. SURFACE TESTER
   i. Number of factors: 4 (DIRECTION, MATERIAL, SIDE, YARNS)
   ii. Response variables: MIU, MMD, SMD.

Obteined, in this way, the following experimental desing about SURFACE TESTER:

Surface2

	YARN	MATERIAL	DIRECTION	SIDE	MIU	MMD	SMD
1	1	A	WARP	A	0.183	0.0001	1.070
2	2	A	WARP	A	0.508	0.0310	7.500
3	3	A	WARP	A	0.414	0.0178	9.195
4	4	A	WARP	A	0.312	0.0160	3.875
5	1	B	WARP	A	0.174	0.0179	4.730
6	2	B	WARP	A	0.272	0.0295	7.010
7	3	B	WARP	A	0.331	0.0242	9.110
8	4	B	WARP	A	0.375	0.0461	8.450
9	1	C	WARP	A	0.184	0.0003	1.105
10	2	C	WARP	A	0.256	0.0308	6.015
11	3	C	WARP	A	0.252	0.0328	9.940
12	4	C	WARP	A	0.290	0.0345	5.675
13	1	D	WARP	A	0.183	0.0190	3.490
14	2	D	WARP	A	0.264	0.0336	4.305
15	3	D	WARP	A	0.402	0.0561	10.395
16	4	D	WARP	A	0.216	0.0380	8.125
17	1	A	WEFT	A	0.230	0.0001	1.990
18	2	A	WEFT	A	0.364	0.0242	7.760
19	3	A	WEFT	A	0.516	0.0304	8.935
20	4	A	WEFT	A	0.336	0.0191	4.635
21	1	B	WEFT	A	0.188	0.0148	4.875
22	2	B	WEFT	A	0.255	0.0279	9.645
23	3	B	WEFT	A	0.280	0.0301	5.735
24	4	B	WEFT	A	0.215	0.0201	4.080
25	1	C	WEFT	A	0.227	0.0001	1.630
26	2	C	WEFT	A	0.416	0.0375	7.850
27	3	C	WEFT	A	0.456	0.0236	8.630
28	4	C	WEFT	A	0.376	0.0337	5.415
29	1	D	WEFT	A	0.171	0.0243	3.385
30	2	D	WEFT	A	0.468	0.0419	4.710
31	3	D	WEFT	A	0.323	0.0321	9.710
32	4	D	WEFT	A	0.354	0.0437	10.170
33	1	A	WARP	B	0.257	0.0001	1.905
34	2	A	WARP	B	0.579	0.0412	4.015
35	3	A	WARP	B	0.400	0.0186	6.165
36	4	A	WARP	B	0.593	0.0292	4.340
37	1	B	WARP	B	0.141	0.0139	3.130
38	2	B	WARP	B	0.280	0.0348	1.514
39	3	B	WARP	B	0.386	0.0460	11.215

Image 33 – Experimental design about SURFACE TESTER

2. COMPRESSION TESTER

i. Number of factors: 2 (MATERIAL, YARNS)

ii. Response variables: WC,RC

Obteined, in this way, the following experimental desing about COMPRESSION TESTER:

Compress...

	YARN	MATERIAL	WC	RC
1	1	A	0.221	48.87
2	2	A	0.878	26.20
3	3	A	1.000	29.14
4	4	A	0.287	30.66
5	1	B	0.154	59.09
6	2	B	1.840	42.45
7	3	B	1.950	43.19
8	4	B	0.504	37.50
9	1	C	0.254	40.55
10	2	C	0.794	30.23
11	3	C	0.781	42.97
12	4	C	0.251	29.88
13	1	D	0.166	59.04
14	2	D	0.788	60.15
15	3	D	0.357	51.54
16	4	D	0.397	53.90

Image 34 – Experimental design about COMPRESSION TESTER

3. **BENDING TESTER**
    i. Number of factors: 3 (MATERIAL/YARNS/DIRECTION)
    ii. Response variable: B, 2HB

Obteined, in this way, the following experimental desing about BENDING TESTER:

Bending2

	YARN	MATERIAL	DIRECTION	B	X2HB
1	1	A	WARP	0.0486	0.0325
2	2	A	WARP	0.2760	0.3497
3	3	A	WARP	0.1035	0.2013
4	4	A	WARP	0.0415	0.0738
5	1	B	WARP	0.4590	0.3703
6	2	B	WARP	0.4590	0.3703
7	3	B	WARP	0.3158	0.4649
8	4	B	WARP	0.4841	0.3611
9	1	C	WARP	0.0142	0.0030
10	2	C	WARP	0.1879	0.4024
11	3	C	WARP	0.2284	0.3424
12	4	C	WARP	0.1368	0.1983
13	1	D	WARP	0.0705	0.2851
14	2	D	WARP	0.0684	0.0485
15	3	D	WARP	0.0623	0.2006
16	4	D	WARP	0.0351	0.0929
17	1	A	WEFT	0.0178	0.0143
18	2	A	WEFT	0.2799	0.3525
19	3	A	WEFT	0.3219	0.2700
20	4	A	WEFT	0.1350	0.3111
21	1	B	WEFT	0.4116	0.3326
22	2	B	WEFT	0.3075	0.3497
23	3	B	WEFT	0.0139	0.3398
24	4	B	WEFT	0.0610	0.3073
25	1	C	WEFT	0.0286	0.0112
26	2	C	WEFT	0.0327	0.0889
27	3	C	WEFT	0.0590	0.1126
28	4	C	WEFT	0.0549	0.0538
29	1	D	WEFT	0.3011	0.2270
30	2	D	WEFT	0.0075	0.1102
31	3	D	WEFT	0.0048	0.1602
32	4	D	WEFT	0.0703	0.1901

Image 35 – Experimental design about BENDING TESTER

4. **TENSILE TESTER**
    i. Number of factors: 3 (MATERIAL/YARNS/DIRECTION)
    ii. Response variable: LT, WT, RT.

Obteined, in this way, the following experimental desing about TENSILE TESTER:

Tensile2

	YARN	MATERIAL	SIDE	WT	RT	LT
1	1	A	WARP	1.10	86.36	0.419
2	2	A	WARP	5.50	28.19	0.141
3	3	A	WARP	4.50	31.11	0.353
4	4	A	WARP	3.05	39.34	0.434
5	1	B	WARP	10.50	50.00	0.435
6	2	B	WARP	4.35	36.78	0.437
7	3	B	WARP	7.30	38.36	0.378
8	4	B	WARP	5.45	32.11	0.436
9	1	A	WEFT	2.05	65.85	0.488
10	2	A	WEFT	3.00	33.33	0.469
11	3	A	WEFT	1.10	40.91	0.192
12	4	A	WEFT	4.90	30.61	0.482
13	1	B	WEFT	10.27	53.66	0.431
14	2	B	WEFT	15.30	15.30	0.461
15	3	B	WEFT	5.20	45.19	0.499
16	4	B	WEFT	15.10	36.78	0.580

Image 36 – Experimental design about TENSILE TESTER

5. **SHEAR TESTER**
   i. Number of factor: 3 (MATERIAL/YARNS/DIRECTION)
   ii. Response variable: G, 2HG

Obteined, in this way, the following experimental desing about SHEAR TESTER:

Shear2

	YARN	MATERIAL	DIRECTION	G	X2HG
1	1	A	WARP	0.32	0.93
2	2	A	WARP	0.15	0.45
3	3	A	WARP	0.17	0.48
4	4	A	WARP	0.14	0.50
5	1	B	WARP	0.87	1.35
6	2	B	WARP	2.37	8.95
7	3	B	WARP	3.10	6.15
8	4	B	WARP	4.44	15.58
9	1	C	WARP	0.40	0.90
10	2	C	WARP	0.45	1.30
11	3	C	WARP	0.85	2.70
12	4	C	WARP	0.95	1.78
13	1	D	WARP	0.49	0.53
14	2	D	WARP	2.05	4.25
15	3	D	WARP	1.84	4.33
16	4	D	WARP	1.43	3.03
17	1	A	WEFT	0.38	0.98
18	2	A	WEFT	0.17	0.43
19	3	A	WEFT	0.10	0.35
20	4	A	WEFT	0.16	0.38
21	1	B	WEFT	1.28	1.80
22	2	B	WEFT	2.27	5.83
23	3	B	WEFT	2.97	9.55
24	4	B	WEFT	2.21	9.18
25	1	C	WEFT	0.43	0.78
26	2	C	WEFT	0.27	0.58
27	3	C	WEFT	0.73	4.00
28	4	C	WEFT	0.43	0.35
29	1	D	WEFT	0.92	1.08
30	2	D	WEFT	1.45	2.58

Image 37 – Experimental design about SHEAR TESTER

**In TENSILE TESTER only the woven fabrics were been studied, because the knitting fabric, due to their elastic structure, it's imposible study theis properties with this type of tester.*

Once all the experimental designs have been proposed for each tester, the next step is to introduce the results in the program, obtained in the testers, and proceed to the data analysis.

First of all, once the results are entered, what you get is a "statistics table"; where the factors you enter for each design of experiment appear. In this table the level of influence of each factor in the experiment (always appears the number of factors minus one) is represented by an asterisk (one influence, two more influence, three the most influential factor).

In addition, "R-squared"; (determination coefficient) appears in order to know how to predict the behavior of the variable responses of each experiment design. It is expressed as a percentage, and if this value is closer to 100%, the experimental design will predict better the behavior of each response variable.

There is an example of this "statiscs table":

```
Coefficients:
              Estimate Std. Error t value  Pr(>|t|)
(Intercept)     6.1669     0.8664   7.118 0.0000322 ***
YARN.L          0.2063     1.7327   0.119    0.9076
YARN.Q          0.7712     1.7327   0.445    0.6657
YARN.C          1.9415     1.7327   1.120    0.2887
MATERIAL1       3.0169     0.8664   3.482    0.0059 **
SIDE1           0.9481     0.8664   1.094    0.2994
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.465 on 10 degrees of freedom
Multiple R-squared:  0.5966, Adjusted R-squared:  0.395
F-statistic: 2.958 on 5 and 10 DF,  p-value: 0.06794
```

Image 38 – Example of statiscal table

The next step of this evaluation will be interpret the results:

SURFACE TESTER | RESPONSE VARIABLES AND THEIR INTERPRETATION

MIU (COEFFICIENT OF FRICTION): high values represent less tendency to slip.

MMD (FLUCTUATION (VARIATION)): high values represent less softness and more surface roughness.

SMD (GEOMETRIC ROUGHNESS): high values more irregularities on the surface.

COMPRESSION TESTER | RESPONSE VARIABLES AND THEIR INTERPRETATION

WC (COMPRESSION SUSCEPTIBILITY): high values more compression susceptibility.

RC (COMPRESSIONAL RESILENCE): values close to 100 represent greater recovery capacity to the compression effort.

BENDING TESTER | RESPONSE VARIABLES AND THEIR INTERPRETATION

B (BENDING RIGIDITY): high values more rigidity flexion.

2HB (COMPRESSIONAL RESILENCE): high values less recovery capacity to the bending effort.

TENSILE TESTER | RESPONSE VARIABLES AND THEIR INTERPRETATION

RT (TENSILE RESILENCE): values close to 100 represent greater recovery capacity to the tensile effort.

WT (STRETCHING CAPACITY): high values more stretching capacity.

LT (TRACTION SITFFNESS): values close to 1 high average traction stiffness.

SHEAR TESTER | RESPONSE VARIABLES AND THEIR INTERPRETATION

G (SHEAR STIFFNESS): high values represent a harder cut

2HG (CAPACITY OF RECOVERY TO THE SHEAR ESFFORT): high values less recovery capacity to the shear effort.

5. RESULTS

5.1 FIRST TESTS CARRIED OUT ON KNITTED FABRICS | WITHOUT INSERTION OF CONDUCTIVE THREAD

5.1.1 SURFACE TESTER

COTTON FABRIC

- ✓ Regarding the “MIU" response variable (coefficient of friction): the cotton fabric presents low values. That means that the fabric has a greater tendency to slip as such.

- ✓ Regarding the “SMD" response variable (surface roughness): it obtained fairly low values, this represents that this fabric doesn’t have any irregularities on the surface.

- ✓ Regarding the “MMD" response variable (variation of the average coefficient of friction): the values are quite low. This means that this fabric has a high surface smoothness and no surface roughness.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SURFACE TEST
High tendency to slip.
Absence of surface irregularities
High surface smoothness. No roughness.

Table 4 – Table of cotton (knitted) surface properties before yarns inserted

COTTON - ELASTANE FABRIC

- ✓ Regarding the “MIU" response variable (coefficient of friction): the cotton-elastane fabric presents low values. That means that the fabric has a greater tendency to slip as such.

- ✓ Regarding the “SMD" response variable (surface roughness): it obtained fairly low values, represents that this fabric doesn’t have any irregularities on the surface.

- ✓ Regarding the “MMD" response variable (variation of the average coefficient of friction): the values are quite low.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SURFACE TEST
High tendency to slip.
Absence of surface irregularities
High surface smoothness. No roughness.

Table 5 – Table of cotton - elastane (knitted) surface properties before yarns inserted

5.1.2 COMPRESSION TESTER

COTTON FABRIC

- ✓ Regarding the “WC" response variable (compression susceptibility): the cotton fabric, after making the average, presents a quite low value, very similar to the cotton-elastane fabric, of 0. 253 gf/cm^2. This means, due to present a rather low value, that it presents little susceptibility to understanding.

- ✓ Regarding the “RC" response variable (compressional resilence): the cotton fabric presents a 44. 44% of resilience percentage, approximately. It therefore presents a good capacity for recovery after this effort of understanding has been applied.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
Low susceptibility to compression effort.
Good capacity of recovery to the compression effort.

Table 6 – Table of cotton (knitted) compression properties before yarns inserted

COTTON - ELASTANE FABRIC

- ✓ Regarding the “WC" response variable (compression susceptibility): the cotton - elastane fabric, has a rather low value of 0. 234 gf/cm^2. This means, due to present a rather low value, presents low susceptibility. Being very similar to cotton fabric.

- ✓ Regarding the “RC" response variable (compressional resilence): the cotton - elastane fabric presents 40%. Therefore, this fabric presents a good capacity of recovery respect to the compression effort but, this capacity is lower than which has the cotton fabric.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
Low susceptibility to compression effort.
Good capacity of recovery to the compression effort.

Table 7 – Table of cotton - elastane (knitted) compression properties before yarns inserted

5.1.3 BENDING TESTER

COTTON FABRIC

- ✓ Regarding the “B" response variable (bending rigidity): the cotton fabric presents a smaller value in the longitudinal direction than in the transversal one which is a little higher. Even so, as these values are quite low, it can be concluded that this fabric has very little flexural rigidity.

- ✓ Regarding the “2HB" response variable (compressional resilence): the values are quite low although there is a difference between the values in the longitudinal and transversal directions. So this fabric prsents a greater capacity for resilience in the transverse direction.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE BENDING TEST
Highly flexible
Good capacity of recovery to the bending effort. Better in the transversal direction. High elasticity.

Table 8 – Table of cotton (knitted) bending properties before yarns inserted

COTTON - ELASTANE FABRIC

- ✓ Regarding the “B" response variable (bending rigidity); the cotton-elastane fabric, this fabric has a more rigid bending in the longitudinal direction than in the transversal one. Even so, the values are quite low so it can be concluded that it is a very flexible fabric

- ✓ Regarding the “2HB" response variable (compressional resilence): it possible observe that in the longitudinal direction it has a lower capacity for recovery than in the transverse direction. The values are low in both, so it presents a good capacity of recovery in general.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE BENDING TEST
Highly flexible
Good capacity of recovery to the bending effort. Better in the longitudinal direction. High elasticity.

Table 9 – Table of cotton - elastane (knitted) bending properties before yarns inserted

5.1.4 SHEAR TESTER

COTTON FABRIC

- ✓ Regarding the “G" response variable (shear stiffness): the values obtained are quite similar on both sides of the fabric tested. As the values are low, this shows that this type of fabric has less rigidity against shear stress.

- ✓ Regarding the “2HG" response variable (capacity of recovery to the shear effot): That’s because these values are also low, the capacity to recover from shear stress is quite low. This is due to the fact that, as it is a knitted fabric, it has a fairly flexible structure.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SHEAR TEST
Low shear rigidity
Low capacity of recovery to the shear effot

Table 10 – Table of cotton (knitted) shear properties before yarns inserted

COTTON - ELASTANE FABRIC

- ✓ Regarding the “G" response variable (shear stiffness): this fabric presents practically equal values in the longitudinal and transversal direction, therefore, it can be concluded that both directions of the fabric present a lower rigidity against the cut/shear effort, even lower than the 100% cotton fabric.

- ✓ Regarding the “2HG" response variable (capacity of recovery to the shear effot): as these values are also low, the recovery capacity against the shear effort is quite low. There is still a difference between the results obtained from one tissue and another. This fabric has a slightly higher recovery capacity than 100% cotton. This is quite logical because this fabric has a small part of elastane composition, quite elastic fiber capable of providing that greater recovery compared to the fabric that is only composed of cotton.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SHEAR TEST
Low shear rigidity
Low resilience to shear stress. Better capacity of recovery compared to cotton fabric.

Table 11 – Table of cotton - elastane (knitted) shear properties before yarns inserted

5.1.5 TENSILE TESTER

COTTON FABRIC

- ✓ Regarding the “RT " response variable (tensile resilence): this fabric presebts 20. 40%. With respect to 100%, this fabric has a very low recovery capacity.
- ✓ Regarding the “WT " response variable (stretching capacity): this fabric has a relatively high value therefore the stretching capacity is high. It is logical since it has a knitted structure, is elastic and therefore one of the properties is a good capacity for stretching.
- ✓ Regarding the “LT " response variable (traction stiffness): this type of fabric has a value very close to 1, therefore the average tension it presents is quite firm.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SHEAR TEST
Low recovery capacity to the tensile effort.
Low resilience to shear stress. Better capacity of recovery compared to cotton fabric.
Quiet firm traction stiffness.

Table 12 – Table of cotton (knitted) tensile properties before yarns inserted

COTTON - ELASTANE FABRIC

It has not been possible to carry out the tension test on the cotton-elastane fabric. This fabric presents a structure with great flexibility and that why when it tried to make this test no values were obtained to be studied.

5.2 FIRST TESTS CARRIED OUT ON WOVEN FABRICS | WITHOUT INSERTION OF CONDUCTIVE THREAD

5.2.1 SURFACE TESTER

COTTON - POLYESTER FABRIC

- ✓ Regarding the “MIU" response variable (coefficient of friction): the cotton - polyester fabric presents quite similar values on both sides. Observing such values, the tissue has more tendency to slide as one. Very similar values when studying knitted cotton fabric.

- ✓ Regarding the “SMD" response variable (surface roughness): measured in microns, the cotton fabric presents quite similar values on both sides. The values are not very high, but they are such compared to those measured in knitted tissues. Therefore, values representing the presence of irregularities on the surface already appear in this type of fabrics.

- ✓ Regarding the “MMD" response variable (variation of the average coefficient of friction): the values are quite low. This means that this tissue has high surface softness and no surface roughness (less than in the knitted facris studied).

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SURFACE TEST
High tendency to slip. Values similar to those obtained for knitted fabric.
Surface irregularities
High surface softness. No roughness. Less than in the studied knitted fabrics.

Table 13 – Table of cotton - polyester (woven) surface properties before yarns inserted

COTTON FABRIC

- ✓ Regarding the “MIU" response variable (coefficient of friction): the cotton fabric presents fairily similar values on both sides. Values below this means that the fabric has more tendency to slide as such. With reference to the sliding trend, it would be found between the knitted fabrics studied and the cotton-polyester fabric.

- ✓ Regarding the “SMD" response variable (surface roughness): measured in microns, the cotton fabric presents quite similar values on both sides.

- ✓ The values obtained are higher than those obtained in the cotton-polyester fabric. This means that it has greater surface irregularities.

- ✓ Regarding the “MMD" response variable (variation of the average coefficient of friction): the values are quite low. This means that this fabric has high surface smoothness and no surface roughness (which has resulted less compared to the knitted fabrics studied.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SURFACE TEST
High tendency to slip. Values similar to those obtained for knitted fabric.
Surface irregularities
High surface softness. No roughness. Very similar to cotton-polyester fabric.

Table 14 – Table of cotton (woven) surface properties before yarns inserted

5.2.2 COMPRESSION TESTER

COTTON - POLYESTER FABRIC

- ✓ Regarding the "WC" response variable (compression susceptibility): the cotton - polyester fabric, after averaging presents a rather low value of 0.166 gf/cm2. This result as such because it has a fairly low value, it has little susceptibility to compression . Less than those of the studied knitted fabrics.

- ✓ Regarding the "RC" response variable (compressional resilence): the cotton - polyester fabric presents a 59.04% of resilience, approximately.It therefore has a good capacity for recovery after this compression effort has been applied. Better than the knitting studied.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
Low susceptibility to compression effort
Favorable resilience to compression effort. Better than that of knitted fabrics.

Table 15 – Table of cotton - polyester (woven) compression properties before yarns inserted

COTTON FABRIC

- ✓ Regarding the "WC" response variable (compression susceptibility): the cotton fabric, after averaging, has a rather low value of 0.154 gf/cm2. This means, by presenting a rather low value, that there is low susceptibility to compression. Lower than those of the knitted fabrics studied and better than that of the cotton fabric – polyester
- ✓ Regarding the "RC" response variable (compressional resilence): the cotton - polyester fabric presents approximately a 59.09% of resilience. Therefore, it has a good capacity of recovery after being applied, this compression effort isvery similar to the one presented by the cotton fabric - polyester.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
Low susceptibility to compression effort.
Favorable resilience to compression effort. Better than that of knitted fabric

Table 16 – Table of cotton (woven) compression properties before yarns inserted

5.2.3 BENDING TESTER

COTTON - POLYESTER FABRIC

- ✓ Regarding the "B" response variable (bending rigidity): the cotton - polyester fabric has a smaller value in the longitudinal direction than in the transverse one that results quite more high. In this way, it can be enhanced that it has much more rigidity to the bending in the transverse direction than in the longitudinal.
- ✓ Regarding the "2HB" response variable (compressional resilence): the values are higher than those obtained in knitted fabrics, being similar in both directions. Being taller, this tissue has less resilience than the knitted tissues studied.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
More flexible in the longitudinal direction than in the transversal.
Lower recovery capacity. Limited elasticity.

Table 17 – Table of cotton - polyester (woven) bending properties before yarns inserted

COTTON - FABRIC

- ✓ Regarding the "B" response variable (bending rigidity); the cotton fabric presents similar values in both directions.Therefore, it can be enhanced that it has a fairly rigid bending. The highest between the studied tissues.
- ✓ Regarding the "2HB" response variable (compressional resilence): the values are higher than those obtained in knitted fabrics, being similar on both sides. Being taller, this fabric has less resilience than the knitted fabrics studied and the cotton fabric - polyester.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE COMPRESSION TEST
Particularly low flexibility in both directions of tissue.
Lower recovery capacity. Meager elasticity

Table 18 – Table of cotton (woven) bending properties before yarns inserted

5.2.4 SHEAR TESTER

COTTON - POLYESTER FABRIC

- ✓ Regarding the “G" response variable (shear stiffness):, the value obtained in the transverse direction is higher than in the longitudinal direction. This shows that this type of fabric has a lower rigidity compared to the shear/shear force in the transverse direction than in the longitudinal one, which is more rigid.
- ✓ Regarding the “2HG" response variable (capacity of recovery to the shear effot): the value obtained in the transverse direction is higher than in the one in longitudinal direction. This means that this tissue has a lower deformation capacity in the transverse direction than in the longitudinal one, which decreases by almost half.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SHEAR TEST
Low shear force stiffness in the transverse direction than in the longitudinal direction
Low recovery capacity from cutting/shearing effort in the transverse and longitudinal direction.

Table 19 – Table of cotton - polyester (woven) shear properties before yarns inserted

COTTON FABRIC

- ✓ Regarding the “G" response variable (shear stiffness): the value obtained in the transverse direction is higher than in the longitudinal direction. This shows that this type of fabric has a lower rigidity compared to the shear/shear force in the transverse direction than in the longitudinal one, which is more rigid.
- ✓ Regarding the “2HG" response variable (capacity of recovery to the shear effot): the value obtained in the transverse direction is fairily similar to the one obtained in the longitudinal direction. This supposes that this tissue is the tissue that has the least capacity to recover from the deformation cut/shear.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE SHEAR TEST
Low stiffness to shear/shear force in the transverse direction than in the longitudinal.
Low recovery capacity from cutting/shearing effort in the transverse and longitudinal direction.

Table 20 – Table of cotton (woven) shear properties before yarns inserted

5.2.5 TENSILE TESTER

COTTON - POLYESTER FABRIC

- ✓ Regarding the “RT " response variable (tensile resilence): it has similar values on both sides, of 51.83% doing the average. This means that it has a medium resilience.
- ✓ Regarding the “WT " response variable (stretching capacity): it presents very similar values in both directions. These values are lower than those obtained when studying knitting tissue. Therefore, it has a lower (rather lower) stretch capacity than knitted tissue
- ✓ Regarding the “LT " response variable (traction stiffness): this type of tissue has a value just close to 1, therefore the average tension that it presents is not firm.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE TENSILE TEST
Medium capacity of recovery.
Particularly low stretching capacity.
Weak medium tension

Table 21 – Table of cotton - polyester (woven) tensile properties before yarns inserted

COTTON FABRIC

- ✓ Regarding the “RT " response variable (tensile resilence): it has a value of 76.11% making the average. This means that it has a high recovery capacity, greater than the one obtained in cotton - polyester fabric.
- ✓ Regarding the “WT " response variable (stretching capacity): it has fairily low values in both directions. This means that this tissue has very little stretching capacity, being the least of all the tissues studied in terms of streching capacity.
- ✓ Regarding the “LT " response variable (traction stiffness): this type of tissue has a value just close to 1, therefore the average tension that it presents is not firm.

PROPERTIES - REGARD TO THE RESULTS OBTAINED AFTER THE TENSILE TEST
Medium capacity of recovery.
Particularly low stretching capacity.
Weak medium tension

Table 22 – Table of cotton (woven) tensile properties before yarns inserted

5.3 FIRST TESTS CARRIED OUT ON KNITTED FABRICS | WITHOUT INSERTION OF CONDUCTIVE THREAD

5.3.1 RESULTS | SURFACE TESTER

The corresponding statistical table with the response variable "MIU" is presented. In this way, it is possible to observe which are the factors that have the most influence regarding coeffient of friction.

```
Coefficients:
                Estimate Std. Error t value  Pr(>|t|)
(Intercept)     0.375813   0.022286  16.863   < 2e-16 ***
YARN.L          0.078724   0.022286   3.532  0.000842 ***
YARN.Q         -0.098406   0.022286  -4.416 0.0000476 ***
YARN.C          0.038167   0.022286   1.713  0.092423 .
MATERIAL[T.B]  -0.101438   0.031517  -3.218  0.002163 **
MATERIAL[T.C]  -0.084938   0.031517  -2.695  0.009320 **
MATERIAL[T.D]  -0.079938   0.031517  -2.536  0.014073 *
DIRECTION1      0.010828   0.011143   0.972  0.335438
SIDE1           0.003266   0.011143   0.293  0.770578
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.08914 on 55 degrees of freedom
Multiple R-squared:  0.4678, Adjusted R-squared:  0.3904
F-statistic: 6.043 on 8 and 55 DF,  p-value: 0.00001447
```

Image 39 – Corresponding statistical table with the response variable "MIU"

So, in this table, it is possible observe that the yarn and the material are the two factors more important regarding coefficient of friction. Being the most significat the kind of yarn that are inserted that the kind of material.

In addition, the model has a determination coefficient 46,78%, so it can be decided that the model predicts not very well the behavior of the response variables studied in this design of experiments.

Bellow is the statistical table obtined for the response variable “MMD”:

```
Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.0185562  0.0022537   8.234 3.63e-11 ***
YARN.L          0.0150809  0.0022537   6.692 1.21e-08 ***
YARN.Q         -0.0121219  0.0022537  -5.379 1.58e-06 ***
YARN.C          0.0060472  0.0022537   2.683  0.00961 **
MATERIAL[T.B]   0.0135000  0.0031872   4.236 8.74e-05 ***
MATERIAL[T.C]   0.0038375  0.0031872   1.204  0.23373
MATERIAL[T.D]   0.0161563  0.0031872   5.069 4.84e-06 ***
DIRECTION1      0.0003922  0.0011268   0.348  0.72914
SIDE1           0.0009516  0.0011268   0.844  0.40207
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.009015 on 55 degrees of freedom
Multiple R-squared:  0.6797, Adjusted R-squared:  0.6331
F-statistic: 14.59 on 8 and 55 DF,  p-value: 3.575e-11
```

Image 40 – Corresponding statistical table with the response variable "MMD"

In this case, the resopnse variable that it studied is the fluctuation (variation) to the surface esffort.

So, in this table, it is possible observe that the yarn and the material are the two factors more important regarding coefficient of friction. The inserted yarns are almost as important as the material of each prototype.

Furthermore, the model has a determination coefficient 67,97%, so it can be decided that the model predicts well the behavior of the response variables studied in this design of experiments.

Finally this third table is the statistical table obtained for the response variable "SMD":

```
Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)      4.7928     0.4671  10.260 2.21e-14 ***
YARN.L           2.6948     0.4671   5.769 3.79e-07 ***
YARN.Q          -3.1862     0.4671  -6.821 7.42e-09 ***
YARN.C          -0.7590     0.4671  -1.625  0.10991
MATERIAL[T.B]    2.1656     0.6606   3.278  0.00182 **
MATERIAL[T.C]    0.4684     0.6606   0.709  0.48128
MATERIAL[T.D]    2.0928     0.6606   3.168  0.00251 **
DIRECTION1       0.1833     0.2336   0.785  0.43596
SIDE1           -0.2488     0.2336  -1.065  0.29151
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.869 on 55 degrees of freedom
Multiple R-squared:  0.6478, Adjusted R-squared:  0.5966
F-statistic: 12.64 on 8 and 55 DF,  p-value: 4.237e-10
```

Image 41 – Corresponding statistical table with the response variable "SMD"

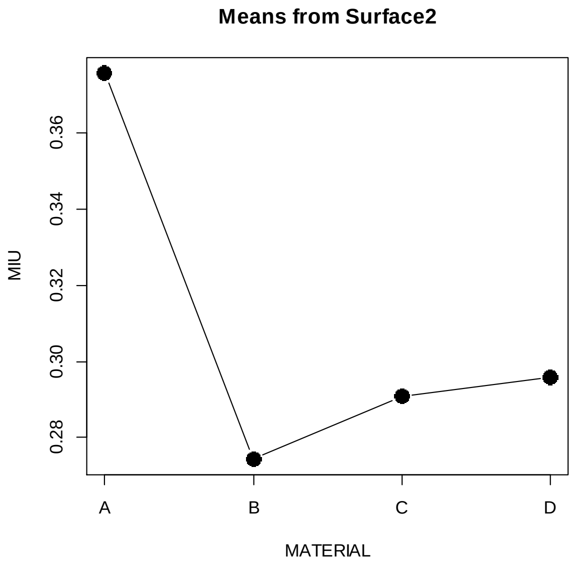
So, in this table, it is possible observe that the yarn and the material are the two factors more important regarding geometric roughness. Being the most significat the kind of yarn that are inserted that the kind of material.

In addition, the model has a determination coefficient 64,78%, so it can be decided that the model predicts well the behavior of the response variables studied in this design of experiments.

5.3.1.1 Influence of the material regarding "MIU", “MMD” and “SMD”:

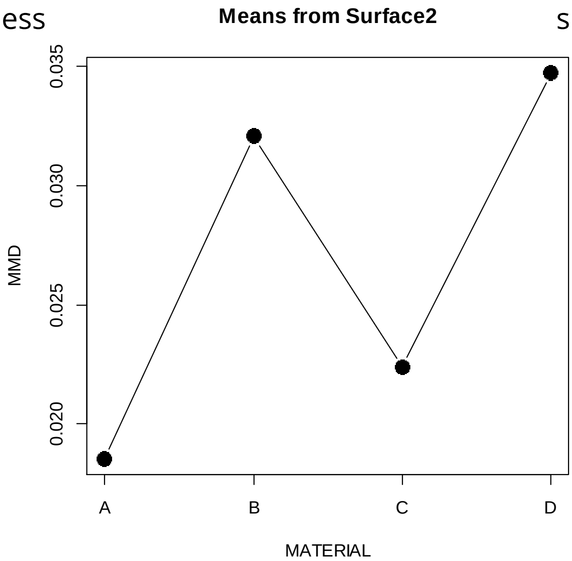
In this graphic it possible observe how the cotton-elastane (knitted) (A) material has the highest value and therefore is the one with the lowest tendency to slip.
The other have lower values although the difference is not very big between values. So these fabrics have a greater tendency to slip.

This coulb be due to the kind of structure that present each prototype.



Graphic 1 – Influence of the material regarding "MIU"

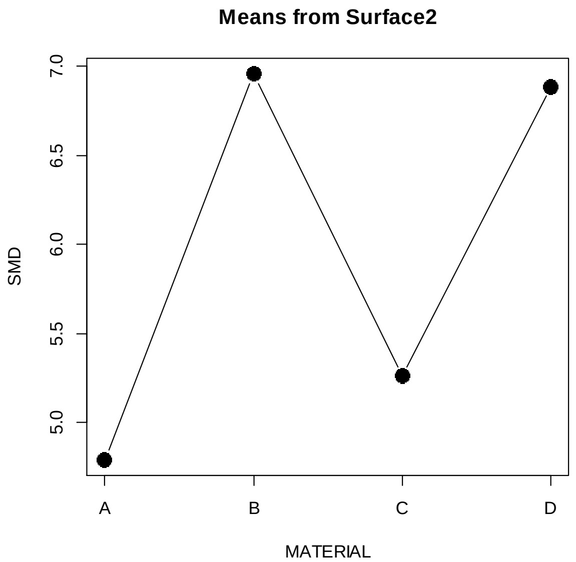
So this table present more differences between the materials and the response variable studied (MMD). It possible observe how the prototype that present a woven structure (B) (D) have a higher fluctuation due to friction coefficient and that's why they have less smoothness and more surface roughness.



Graphic 2 – Influence of the material regarding "MMD"

On the other hand, the prototype that present a knitted structure (A) (C) have less fluctuation due to friction coefficient and that's why they have higher smoothness and less Surface roughness.

In this table, values very similar to the previous table are obtained. It can be seen that fabrics with a woven structure (B) (D) have greater surface roughness than those with a knitted structure (A) (C).

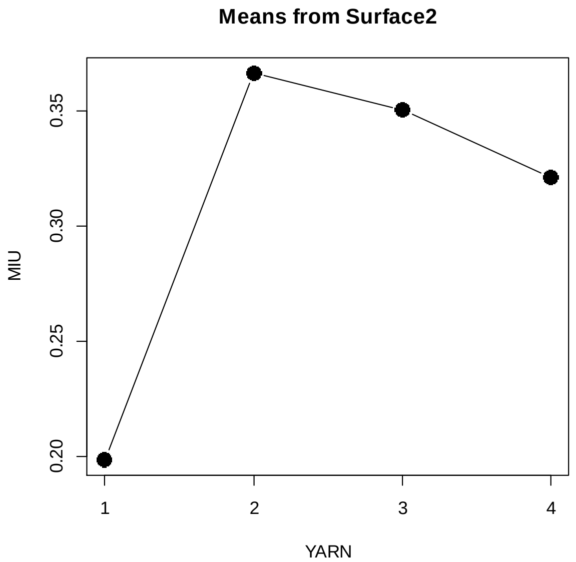


Graphic 3 – Influence of the material regarding "SMD"

5.3.1.2 Influence of the conductive yarns regarding "MIU", "MMD" and "SMD":

In this graph it possible observe clearly that the fabric without yarn inserted (1) has the lowest "MIU" value and so that means it is the one with the greatest tendency to slip.

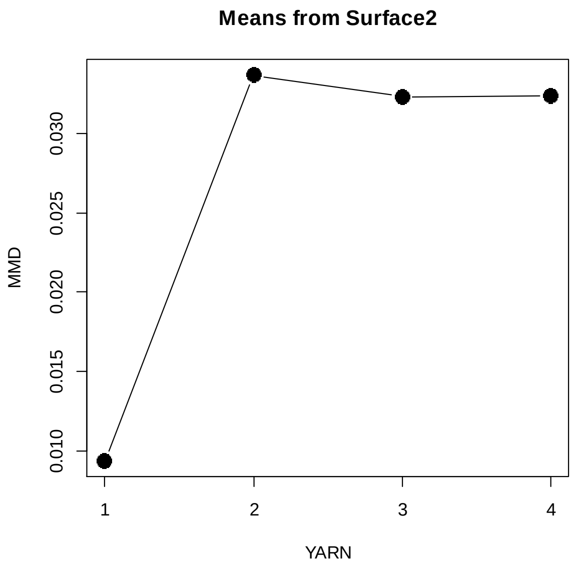
So the other prototypes which have conductive yarns inserted (2) (3) (4) have the highest "MIU" value and so this means that when the conductive yarns are inserted into the prototypes they are much less likely to slip.



Graphic 4 – Influence of the conductive yarn regarding "MIU"

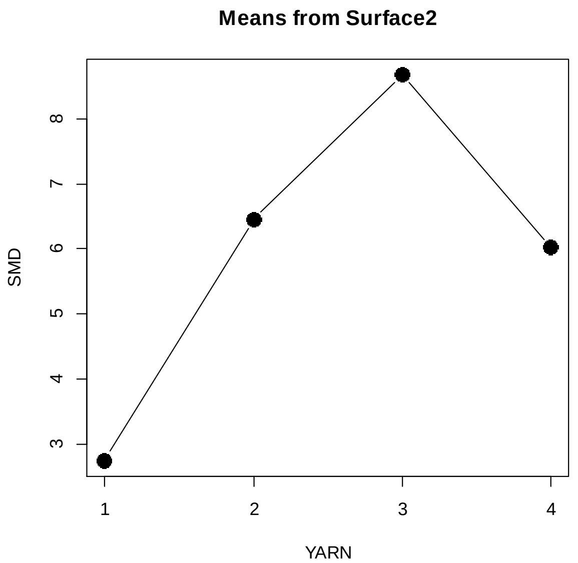
This graph shows the efecto to insert conductive yarns into prototypes due to "MMD" value and it possible observe so clearly what happen. Whe the prototype hasn't a conductive yarn inserted presents the lowest "MMD" value and this means that it has more smoothness and less surface roughness.

Conversely, when this insertion of conductive yarns (2) (3) (4) is carried out, the surface roughness increases and the softness decreases.



Graphic 5 – Influence of the conductive yarn regarding "MMD"

This graph refers to surface roughness. It can be seen how the insertion of threads (2) (3) (4) causes and increase in surface roughness in the tissue, being of different levels depending on the conductive thread inserted. Consequently, the prototype wihout a conductive wire has the least surface roughness.

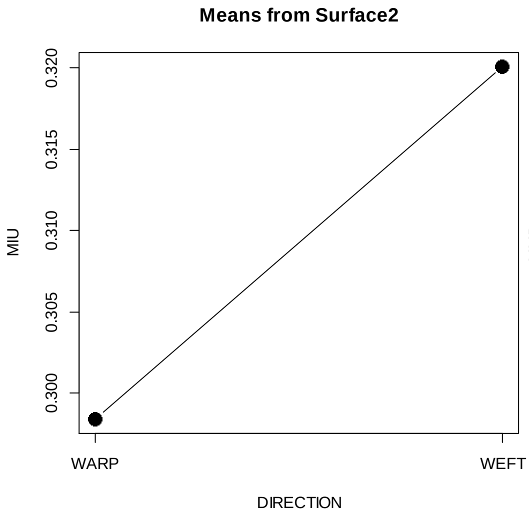


Graphic 6 – Influence of the conductive yarn regarding "SMD"

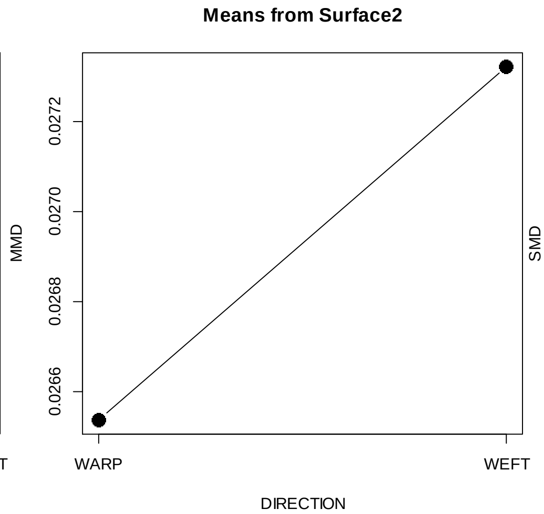
5.3.1.3 Influence of the study of the directions of the yanrs in the fabric regarding "MIU", "MMD" and "SMD":

In the study of the directions of the yarn in this type (WARP and WEFT) of test, the difference in values obtained is minimal. Therefore, the three graphs have been put together to clearly observe how this difference is minimal and always, for the three response variables (MIU, MMD, SMD), they behave in the same way, with the WEFT direction always being a little higher.

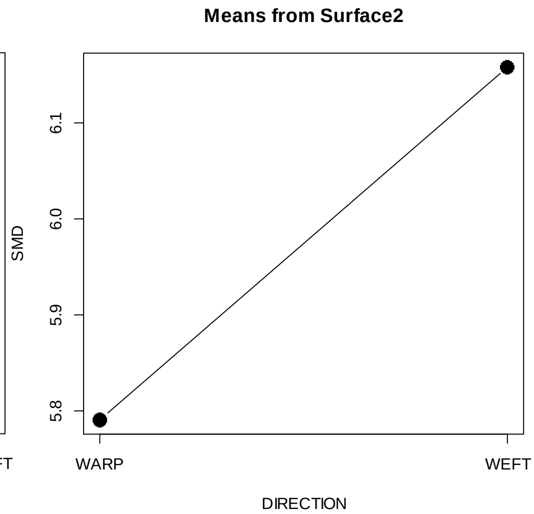
Thus this difference presents a small lesser tendency to slip, less smoothness and a minimal greater surface roughness.



Graphic 7 – Influence of the direction regarding "MIU"



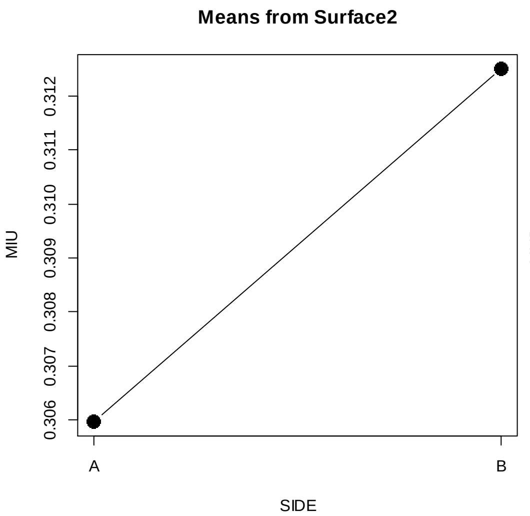
Graphic 8 – Influence of the direction regarding "MMD"



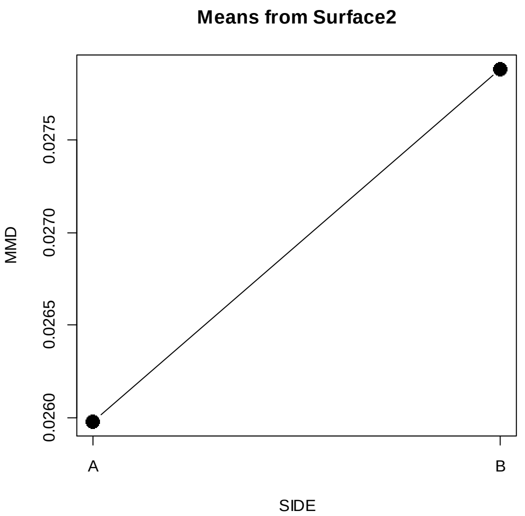
Graphic 9 – Influence of the direction regarding "SMD"

5.3.1.4 Influence of the study of the fabric's sides regarding "MIU", "MMD" and "SMD":

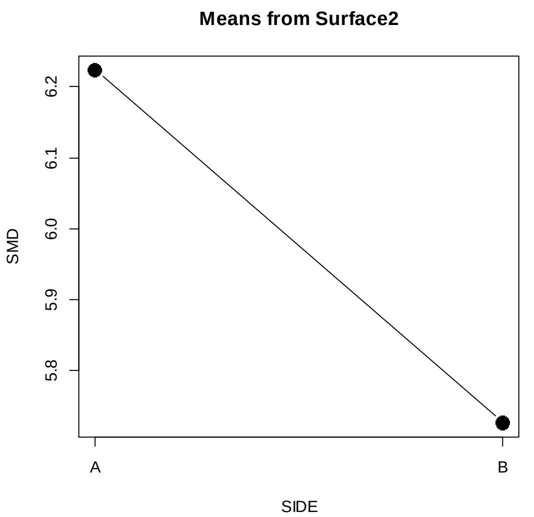
As in the previous section, the difference in values obtained with respect to the study of the faces of the fabric is minimal.



Graphic 10 – Influence of the side regarding "MIU"



Graphic 11 – Influence of the side regarding "MMD"



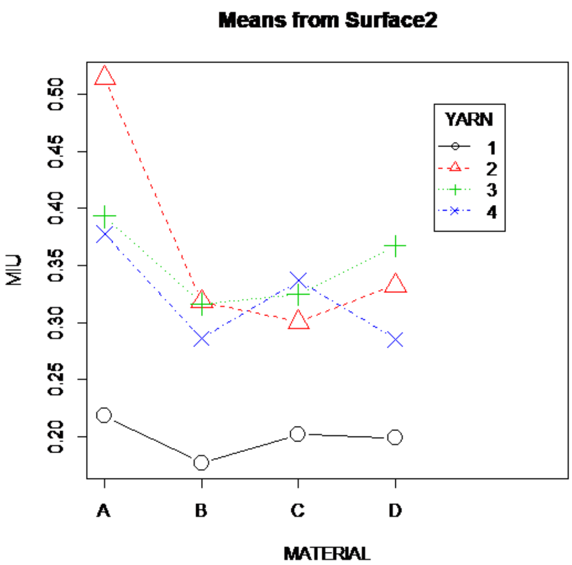
Graphic 12 – Influence of the side regarding "SMD"

All three are presented together as they behave in the same way for all three response variables. It can be seen that in the graph corresponding to “SMD", surface roughness (the third one), there is a change and the behavior is the opposite. But the difference between one value and another is so minimal that it can be considered that both sides of the fabric continue to behave in the same way for this response variable.

5.3.1.5 Interactions of materials and conductivity yarns regarding “MIU”,”MMD” and “SMD”:

With regard to the sliding tendency “MIU", it can be perfectly observed how the prototypes without inserted conductive wire have a greater tendency to slide. Meanwhile, as this insertion of conductive wires is carried out, this value increases and therefore the tendency to slip is lower. It can be seen that for each fabric, the prototype with the least tendency to slip depends on the conductive thread that is inserted.

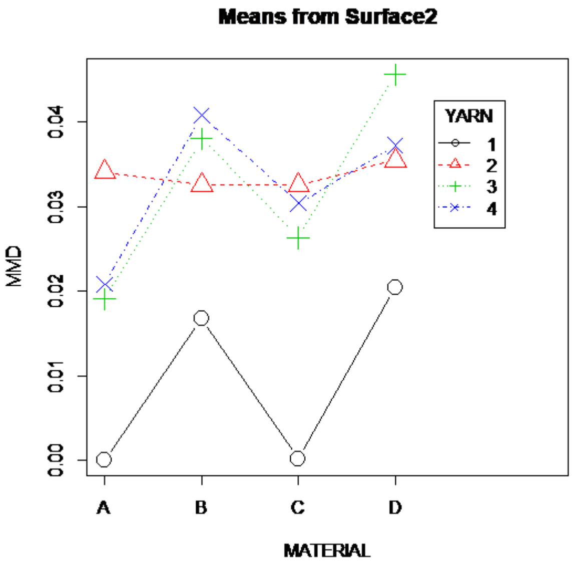
So in the cotton-polyester prototype (D), the yarn that most reduces this trend is the multifilament stainless steel (3). For the cotton material (woven) (B) the most influential thread is the multifilament stainless steel (3) almost as much as the multifilament stainless steel (2). In cotton (knitted) (C) the multifilament stainless steel (2) and the monofilament with conductive covered (4) almost the same. And in the prototype cotton-polyester (D), the most influential thread is the multifilament stainless steel (3) almost as much as the multifilament stainless steel (2).



Graphic 13 – Interactions of materials and conductivity yarns regarding “MIU”

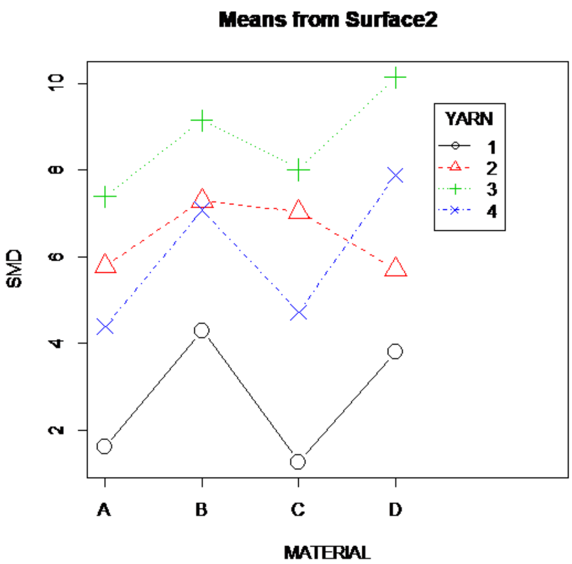
Regarding the friction coefficient, it can be seen that all the prototypes have a greater smoothness and less roughness without thread insertion (woven fabrics (B) (D) have less smoothness and more roughness than knitted fabrics (A) (C)). With the threads inserted this softness decreases and the surface roughness increases.

It can be seen that in woven fabrics, the multifilament stainless steel (3) yarn is the one that most varies this property, followed by the multifilament stainless steel (2). On the other hand, in the case of knitted fabrics (A) (C), the opposite happens. The most variable property is multifilament stainless steel (2) followed by multifilament stainless steel (3).



Graphic 14 – Interactions of materials and conductivity yarns regarding "MMD"

With regard to the surface roughness, it can be seen, in a certain order, which are the threads that have the greatest influence to vary this property according to the material. If we look at it this way (from top to bottom), the wire that most increases surface roughness is the multifilament stainless steel (3), followed by the multifilament stainless steel (2), then the monofilament with conductive covered (4) and finally, the prototypes without insertion of conductive yarns (1).



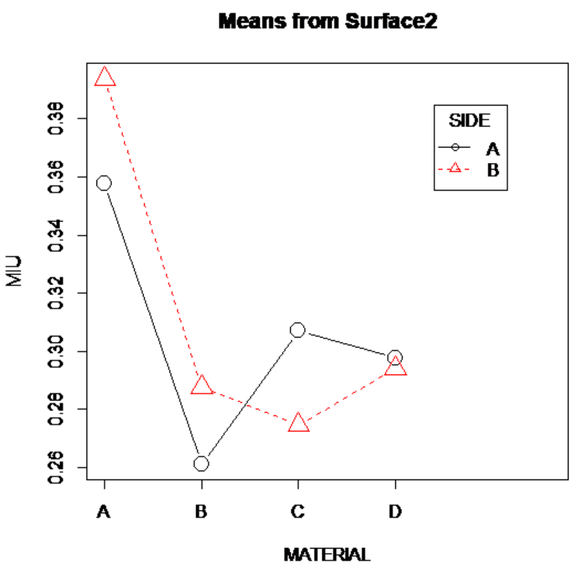
Graphic 15 – Interactions of materials and conductivity yarns regarding "SMD"

As can also be seen, the prototypes with the greatest surface roughness once the conductive yarns have been inserted are woven fabrics (B) (D), and secondly, yarns with a knitted structure (A) (C).

5.3.1.6 Interactions of materials and fabric's sides regarding "MIU","MMD" and "SMD":

Respect the MIU response variable and the fabric-side interaction, it can be seen that both faces practically follow the same behaviour except in materials cotton (knitted) (C) and cotton-polyester (woven) (D), which vary a little bit. For materials cotton-elastane (knitted) (A) and cotton (woven) (B), the difference being very small, face A has less tendency to slide than back side (B). On the other hand, in cotton (knitted) material (C) it is the opposite and in material cotton-polyester (woven) (D) there is hardly any difference.

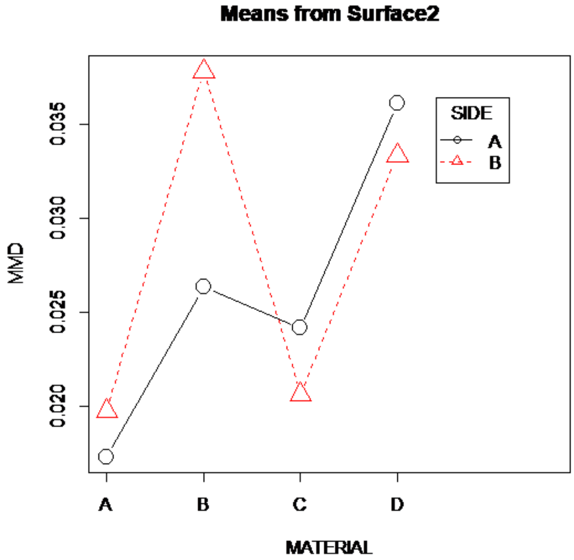
Even so, the difference in values obtained between the two sides is very small. So they behave pretty much the same way.



Graphic 16 – Interactions of materials and fabric's sides regarding "MIU"

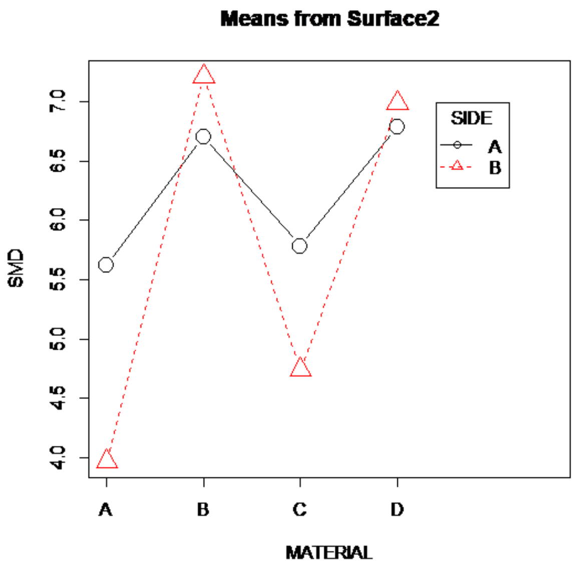
Regarding the MMD response variable, it can be seen that in materials cotton-elastane (knitted) (A) and cotton (knitted) (B) the smoothness is lower and the roughness higher on the front side (A) than on the back side (B). In materials and cotton-polyester (woven) (D) and cotton (knitted) materual (C) it is the opposite, but, the variation is so small that they have practically the same smoothness and surface roughness on both sides.

In the graph it can see perfectly how the cotton (woven) material (B) is the least smooth surface and the most roughness.



Graphic 17 – Interactions of materials and fabric's sides regarding "MMD"

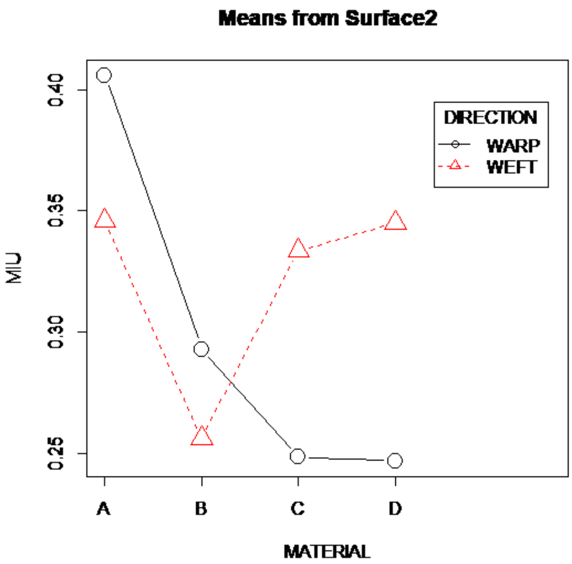
Regarding the SMD variable response, materials cotton-elastane (knitted) (A) and cotton knitted (C) show the same behaviour. On the front side (A) side the surface roughness is a little higher than on the back side (B). The same happens with the cotton (woven) (B) and cotton-polyester (D) materials, they have the same behaviour but this time the surface roughness is higher on the back side (B).



Graphic 18 – Interactions of materials and fabric's sides regarding "SMD"

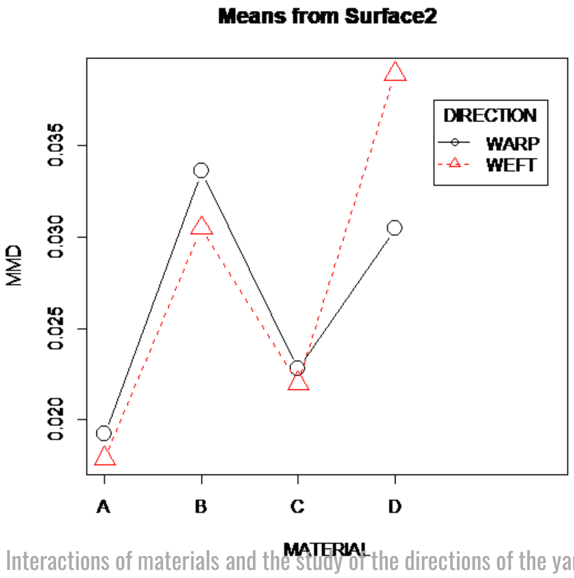
5.3.1.7 Interactions of materials and the study of the directions of the yanrs regarding “MIU”,”MMD” and “SMD”:

With respect to the variable MIU response, it is observed that in the WEFT direction the tendency to slip is less than in the WARP direction for materials cotton – elastane (A) and cotton (woven) (B). In the cotton knitted (C) and cotton-polyester (D) materials the opposite occurs; in the WEFT direction this tendency to slip is less.



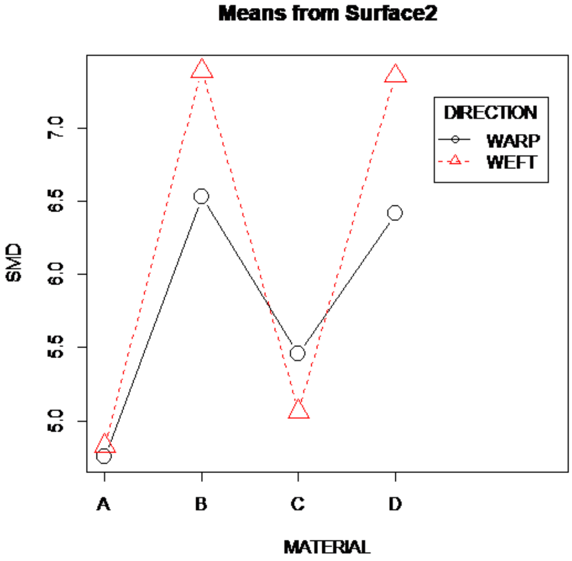
Graphic 19 – Interactions of materials and the study of the directions of the yanrs regarding “MIU”

With respect to the variable MMD response, materials cotton – elastane (knitted) (A) cotton (woven) (B) and cotton knitted (C) show less smoothness and greater surface roughness in the WARP direction. In contrast, in material cotton – polyester (D) it is the other way around. The surface roughness is higher in the WEFT direction decreasing the surface smoothness.



Graphic 20 – Interactions of materials and the study of the directions of the yanrs regarding "MMD"

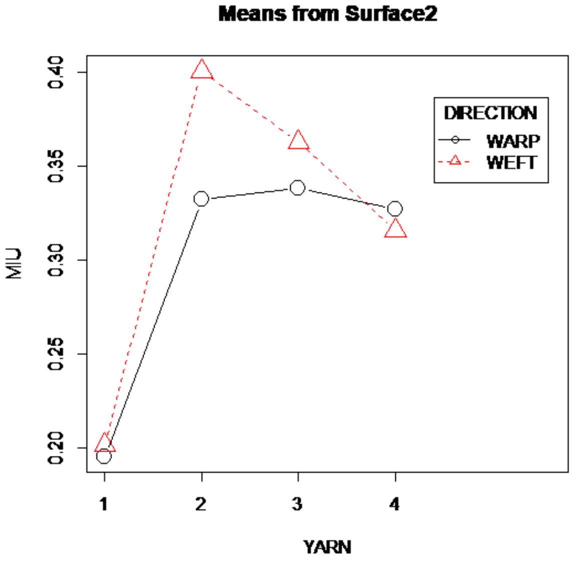
Finally, with respect to the variable SMD response, cotton – elastane (knitted) (A), cotton (woven) and (B) cotton – polyester (D) materials present greater surface roughness in the WEFT direction, while material cotton knitted (C) presents greater surface roughness in the WARP direction.



Graphic 21 – Interactions of materials and the study of the directions of the yanrs regarding "SMD"

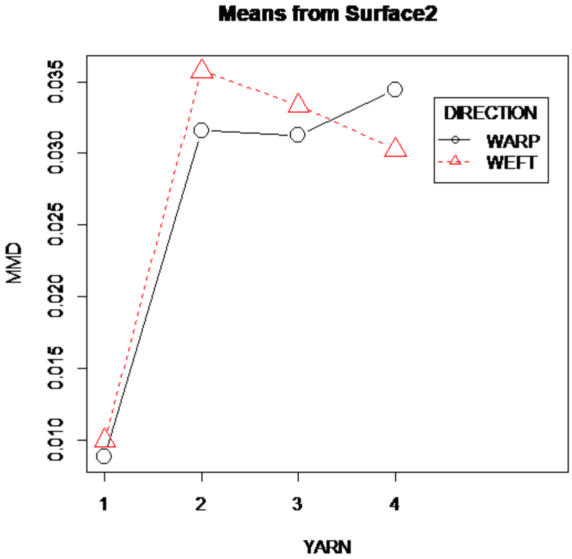
5.3.1.8 Interaction of conductive yarns and the study of the directions of the yanrs regarding “MIU”,”MMD” and “SMD”:

With respect to the MIU, it can be seen that in the prototypes withoy conductive yarn inserted (1) there is hardly any difference between the warp and weft directions. On the other hand, when each of the conductive wire insertions (2) (3) (4) is insert, it can be seen that the behaviour is the same: in the WARP direction the tendency to slip is greater and in the WEFT direction less.



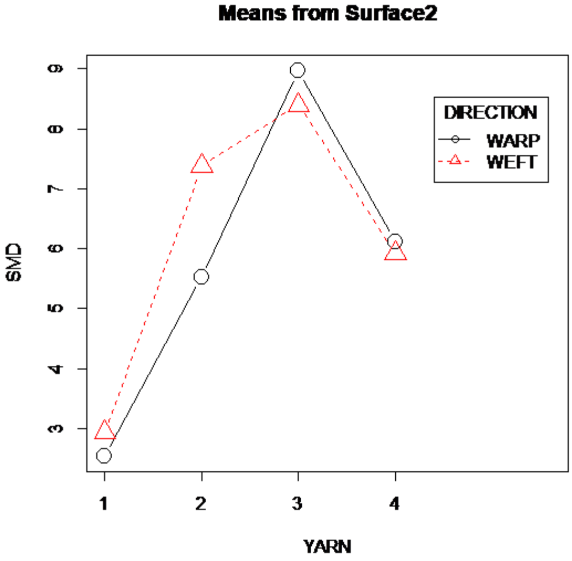
Graphic 22 – Interactions of conductive yarns and the study of the directions of the yanrs regarding “MIU”

As for the MIU, it's the same way. on prototypes without insertion of a conductive yarn (1) there is little difference between WEFT and WARP direction. On the other hand, as the yarns are inserted multifilament stainless steel (2) multifilament stainless steel (3) and monofilament with conductive covered (4), in the WEFT direction the smoothness is lower and the surface roughness is higher; and in the WARP direction the opposite.



Graphic 23 – Interactions of conductive yarns and the study of the directions of the yanrs regarding “MMD”

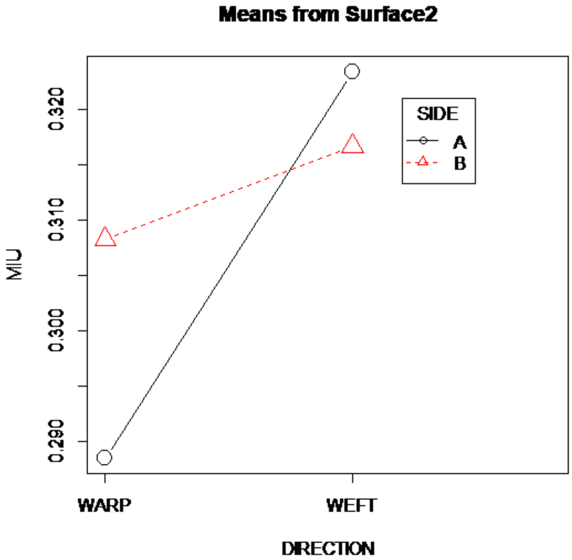
Finally, in prototypes without insertion of yarns (1) the behaviour in both directions is practically the same. On the other hand, in prototypes with the insertion of conductive yarns multifilament stainless steel (2) multifilament stainless steel (3) and monofilament with conductive covered (4) the surface irregularities increase, the increase being practically the same in both directions.



Graphic 24 – Interactions of conductive yarns and the study of the directions of the yanrs regarding "SMD"

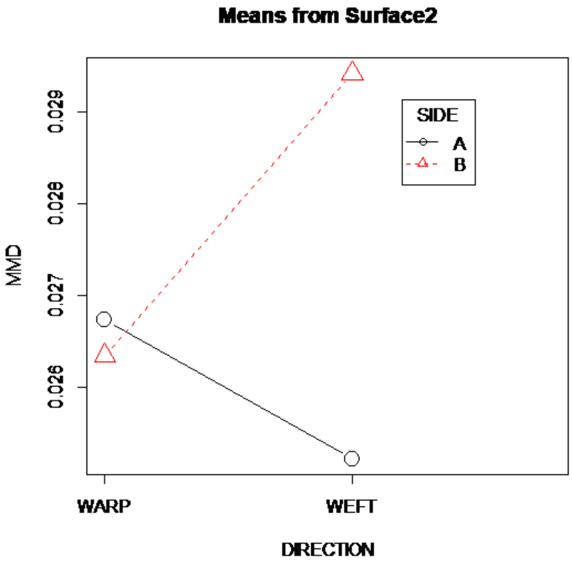
5.3.1.9 Interactions of fabric's sides the study of the directions of the yanrs regarding "MIU","MMD" and "SMD":

The WARP and WEFT directions with respect to interaction at the MIU with the fabric's sides behave in opposite ways. In the WARP direction the tendency to slip is less on the back side (B) than on the front side (A). In the WEFT direction the opposite occurs; the tendency to slip is less in the WARP direction than in the WEFT.



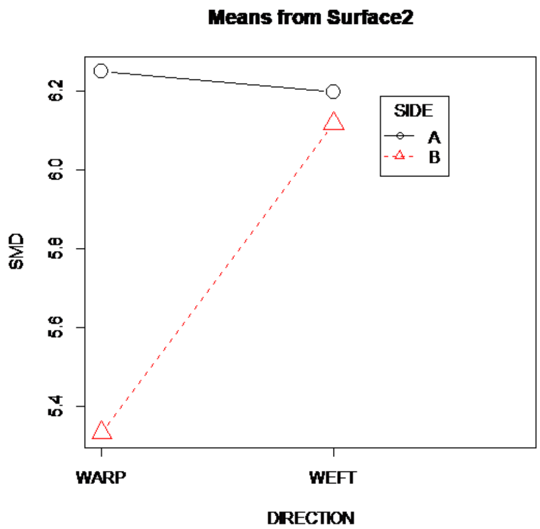
Graphic 24 – Interactions of fabric's sides the study of the directions of the yanrs regarding "MIU"

The WARP and WEFT directions with respect to the interaction in MMD with the fabric's sides present opposite behaviours. In the WARP direction the surface roughness is greater on the front side (A) side than on the back side (B) side, while in the WEFT direction this surface roughness is greater on the back side (B) side than on the front side (A).



Graphic 25 – Interactions of fabric's sides the study of the directions of the yanrs regarding "MMD"

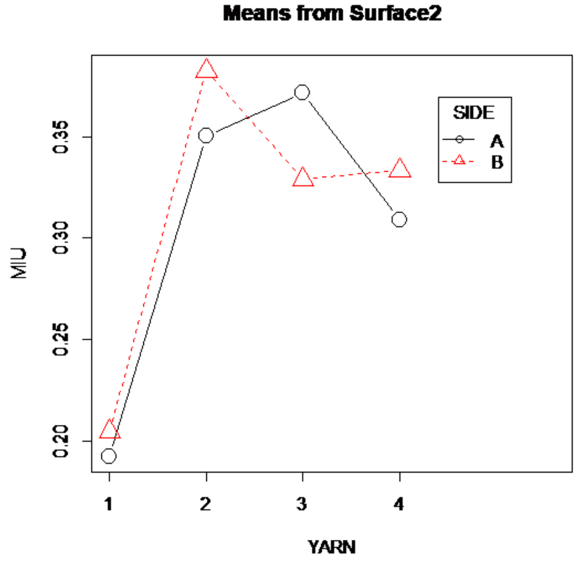
The WARP and WEFT directions with respect to the interaction in SMD, in this case, present the same behavior. For both directions the surface irregularities are greater on front side (A) than on back side (B). Face A presents practically identical values in both directions, while on face back side (B) the surface irregularities are much greater in the WEFT direction.



Graphic 26 – Interactions of fabric's sides the study of the directions of the yanrs regarding "SMD"

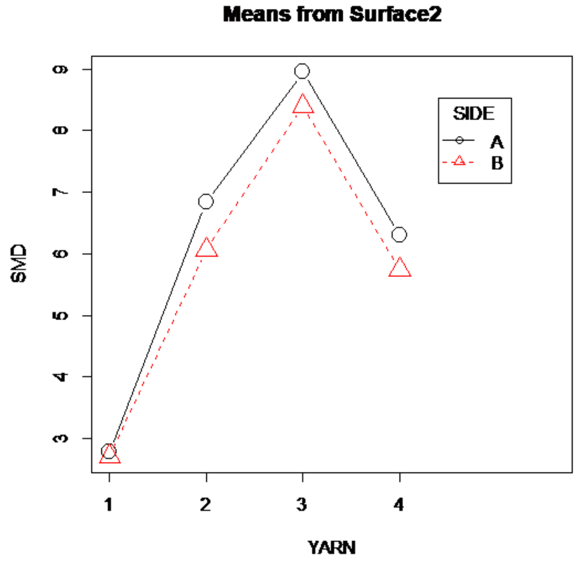
5.3.1.10 Interaction of fabric's sides the conductive yanrs regarding "MIU","MMD" and "SMD":

This graph shows how in the prototypes without a conductive yarn (1) the tendency to slip is much lower and the behaviour in both directions is the same. On the other hand, as the yarns multifilament stainless steel (2) multifilament stainless steel (3) and monofilament with conductive covered (4) are inserted, this tendency to slip is less and less, being in the yarns multifilament stainless steel (2) and monofilament with conductive covered smaller in the back side (B) and in the multifilament stainless steel (3) larger in the front (A) side.



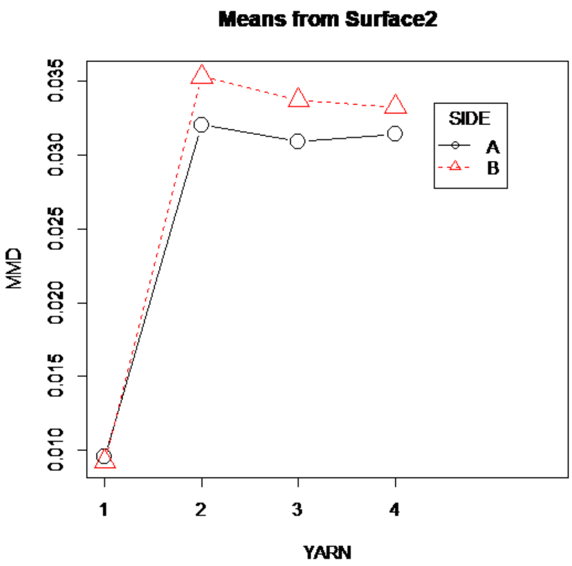
Graphic 27 – Interactions of fabric's sides the study of fabric's sides the conductive yanrs regarding "MIU"

This graph shows how the smoothness is much higher and the surface roughness is lower in prototypes without a conductive wire (1). However, as the threads are inserted, the softness decreases and the roughness is greater. In the conductive yarns multifilament stainless steel (2) multifilament stainless steel (3) and monofilament with conductive covered (4) this surface roughness is higher on the back side (B) than on the front side (A).



Graphic 28 – Interactions of fabric's sides the study of fabric's sides the conductive yanrs regarding "SMD"

Finally, this graph shows how in the prototypes without a conductive yarn inserted (1) the surface irregularities are much less. On the other hand, as the conductive yarns multifilament stainless steel (2) multifilament stainless steel (3) and monofilament with conductive covered (4) are inserted, the surface irregularities are greater on back side (B) than on the front side (A).



Graphic 29 – Interactions of fabric's sides the study of fabric's sides the conductive yanrs regarding "MMD"

5.3.2 RESULTS | COMPRESSION TESTER

Firstly, the corresponding statistical table with the response variable "WC" is presented. In this way, it is possible to observe which are the factors that have the most influence regarding bending rigidity.

```
Residuals:
     Min       1Q   Median       3Q      Max
-0.49287 -0.13150  0.01488  0.20037  0.47988

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.59650    0.17197   3.469  0.00706 **
YARN.L         0.09615    0.17197   0.559  0.58972
YARN.Q        -0.76925    0.17197  -4.473  0.00155 **
YARN.C         0.07155    0.17197   0.416  0.68709
MATERIAL[T.B]  0.51550    0.24320   2.120  0.06307 .
MATERIAL[T.C] -0.07650    0.24320  -0.315  0.76027
MATERIAL[T.D] -0.16950    0.24320  -0.697  0.50343
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3439 on 9 degrees of freedom
Multiple R-squared:  0.7695, Adjusted R-squared:  0.6158
F-statistic: 5.006 on 6 and 9 DF,  p-value: 0.01599
```

Image 42 – Corresponding statistical table with the response variable "WC"

It can be seen thath one oof the inserted threads is quite significant as well as the first material for the "WC" response variable, corresponding to compression susceptibility.

In addition, the model has a determination coefficient 76. 95%, so it can be decided that the model predicts very well the behavior of the response variables studied in this design of experiments.

Below is the statistical table obtained for the response variable "RC":

```
Residuals:
   Min     1Q Median     3Q    Max
-6.170 -3.462 -1.210  3.064  8.188

Coefficients:
              Estimate Std. Error t value   Pr(>|t|)
(Intercept)     33.717      2.913  11.573 0.00000105 ***
YARN.L          -8.889      2.913  -3.051   0.013765 *
YARN.Q           4.202      2.913   1.442   0.183049
YARN.C          -4.418      2.913  -1.517   0.163673
MATERIAL[T.B]   11.840      4.120   2.874   0.018366 *
MATERIAL[T.C]    2.190      4.120   0.532   0.607916
MATERIAL[T.D]   22.440      4.120   5.446   0.000408 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.827 on 9 degrees of freedom
Multiple R-squared:  0.8498, Adjusted R-squared:  0.7497
F-statistic: 8.487 on 6 and 9 DF,  p-value: 0.002714
```

Image 43 – Corresponding statistical table with the response variable "RC"

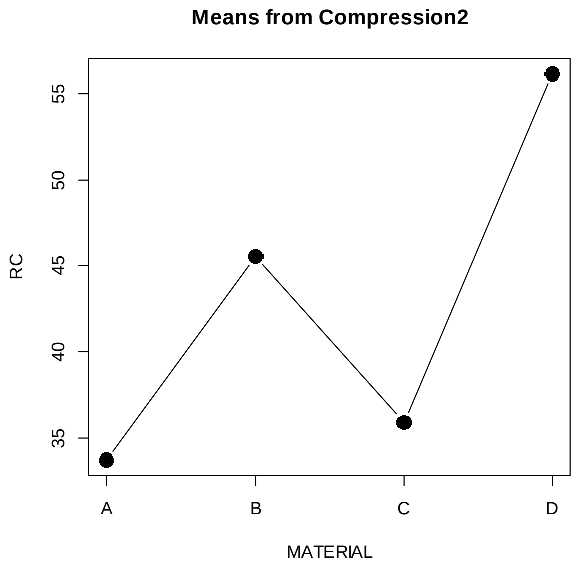
In this case, for the response variable “RC" corresponding to the capacity of recovery from the effort of compression, it is observed as one of the conductive yarns, as well as two of the materials studied being quite significant for this variable.

In addition, the model has a determination coefficient 84. 98%, so it can be decided that the model predicts very well the behavior of the response variables studied in this design of experiments.

5.3.2.1 Influence of the material regarding "RC”:

The graph shows that the cotton-elastane prototype (A) and the cotton prototype (knitting) (C) have a fairly similar behaviour in terms of recovery capacity from compression stress. being the least resilient.

The cotton (woven) (B) material presents an intermediate behaviour, and, the most differentiated behaviour, with a much higher capacity for recovery from the effort of compression is the cotton-polyester (knitting) (D) prototype, this is because it is the most flexible structure of all.

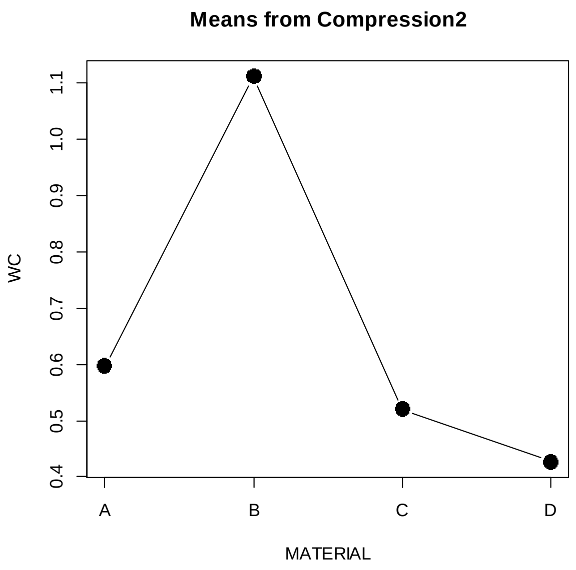


Graphic 30 – Influence of the material regarding "RC”

5.3.2.2 Influence of the material regarding "WC”:

The graph shows that the materials that the cotton-elastane prototype (woven) (B) and the cotton prototype (knitting) (C) present a quite similar behaviour with respect to the compression susceptibility.

The cotton (woven) (B) material, due to its structure, is the most susceptible to the effort of compression, whereas the cotton-polyester (knitting) (D) material is the least susceptible to the effort of compression.

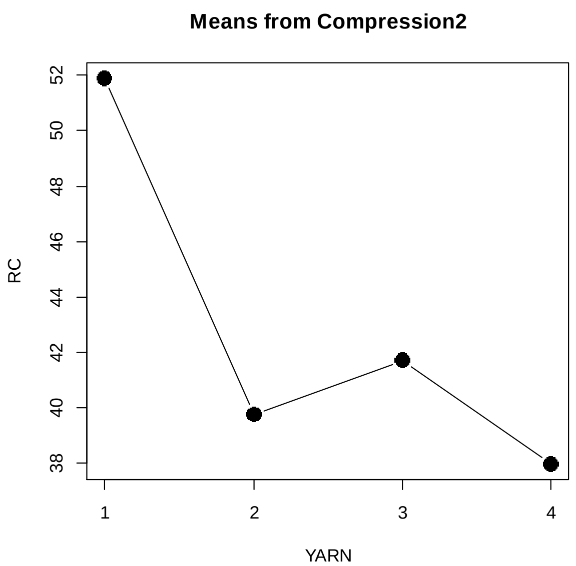


Graphic 31 – Influence of the material regarding "WC"

5.3.2.3 Influence of insertion of conductive yarns regarding "RC":

The graph shows that the prototype without insertion of conductive thread is the one with the greatest capacity for recovery from the effort of compression. thus, the conductive yarns of the blue (2) and red circuits (3) show similar behaviors, since the inserted yarn is quite similar in one case and in the other.

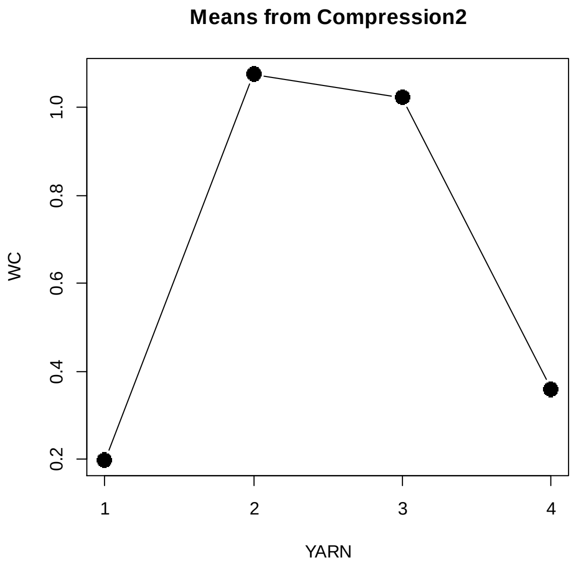
Finally, the one with the least capacity for recovery from the effort of understanding is the monofilament with conductive coverage thread (4).



Graphic 32 – Influence of insertion of conductive yarns regarding "RC"

5.3.2.4 Influence of insertion of conductive yarns regarding "WC":

The graph shows that the prototype without insertion of conductive yarn (1) is the least susceptible to compression. On the other hand, the rest of the conductive threads, there is a difference regarding their influence on the susceptibility to the effort of compression, but, it is such a low difference, that it can be observed that practically all of them influence, in a similar way, much more than the prototype without conductive threads.



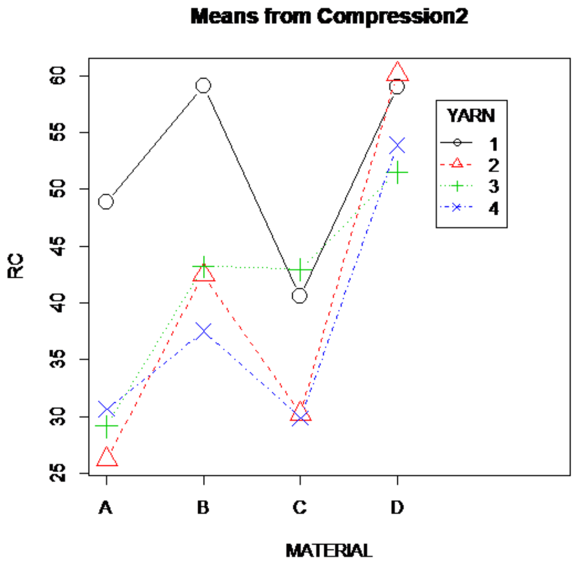
Graphic 33 – Influence of insertion of conductive yarns regarding "WC"

5.3.2.5 Interactions of materials and conductive yarns regarding “RC”:

The behavior of the conductive wires in the prototype of cotton-elastane (woven) (A), is quite similar, presenting low behavior of recovery capacity. on the other hand, it is observed that the fabric without insertion of threads (1) presents a better capacity of recovery in front of the effort of understanding.

The prototype of cotton (woven) (B), the conductive threads make this prototype present a capacity a little more superior to the previous fabric studied.

Finally, in the cotton-polyester prototype (knitting) (D) this is the prototype with the greatest capacity for recovery. In the same way as the previous knitting, the conductive yarns show similar behaviour, making the capacity for recovery a little less than the prototype without yarn insertion.



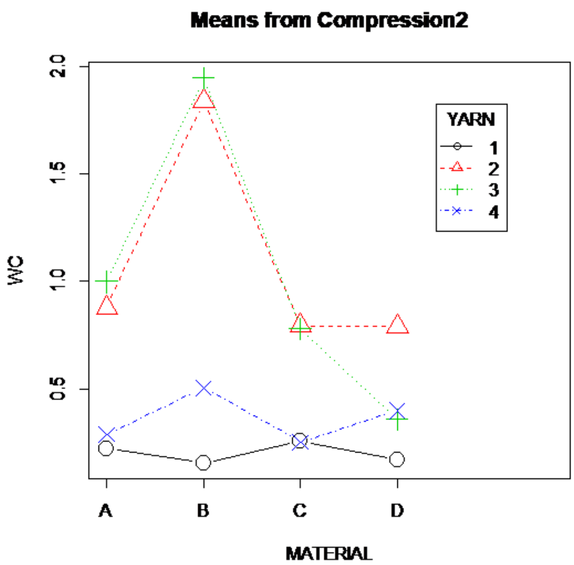
Graphic 34 – Influence of insertion of conductive yarns regarding "RC"

5.3.2.6 Interactions of materials and conductive yarns regarding "WC":

In the graph you can see how, in most of the materials studied, the insertion of conductive yarns causes an increase in the "WC".

The difference in values obtained is very low, therefore it can be said that all the yarns behave in a similar way by increasing this property. It is also worth noting that cotton-elastane (woven) (A), cotton (knitting) (C) and cotton-polyster (knitting) (D) materials are less susceptible to compression than prototypes with a knitting structure.

On the other hand, the prototype cotton (woven) (B) is the most susceptible to compression. With the multifilament stainless steel wires, corresponding to the red (3) and blue circuits (2), it can be clearly seen how the property of susceptibility to compression increases.



Graphic 35 – Influence of insertion of conductive yarns regarding "WC"

5.3.3 RESULTS | BENDING TESTER

Firstly, the corresponding statistical table with the response variable "B" is presented. In this way, it is possible to observe which are the factors that have the most influence regarding bending rigidity.

```
Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.15303    0.04538   3.372  0.00253 **
YARN.L         -0.04213    0.04538  -0.928  0.36247
YARN.Q         -0.02240    0.04538  -0.494  0.62611
YARN.C          0.03341    0.04538   0.736  0.46882
MATERIAL[T.B]   0.16096    0.06418   2.508  0.01931 *
MATERIAL[T.C]  -0.06021    0.06418  -0.938  0.35753
MATERIAL[T.D]  -0.07553    0.06418  -1.177  0.25086
DIRECTION1     -0.02761    0.02269  -1.217  0.23551
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1284 on 24 degrees of freedom
Multiple R-squared:  0.4565, Adjusted R-squared:  0.298
F-statistic:  2.88 on 7 and 24 DF,  p-value: 0.02478
```

Image 44 – Corresponding statistical table with the response variable "B"

The factors that have the most infuence regarding bending rigidity is the first material which corresponds to cotton-elastane (woven). Also it is possible to observe thar the "Multiple R-squared" (determination coefficient) is, 45,65%, so this statiscal design can predict the behavior of the response variable "B" fairly well.

Below is the statistical table obtained for the response variable "2HB":

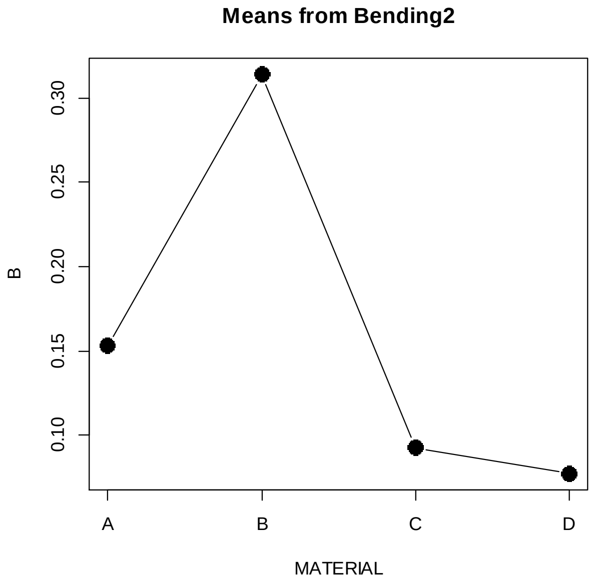
```
Coefficients:
               Estimate Std. Error t value  Pr(>|t|)
(Intercept)    0.200650   0.038727   5.181 0.0000263 ***
YARN.L         0.026743   0.038727   0.691   0.49646
YARN.Q        -0.081225   0.038727  -2.097   0.04667 *
YARN.C         0.007088   0.038727   0.183   0.85631
MATERIAL[T.B]  0.161350   0.054768   2.946   0.00705 **
MATERIAL[T.C] -0.049075   0.054768  -0.896   0.37912
MATERIAL[T.D] -0.036325   0.054768  -0.663   0.51349
DIRECTION1    -0.017681   0.019363  -0.913   0.37025
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1095 on 24 degrees of freedom
Multiple R-squared:  0.5064, Adjusted R-squared:  0.3625
F-statistic: 3.518 on 7 and 24 DF,  p-value: 0.009688
```

Image 45 – Corresponding statistical table with the response variable "2HB"

In this case, it possible observe the factors that have more influence regarding capacity of recovery to the bending effort are the second conductive yarn and the cotton-elastane (woven) material. Also it is possible to observe thar the "Multiple R-squared" is, 50,64%, so this statiscal design can predict the behavior of the response variable "2HB" well.

5.3.3.1 Influence of the material regarding "B":

In this graph it possible observe how the difference in values are very small. Even so, it presents that the cotton - elastane (knitting) (A), cotton (knitting) (C) and cotton – polyester (woven) (D) fabrics, have less bending rigidity due to their composition and structure tan the cotton (woven) (B), which is the material that presents the best bending rigidity.



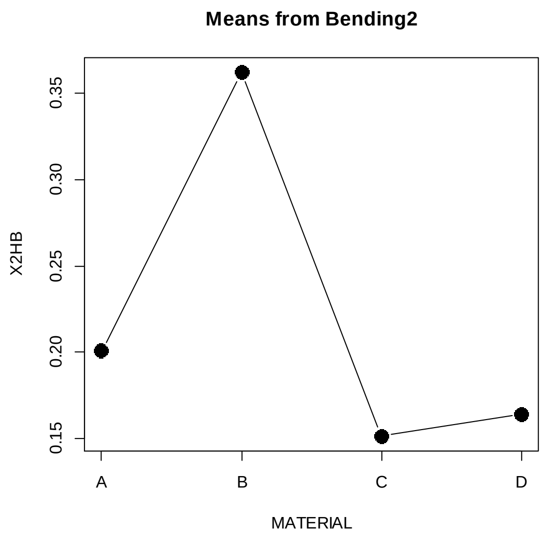
Graphic 36 – Influence of material regarding "B"

5.3.3.2 Influence of the material regarding "2HB":

This graph, that studies the influence of material in regarding capacity of recovery to the bending effort "2HB" is practically the same graph that it obtined in the previous apart. This happen beacuse the capacity of recovery to the bending effort is closely related to the bending rigidity.

In this way, the cotton (woven) (B) fabric, which presents the best bending rigidity is the one that presents less capacity of recovery to the bending effort.

The cotton-elastane (knitting) (A), cotton (knitting) (C) y cotton – polyester (woven) (D) materials, have a better capacity of recovery to the bending effort.

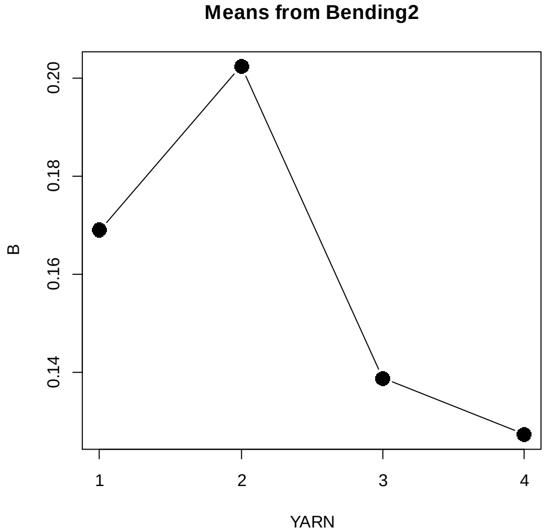


Graphic 37 – Influence of material regarding "2HB"

5.3.3.3 Influence of insertion of conductive yarns regarding "B":

In this graph it possible observe how the difference in values are very small. even so the insertion of the multifilament stainless steel yarn (red circuit) (3) and the monofilament with conductive covered yarn (green circuit) (4) present a bending rigidity very similar to the fabric whithout insertion of conductive yarn (1), hardly varying this capacity.

However, the multifilament stainless steel yarn (blue circuit) (2) is the one that gives to the fabric the highest bending rigidity.

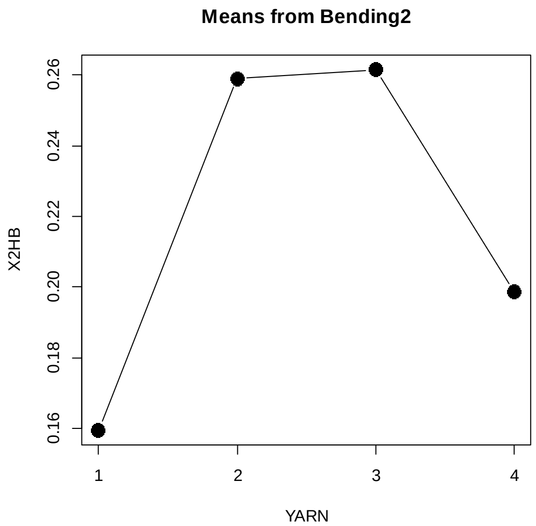


Graphic 38 – Influence of insertion of conductive yarns regarding "B"

5.3.3.4 Influence of insertion of conductive yarns regarding "2HB" -

In this case, the graphic it's a little bit more different but the difference in values are very small. So, it possible observe that the fabric without the insertion of a conductive yarn (1) and the conductive covered yarn (green circuit) (4) present the same capacity of recovery to the bending effort.

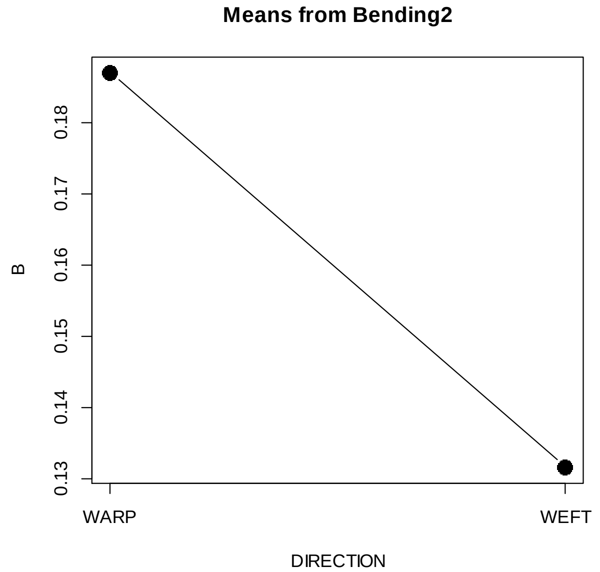
However, the multifilament stainless steel yarn (red circuit) (3) and the multifilament stainless steel yarn (blue circuit) (4), are the yarns thar present the worst capacity of recovery to the bending effort compared to the other two yarns.



Graphic 39 – Influence of insertion of conductive yarns regarding "2HB"

5.3.3.5 Influence of the study of the directions of the yanrs in the fabric regarding "B":

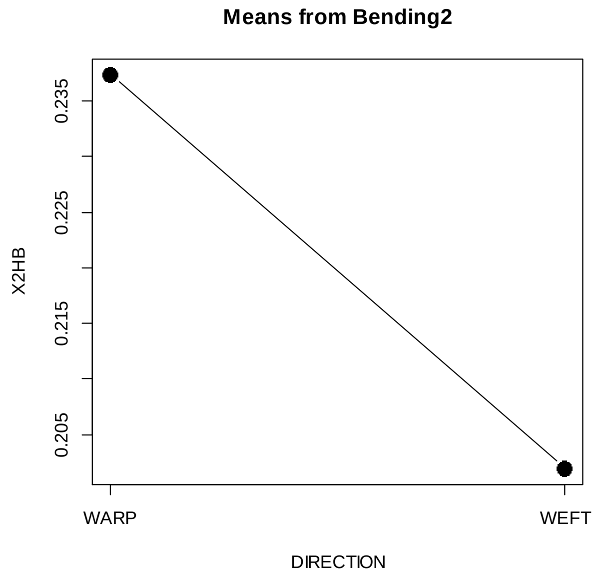
The difference about the behavour of each directions is non-existent (0,05). But it possible observe that the WARP direction presents a slight change having more bending rigidity that the WEFT direction.



Graphic 40 –Influence of the directions of the yanrs in the fabric regarding "B"

5.3.3.6 Influence of the study of the directions of the yanrs in the fabric regarding "2HB":

As it has been observed when studying the influence of materials, the graphs of “B” and “2HB” were practically the same. In this case the same thing happens. The variation between the two directions is very very small, but there is a slight variation. The WEFT direction presents a better capacity of recovery to the bending effort than the WARP direction.

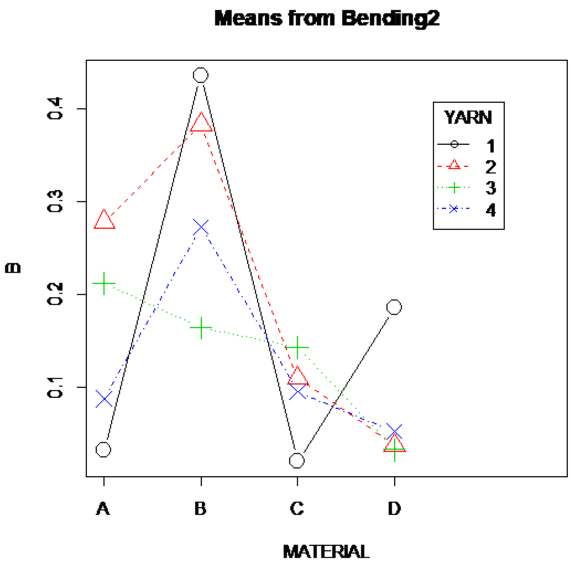


Graphic 41 –Influence of the directions of the yanrs in the fabric regarding "2HB"

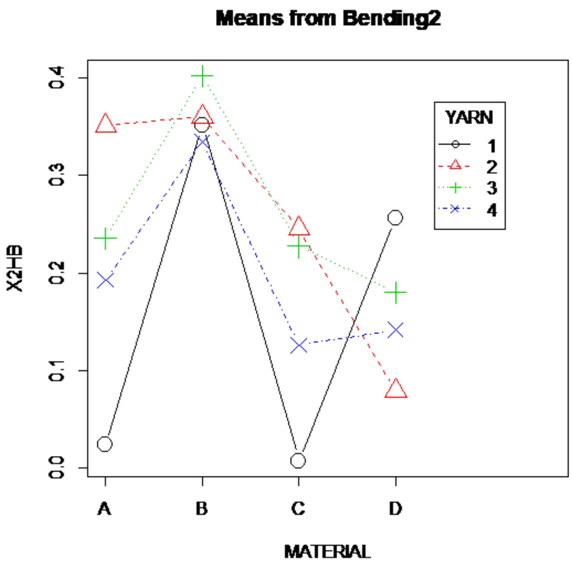
5.3.3.7 Interactions of materials and conductive yarns regarding “B” and “2HB”:

As it can see the interaction graphs are practically the same, studying the variables "B" and "2HB". In summary, it can be seen that the fabric with the greatest bending rigidity and the least recovery capacity is cotton (woven) (B), with the slight variations in values that appear when inserting the conductive yarns.

Whereas, it possible observe that the fabrics with the worst bending flexibility and therefore the best recovery capacity is the cotton-elastane (knitting) (A) and cotton (knitting) (C) fabrics, being the fabrics that without an insertion of conductive yarns present less values and and as the insertion is carried out, those values increase.



Graphic 42 – Interactions of materials and conductive yarns regarding “B”



Graphic 43 – Interactions of materials and conductive yarns regarding “2HB”

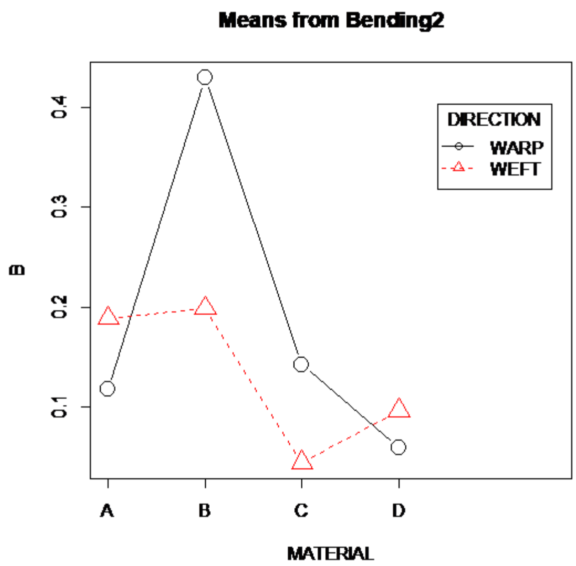
5.3.3.8 Interactions of materials and the directions of yarns regarding “B” and “2HB”:

Similarly, it can be seen how the two interaction graphs are practically the same.

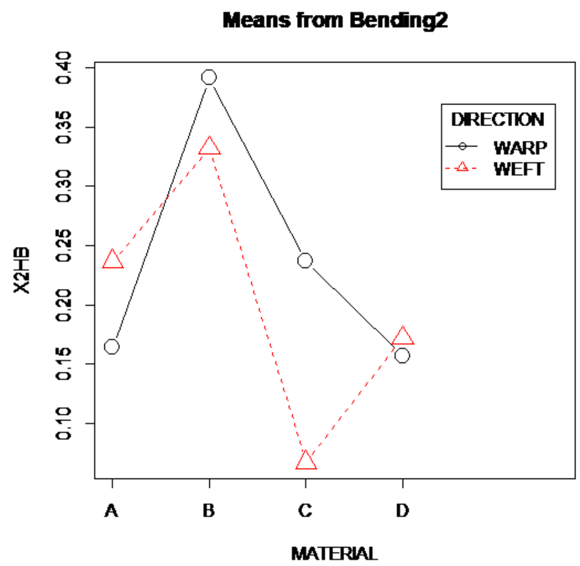
On the one hand, it can be seen that the interaction of the cotton (woven) (B) materials with WARP / WEFT and cotton (knitting) (C) have the same properties. If the WARP direction is studied with these materials, the recovery capacity is less and the bending rigidity is greater. In the same way, if it studies the WEFT dirección with thouse materials, present a better recovery capacity and the bending rigidity is less.

Whereas, the cotton-elastante (knitting) (A) and cotton-polyester (woven) (C) materials, the behavior between them is the same, doing the opposite like the previous apart but

So it can observe so good that there are two opposite behavior according to the dirección and material of the fabric study.



Graphic 44 – Interactions of materials and the directions of yarns regarding "B""



Graphic 45 – Interactions of materials and the directions of yarns regarding "2HB""

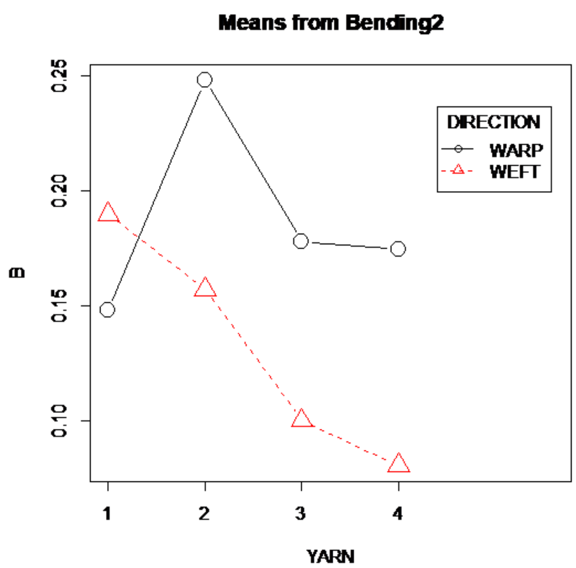
5.3.3.9 Interactions of yarns and the directions of yarns regarding "B" and "2HB":

In this interactions, the results of the graphic are a little bit different thean in the previous aparts.

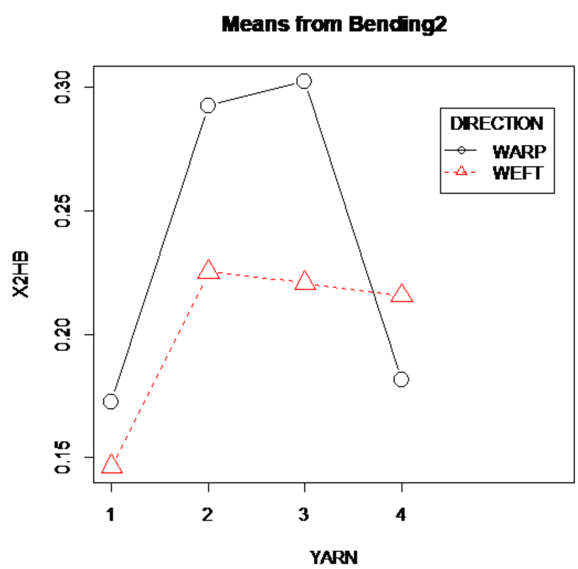
About the recovery capacity, the insertions of conductive yarns have been done in the two differents direcctions (WARP and WEFT), so it can observe that the recovery capacity that present are practically the same, being a littel bit higher in the WEFT direction.

However, when it study the bending rigidity, it can observe that the fabric without the yarn insertion (1) has a better bending rigidity in the WEFT direction than the WARP direction.

Whereas, the behaveour of the rest of conductive yarns are very similar presenting a better bending rigidity in the WARP direction than the WEFT direction.



Graphic 46 – Interactions of of yarns and the directions of yarns regarding "B"



Graphic 47 – Interactions of of yarns and the directions of yarns regarding "2HB"

5.3.4 RESULTS | SHEAR TESTER

Firstly, the corresponding statistical table with the response variable "G" is presented. In this way, it is possible to observe which are the factors that have the most influence regarding shear stiffness.

```
Coefficients:
               Estimate Std. Error t value     Pr(>|t|)
(Intercept)     0.19875    0.20893   0.951      0.35094
YARN.L          0.69206    0.20893   3.312      0.00292 **
YARN.Q         -0.18875    0.20893  -0.903      0.37528
YARN.C          0.01453    0.20893   0.070      0.94512
MATERIAL[T.B]   2.24000    0.29547   7.581 0.0000000807 ***
MATERIAL[T.C]   0.36500    0.29547   1.235      0.22867
MATERIAL[T.D]   1.39250    0.29547   4.713 0.0000861855 ***
DIRECTION1     -0.05312    0.10446  -0.509      0.61571
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5909 on 24 degrees of freedom
Multiple R-squared:  0.7756, Adjusted R-squared:  0.7102
F-statistic: 11.85 on 7 and 24 DF,  p-value: 0.000001921
```

Image 46 - Corresponding statistical table with the response variable "G"

In this table, it possible observe which the factors that are more important regarding shear stiffness are the second conductiviy yarn and the firts and third material studied. Being the most significat the kind of material that the kind of conductive yarns thar are inserted. Furthermore it is possible to observe thar the “Multiple R-squared” is, 77,56%, so this statiscal design can predict the behavior of the response variable "G" very well.

Below is the statistical table obtained for the response variable "2HG":

```
Coefficients:
               Estimate Std. Error t value   Pr(>|t|)
(Intercept)      0.5625     0.8195   0.686    0.49904
YARN.L           2.6458     0.8195   3.229    0.00358 **
YARN.Q          -0.5612     0.8195  -0.685    0.49998
YARN.C           0.2885     0.8195   0.352    0.72792
MATERIAL[T.B]    6.7362     1.1589   5.812 0.00000541 ***
MATERIAL[T.C]    0.9862     1.1589   0.851    0.40318
MATERIAL[T.D]    2.6825     1.1589   2.315    0.02951 *
DIRECTION1      -0.1619     0.4097  -0.395    0.69629
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.318 on 24 degrees of freedom
Multiple R-squared:  0.6783, Adjusted R-squared:  0.5845
F-statistic: 7.229 on 7 and 24 DF,  p-value: 0.0001073
```

Image 47 - Corresponding statistical table with the response variable "2HG"

In this case, the resopnse variable thar it studied is the capacity of recovery to the shear esffort. It possible observe how the first yarns is so significative and the following factor which ir more important is the first contuctivity yarn.

Also t is possible to observe thar the “Multiple R-squared” is, 67,83%, so this statiscal design can predict the behavior of the response variable "2HG" very well.

5.3.4.1 Influence of the material regarding "G":

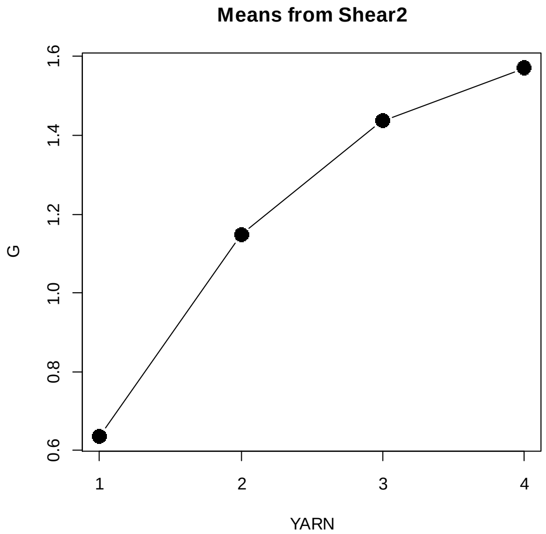
In this graph it possible observe how the cotton (woven) (B) material is the one which present the best shear stiffness in the shear effort. So the material which has the second best shear stiffness is the cotton-polyester (woven) (D). It is due to the fabric woven structure.

Graphic 48 – Influence of the material regarding "G"

However, the cotton-elastane (knitting) (A) and the cotton (knitting) (B) are the materials that present the worst shear stiffness.

5.3.4.2 Influence of insertion of conductive yarns regarding "G":

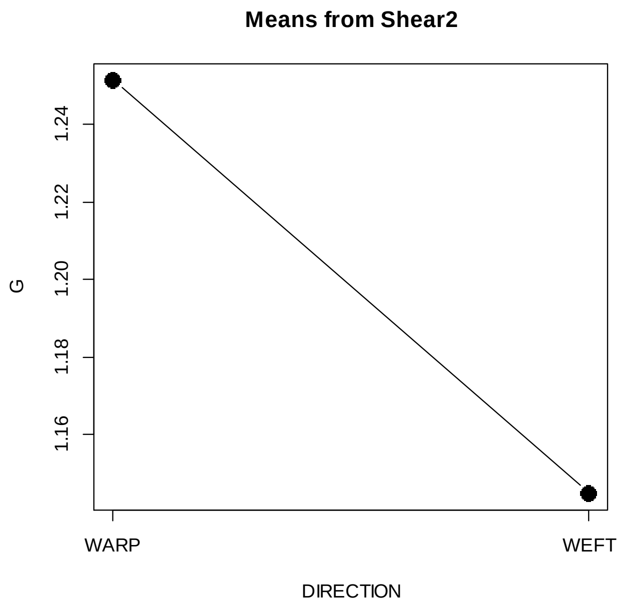
In this graph is possible observe clearly that the fabric without conductive yarn (1) is the prototype that less shear stiffness present. Whereas, the three conductive yarns thar are inserted (the difference is minium) present a similar behavior, increasing the shear stiffness in the prototypes.



Graphic 49 – Influence of insertion of conductive yarns regarding "G"

5.3.4.3 Influence of the study of the directions of the yanrs in the fabric regarding "G":

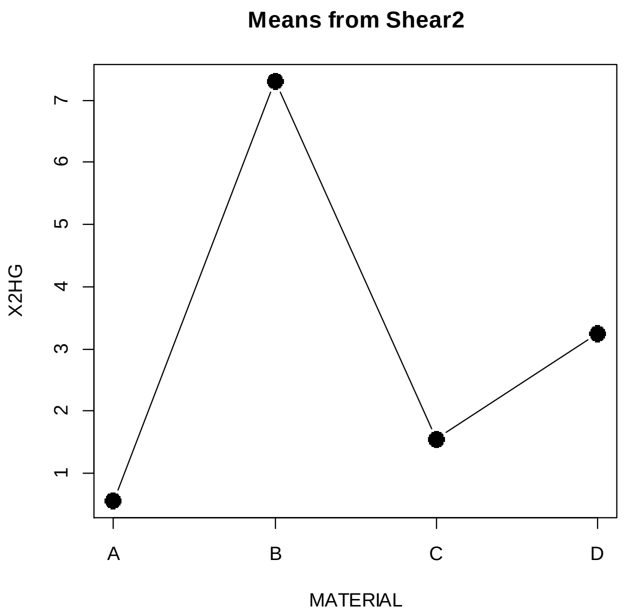
It can be seen that the direction presents a different behavior with respect to the study of the shear stiffness variable, although this difference, if the values are observed, is minimal. Thus, the shear stiffness is slightly higher in the WARP direction than in the WEFT length of the fabric.



Graphic 50 – Influence of the study of the directions of the yanrs in the fabric regarding "G"

5.3.4.4 Influence of the material regarding "2HG":

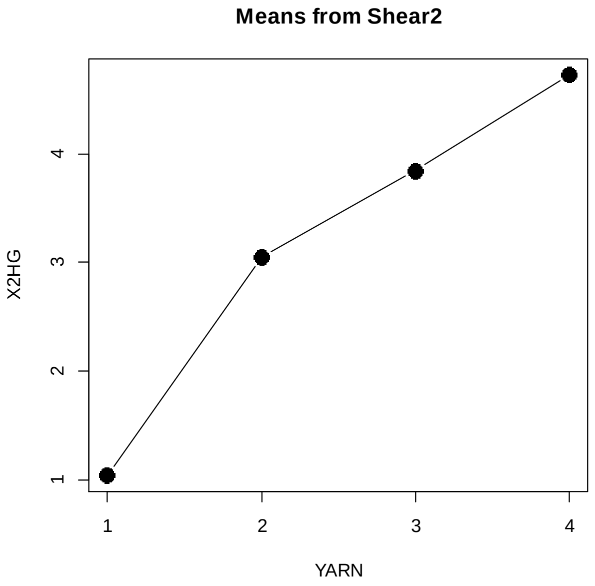
It can be seen how the graph obtained by studying the material with regarding variable "2HG" is practically the same as that studied regarding "G". In the same way, the woven structure materials (B) (D) are the ones that have the least the capacity of recovery whereas the other two knitting structure (A) (C) materials show a better recovery to this effort.



Graphic 51 – Influence of the study of the material regarding "2HG"

5.3.4.5 Influence of insertion of conductive yarns regarding "2HG":

In the same way as the previous section, this graph study the behavior about the conductive yarns according to the response variable “2HG” is practically the same like the previous apart which study the behavour about these yarns according to the response variable “G”.

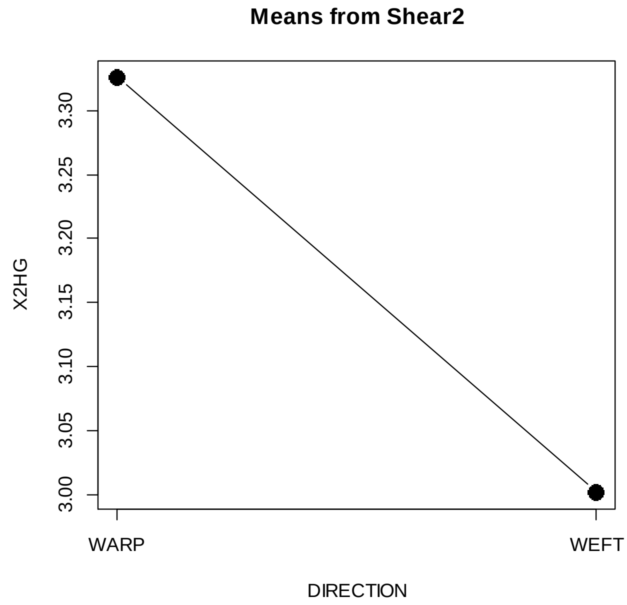


Graphic 52 – Influence of insertion of conductive yarns regarding "2HG"

In this way, it possible observe how the fabric without insertion (1) of conductive yarns has better capacity of recovery to the shear effort, whereas the three conductive yarn (the difference is minimun) act practically in the same way reducing this property.

5.3.4.6 Influence of the study of the directions of the yanrs in the fabric regarding "2HG":

In the same way, the study of the direction with according to the variable "2HG" presents a behavior practically the same as when it is studied according to the variable "G". In this case, the difference between them is slightly larger, but still very low.

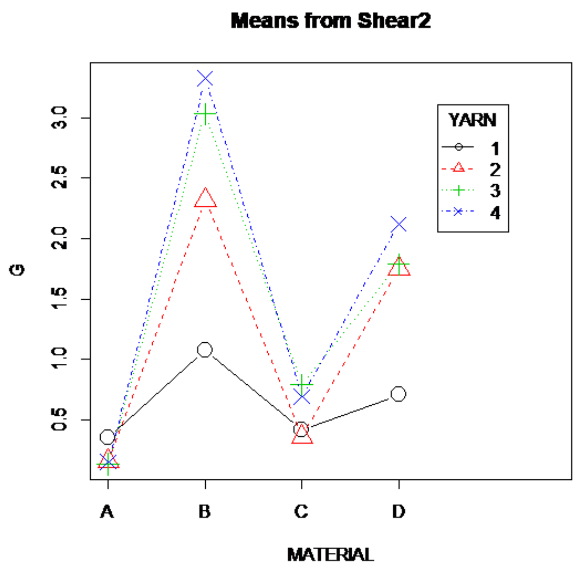


Graphic 53 – Influence of the study of the directions of the yanrs in the fabric regarding "2HG"

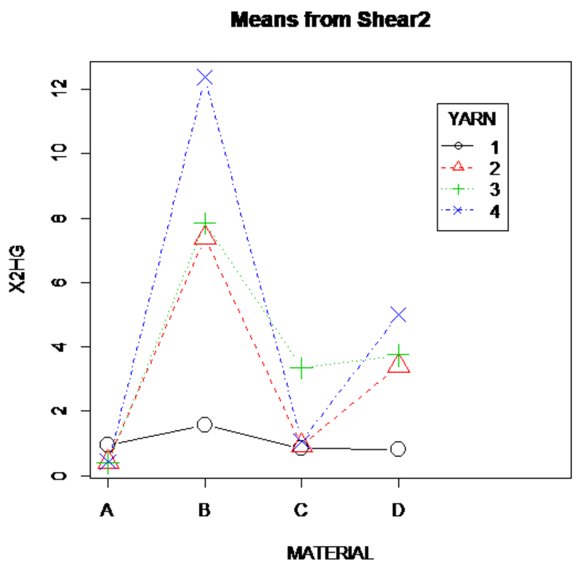
It is observed that the WARP direction presents a lower capacity of recovery of deformation to shear effort than the WEFT direction.

5.3.4.7 Interactions of materials and conductivity yarns regarding “G” and “2HG”:

It can see how the graphs are practically the same. This means that the material-conductive yarns interactions show practically the same behavior for the study of the two variables (“G” and “2HG”).



Graphic 54 – Interactions of materials and conductivity yarns regarding “G”



Graphic 55 – Interactions of materials and conductivity yarns regarding “2HG”

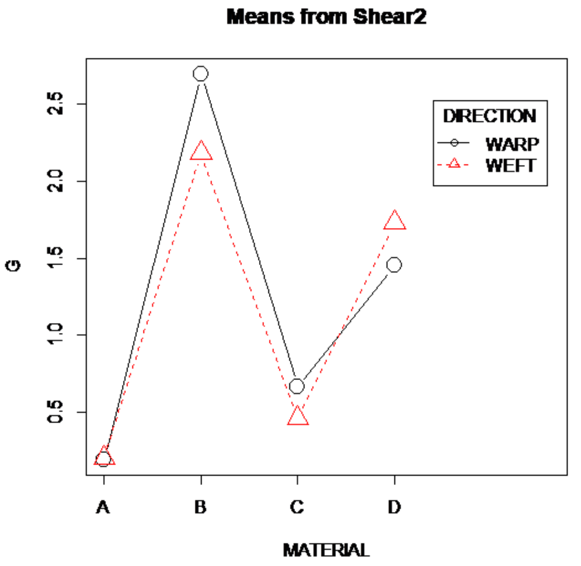
It presents how the materials which has less shear stiffness and better recovery capacity to shear effort are the cotton-elastane (knitting) (A) and cotton (knitting) (C). On both cases, it possible observe how have practically similar values according to shear sitfness and recovery capacity wihout the insertion of the conducitivy yarns. In the cotton-elastane prototype (A) the recovery capacity and shear stiffness are practically the same as the prototype with and without conducitivy yarns inserted (A)-(1). Whereas, in the woven fabrics (B) (D) the recovery capacity decrease a littel and the shear stiffness increases.

On the other hand, those with greater shear stiffness and less recovery capacity to the shear effort present are the cotton (woven) (B) and cotton – elastante (woven) fabrics (D). In both cases it possible observe how the insertion of conducitivity yarns in these structures modify their bending properties.

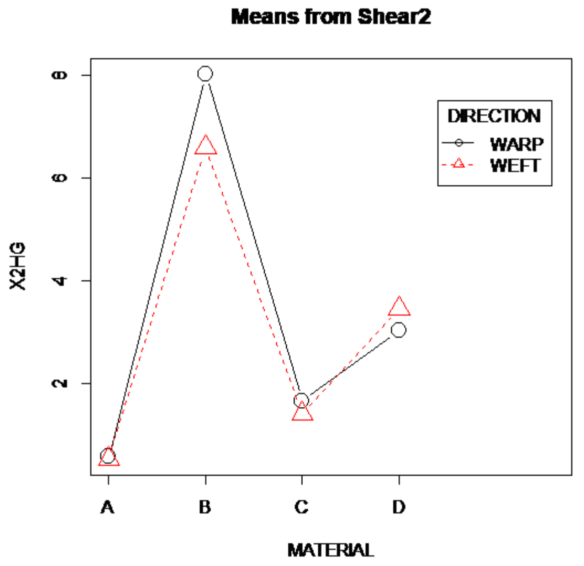
The cotton (woven) (B) fabric is the one with the highest shear stiffness and least recovery capacity.

5.3.4.8 Interactions of materials and the directions of yarns regarding "G" and "2HG":

The graphics are practically the same. This means that the material-direction interactions present the same behavior for the study of the two variables specifically.



Graphic 56 – Interactions of materials and the directions of yarns regarding



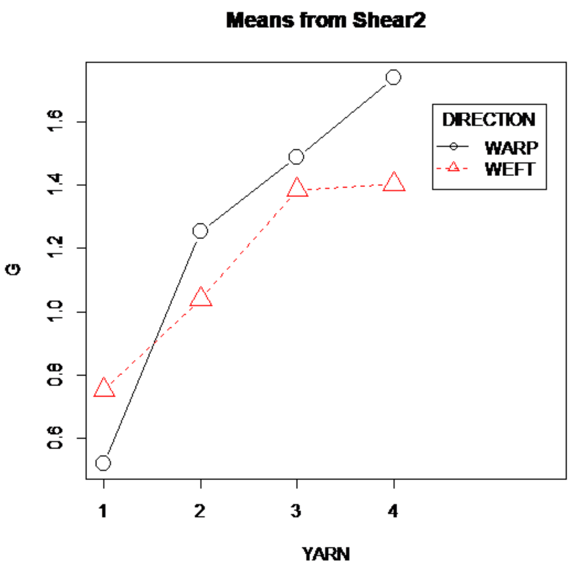
Graphic 57 – Interactions of materials and the directions of yarns regarding "2HG"

It possible observe how all the materiales that have been studied in the WARP direction present a higher shear stiffness in the prototypes which have a woven structure (B) (D), while the other prototypes with a knitting structure (A) (C), in one of the cases are practically the same and in the other the shear stiffness is less.

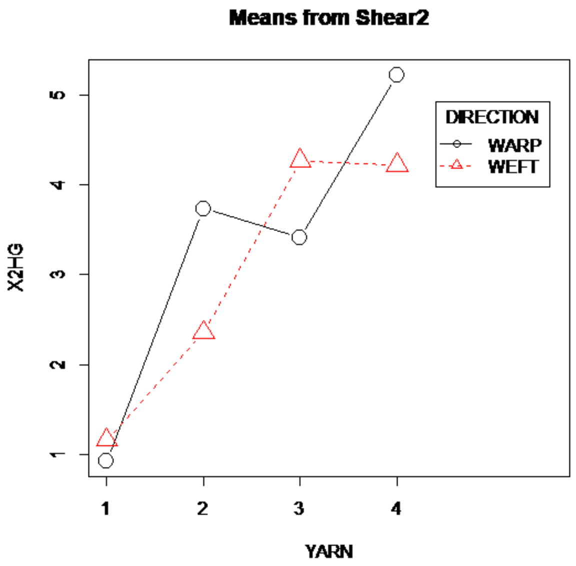
The same thing happens with the recovery capacity, for the woven structure prototype (B) (D), the recovery capacity is less in the WARP dirección than in the WEFT direction. While, in the other prototypes which have knitting structure (A) (C), change, one of these present an opposite behavior and in the other the behavior is practically the same in both directions.

5.3.4.9 Interactions of yarns and the directions of yarns regarding “G” and “2HG”:

On the one hand, it can be seen how, respecto to output variable “G”, fabric without insertion of conductive yarns (1), the shear stiffness is greater in the WEFT direction than in the WARP direciton.



Graphic 58 – Interactions of yarns and the directions of yarns regarding “G”



Graphic 59 – Interactions of yarns and the directions of yarns regarding “2HG”

On the other hand, when this insertion of conductive yarns is carried out, the shear stiffness is greater in the WARP dirección, presenting an opposite behavior.

Whereas, in the graph of study of the intersection in the response variable “2HG”, the behavior presented in each case varies a little more. It is observed that in the prototype without yarn insertion (1) the recovery capacity is greater in both directions studied. However, when this yarn insertion is created, it is the WEFT direction that presents the greatest capacity for recovery, decreasing in the WARP direction.

5.3.5 RESULTS | TENSILE TESTER

In this test, only fabrics with a woven structure could be studied and compared, since knitted fabrics, because they have such an elastic structure, it was impossible to carry out the tension test. Several attempts were made and in some cases results were achieved but not very consistent. So it was decided only to study and compare the woven fabrics.

```
Coefficients:
            Estimate Std. Error t value  Pr(>|t|)
(Intercept)   6.1669     0.8664   7.118 0.0000322 ***
YARN.L        0.2063     1.7327   0.119    0.9076
YARN.Q        0.7712     1.7327   0.445    0.6657
YARN.C        1.9415     1.7327   1.120    0.2887
MATERIAL1     3.0169     0.8664   3.482    0.0059 **
SIDE1         0.9481     0.8664   1.094    0.2994
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.465 on 10 degrees of freedom
Multiple R-squared:  0.5966, Adjusted R-squared:  0.395
F-statistic: 2.958 on 5 and 10 DF,  p-value: 0.06794
```

Image 48 - Corresponding statistical table with the response variable "WT"

These results correspond to the studied response variable “WT", which is the fabric stretching capacity. It can be seen that the material factor will influence this property of the tensile test considerably.

On the other hand, it can be observed that the determination coefficient is 59. 66%, being able to predict quite well the behavior of the response variable “WT"

```
Coefficients:
            Estimate Std. Error t value     Pr(>|t|)
(Intercept)   41.492      2.572  16.131 0.0000000174 ***
YARN.L       -17.280      5.145  -3.359      0.00725 **
YARN.Q        15.692      5.145   3.050      0.01224 *
YARN.C       -13.581      5.145  -2.640      0.02474 *
MATERIAL1     -2.970      2.572  -1.155      0.27509
SIDE1         -1.289      2.572  -0.501      0.62720
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 10.29 on 10 degrees of freedom
Multiple R-squared:  0.7445, Adjusted R-squared:  0.6168
F-statistic: 5.828 on 5 and 10 DF,  p-value: 0.008924
```

Image 49 - Corresponding statistical table with the response variable "RT"

These results correspond to the studied output variable “RT", which is the ability of the tissue to recover from the tensile test. It can be seen that the different threads inserted will have a considerable influence when studying this variable.

On the other hand, it can be observed that the determination coefficient is 74. 45%, being able to predict quite well the behaviour of the response variable “RT”.

```
Coefficients:
             Estimate Std. Error t value     Pr(>|t|)
(Intercept)   0.41469    0.02377  17.443 0.00000000814 ***
YARN.L        0.02186    0.04755   0.460        0.6556
YARN.Q        0.09688    0.04755   2.037        0.0689 .
YARN.C        0.02331    0.04755   0.490        0.6345
MATERIAL1     0.04244    0.02377   1.785        0.1046
SIDE1         0.03556    0.02377   1.496        0.1656
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.0951 on 10 degrees of freedom
Multiple R-squared:  0.5007, Adjusted R-squared:  0.251
F-statistic: 2.005 on 5 and 10 DF,  p-value: 0.1633
```

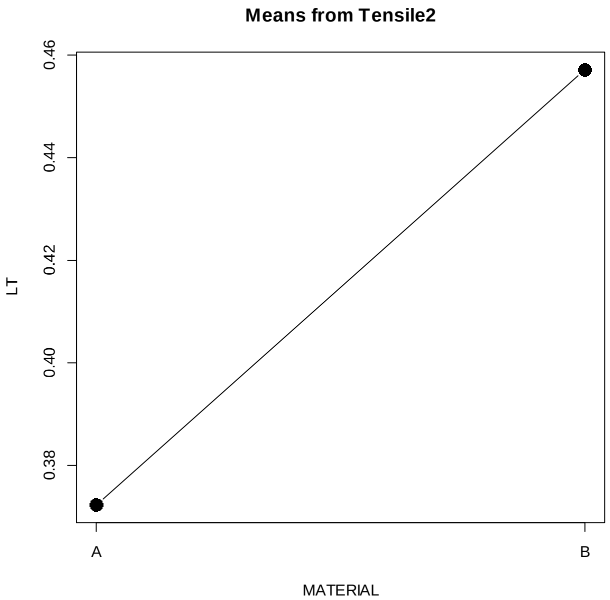
Image 50 - Corresponding statistical table with the response variable "LT"

These results correspond to the studied output variable “LT” which is traction stiffness (average fabric tension). It can be seen that one of the inserted threads will have a greater influence with respect to the studied variable “LT”.

On the other hand, it can be observed that the determination coefficient is 50. 07%, and the behavior of the response variable “LT"; can be quite well measured.

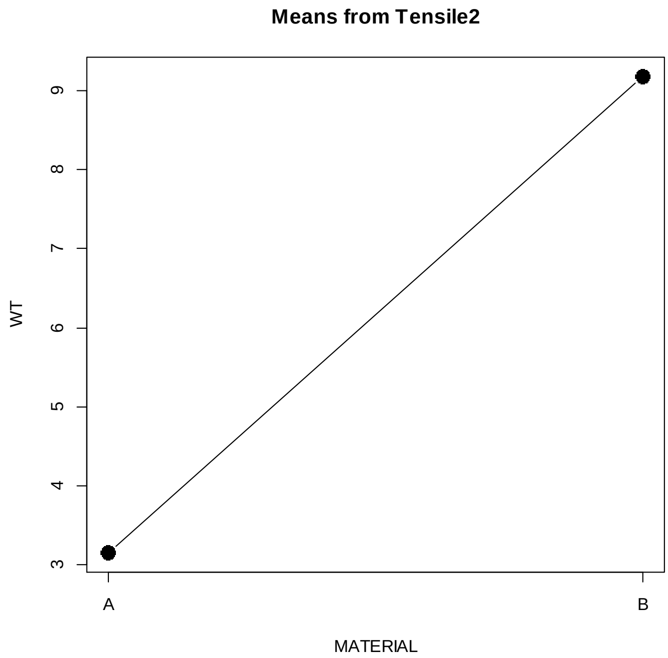
5.3.5.1 Influence of the material regarding “LT”, “RT”, “WT”:

Regard to the average tension of the fabric (tensile stiffness), the cotton-polyester (B) material has a firmer average tension.



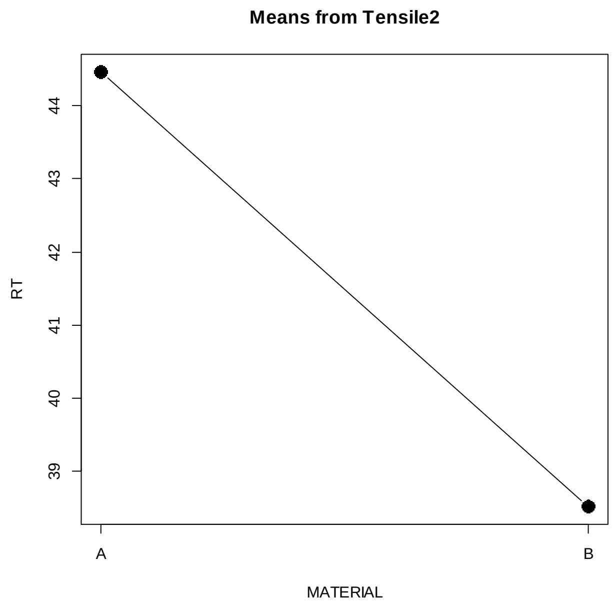
Graphic 60 – Influence of the material regarding “LT”

With respect to “WT”, the stretching capacity, also the cotton-polyester (B) fabric has a higher stretching capacity than the cotton fabric.



Graphic 61 – Influence of the material regarding “WT”

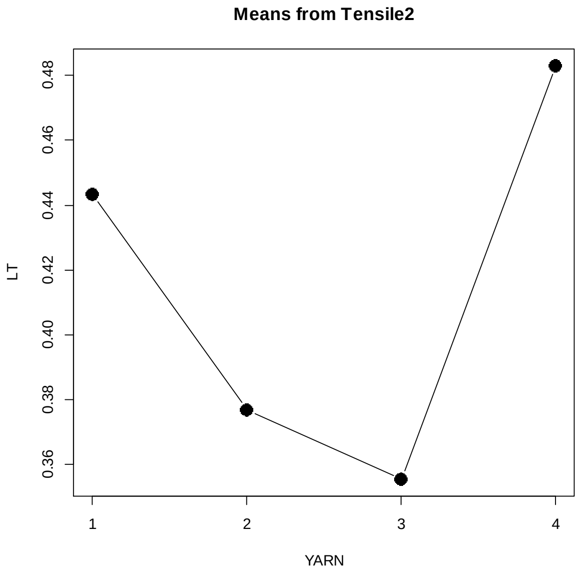
With respect to “RT”, capacity of recovery to the tension effort, in this case the cotton fabric (A) has a greater capacity of recovery than the cotton-polyester fabric (B).



Graphic 62 – Influence of the material regarding “RT”

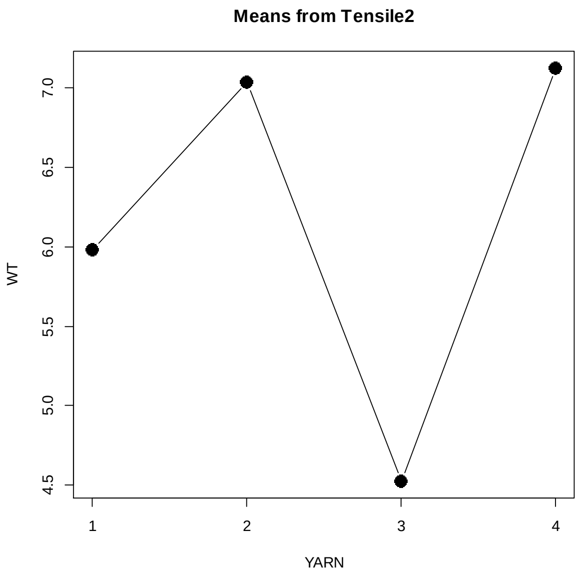
5.3.5.2 Influence of insertion of conductive yarns regarding “LT”, “RT”, “WT”:

In this case, studying the different options of threads inserted in these openwork structures, it can be seen how the fabric with thread insertion of the green circuit (4), is the one that presents the greatest rigidity to traction, while the red circuit (3), is the one that presents the least.



Graphic 63 – Influence of insertion of conductive yarns regarding “LT”

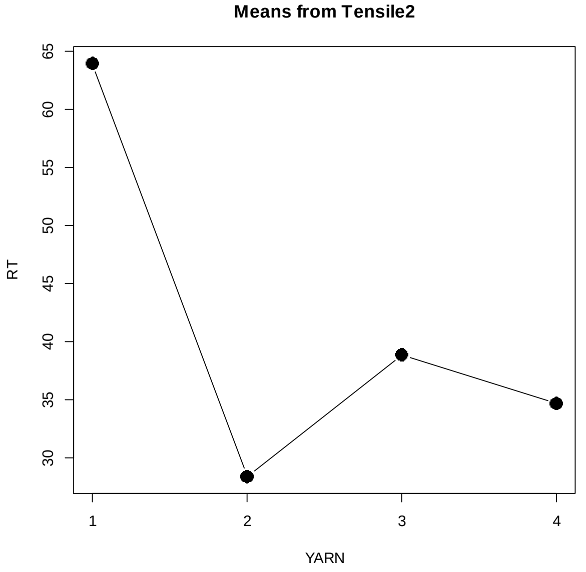
Compared to WT, stretching capacity., the behaviour of the yarn becomes a little more complex. It can be seen that the red circuit (3) wire is the one with the least stretching capacity, whereas the rest of the options have a similar behaviour, more, with a good stretching capacity.



Graphic 64 – Influence of insertion of conductive yarns regarding “WT”

With respect to “RT”, the fabric's capacity for recovery, it can be seen that fabric without yarn insertion (1) has the greatest recovery capacity, but as the thread insertion is carried out, this capacity decreases.

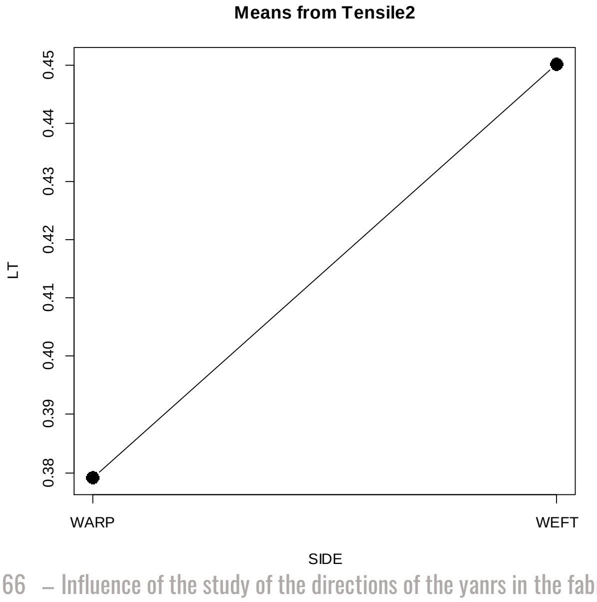
The rest of the yarns that have been inserted have a quite similar behaviour, presenting all of them very low capacity of recovery.



Graphic 65 – Influence of insertion of conductive yarns regarding “RT”

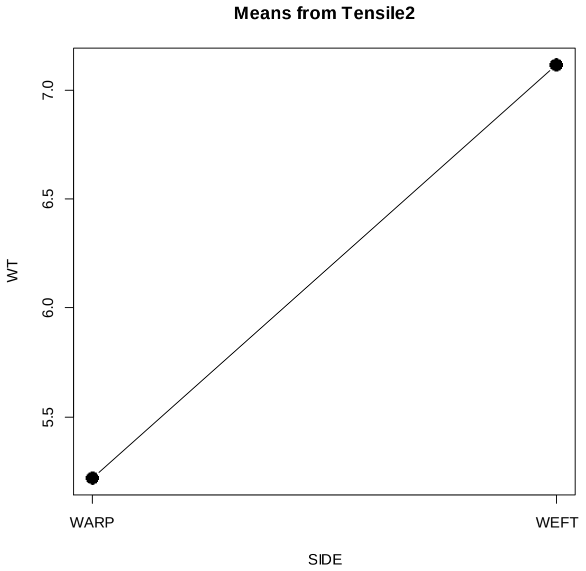
5.3.5.3 Influence of the study of the directions of the yanrs in the fabric regarding “LT”, “RT”, “WT”:

Regarding “LT” to the average tension of the fabric (tensile stiffness), it is observed that in the transversal direction (WEFT) of the woven fabric, this average tension is more firm than in the longitudinal direction (WARP).



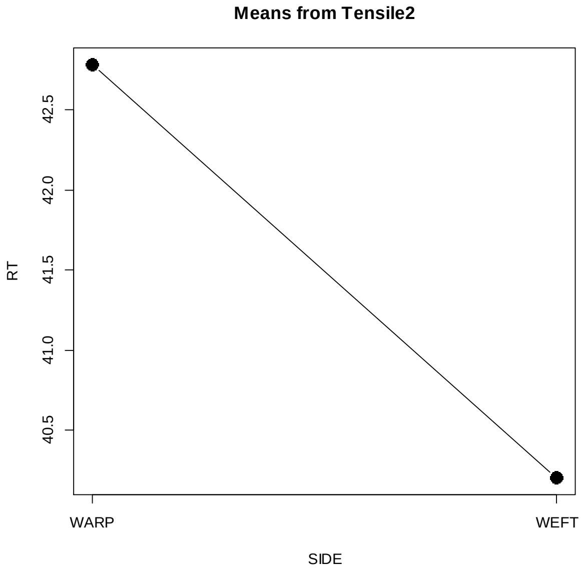
Graphic 66 – Influence of the study of the directions of the yanrs in the fabric regarding “LT”

Respect to "WT" the stretching capacity is higher in the transverse direction (WARP) of the fabrics than in the longitudinal direction (WEFT).



Graphic 67 – Influence of the study of the directions of the yanrs in the fabric regarding "WT"

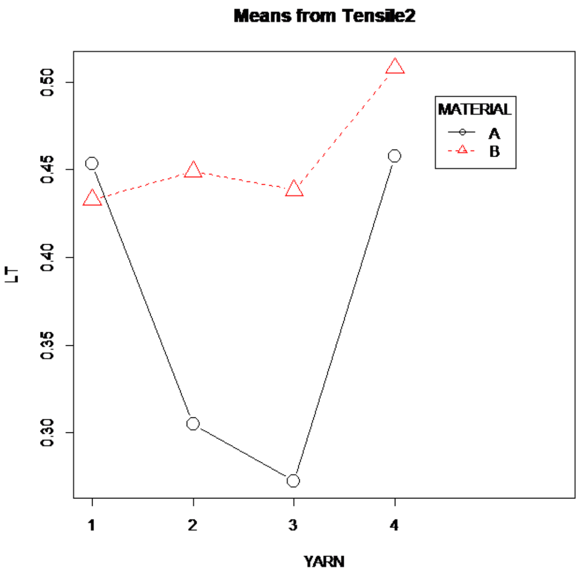
Regarding "RT" tensile resilence capacity, it can be observed that it is slightly higher in the longitudinal WARP direction, but the difference is very small so it could be said that it presents a similar behaviour in both directions.



Graphic 68 – Influence of the study of the directions of the yanrs in the fabric regarding "RT"

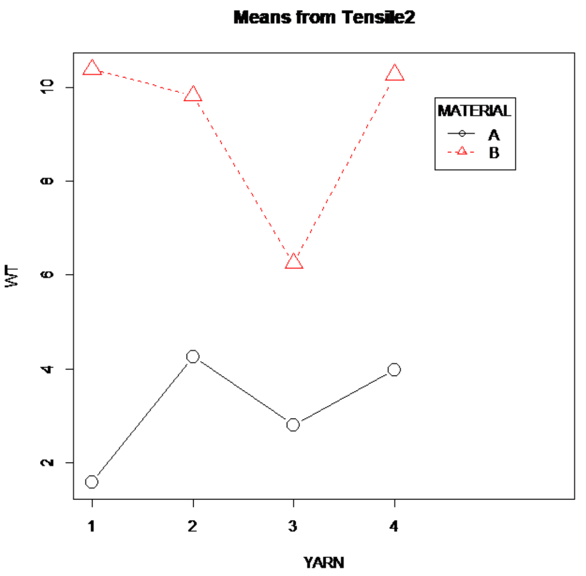
5.3.5.4 Interactions of materials and conductivity yarns regarding "LT", "RT", "WT":

Compared to LT, it can be seen that the tensile stiffness is significantly higher with the insertion of threads in the cotton-polyester fabric (B) than the cotton (woven) (A) fabric, which is significantly lower and even decreases with this thread insertion.



Graphic 69 – Interactions of materials and conductivity yarns regarding “LT”

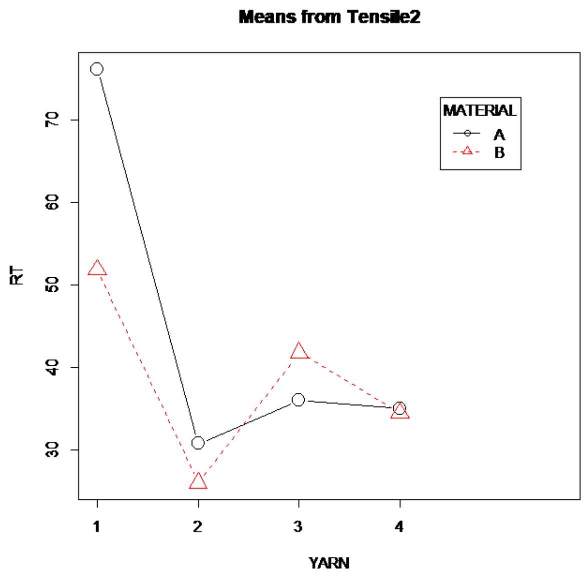
Compared to WT, it can be seen that the stretching capacity is much higher with the insertion of threads (1) in the cotton-polyester (B) fabric than with the cotton (woven) (A) fabric, which is much lower and even decreases with this insertion of threads.



Graphic 70 – Interactions of materials and conductivity yarns regarding “WT”

With respect to “RT” the fabric's capacity for recovery is cab be observed perfectly, in both cases this recovery decreases when the threads are inserted into the fabric.

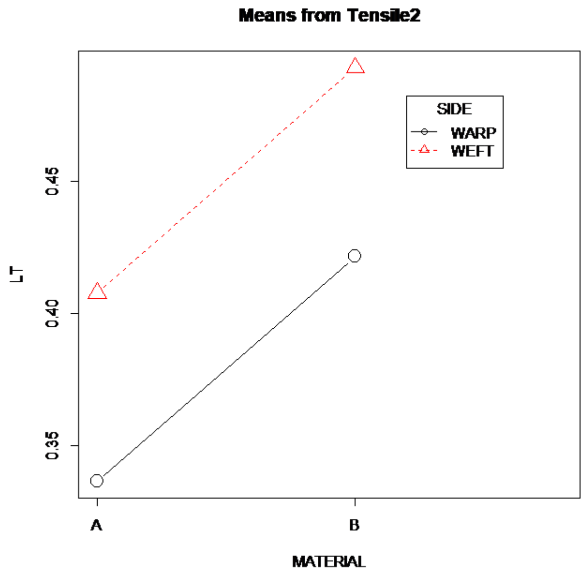
On the other hand, in the fabrics without insertion (1) of conductive threads it is greater without insertion of fabrics, it happens the same in both cases.



Graphic 71 – Interactions of materials and conductivity yarns regarding "RT"

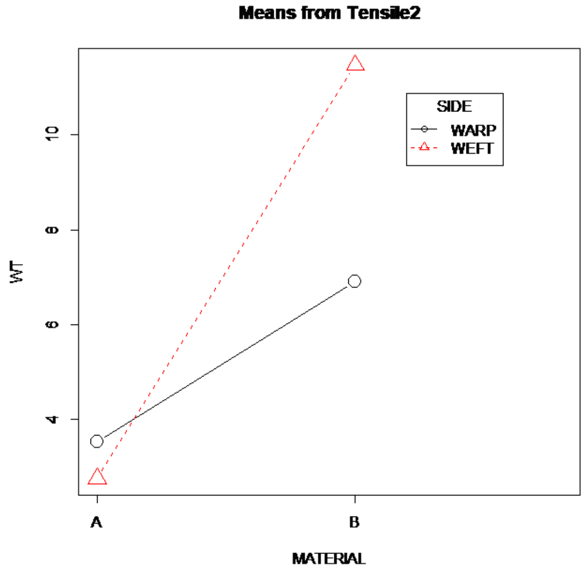
5.3.5.5 Interactions of materials and the directions of yarns regarding "LT", "RT", "WT":

With respect to LT, the tensile stiffness, it can be seen how they present identical behaviour in both fabrics, in WARP and WEFT direction. it can be detected that this tensile stiffness is superior in the cotton-polyester fabric (B).



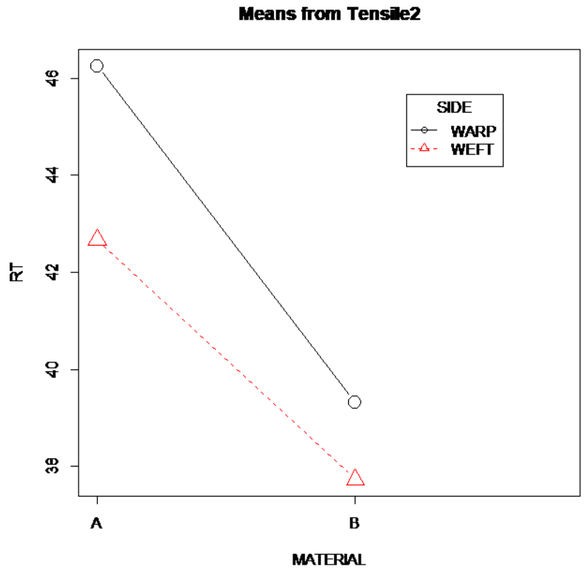
Graphic 72 – Interactions of materials and the directions of yarns regarding "LT"

With respect to WT, stretching capacity, it can be seen how in this case, the fabrics behave in the opposite way depending on the direction of study. For the cotton fabric (A) it is observed, how the stretching capacity is higher in the WARP direction than in the WEFT. it passes in the opposite way in the cotton - polyester fabric (B), which also presents higher values in both directions and therefore its stretching capacity is greater.



Graphic 73 – Interactions of materials and the directions of yarns regarding “WT”

With respect to “RT”, fabric tensile resilence, it can be seen how both tissues behave in the same way depending on the direction of the study. the cotton fabric (A) has a greater capacity for recovery (greater even in the WARP sense), while the cotton-polyester fabric (B) has a lower capacity for recovery.



Graphic 74 – Interactions of materials and the directions of yarns regarding “RT”

6. CONCLUSIONS | STATISCAL STUDY

The objective of the project has been achieved, which is: study the alteration in physical and conductive properties that knitted and woven fabrics undergo once conductive monofilament/multifilament threads have been inserted by means of embroidering.Finally, the conclusions obtained in each test and a final conclusion of the project are presented bellow.

6.1 CONCLUSIONS | SURFACE TESTER

The first tests carried out on the prototypes without insertion of conductive yarn showed that, for the woven fabrics had: high tendency to slip, high surface softness (less than in the studied knitted fabrics); and for the knitted fabrics: high tendency to slip, absence of surface irregularities, high surface smoothness and no roughness.

As the yarns were inserted: the tendency to slip (MIU) was lower, surface roughness (MMD) increased and surface irregularities (SMD) were higher. In addition, the choice of material and conductive yarns are important. On the other hand, the study of directions (WARP/WEFT) and SIDES (front/back) don't make the values variate vary much, so they don't have as much influence.

Finally, it is important to note that the yarns that most cause variations in surface properties in the prototypes studied are: multifilament stainless steel - blue circuit (2) and multifilament stainless steel - red circuit (3).

The prototype cotton-elastane (knitted) (A) with the multifilament stainless steel - blue circuit (2) is the one with the least tendency to slip (MIU). Regard the surface roughness (MMD) once the conductive yarns were inserted, the prototypes showed a fairly similar behaviour. With regard to surface irregularities (MDS), the behaviour is the same in all the prototypes true, increasing surface irregularities in the same way in all prototypes.

6.2 CONCLUSIONS | COMPRESSION TESTER

In the first tests carried out, knitted fabrics presented low susceptibility to compression effort and good capacity of recovery to the compression effort; and woven fabrics: low susceptibility to compression effort, favorable resilience to compression effort (better than that of knitted fabrics).

As the conductive yarns were inserted, the capacity to recover from compressive stress (CR) is lower and, conversely, the susceptibility to compression increases. The insertion of yarns creates a more rigid structure and that's the reason why this happens.

Finally, it is important to point out that the yarns that most cause variations in the compression properties in the studied prototypes are: multifilament stainless steel - blue circuit (2) and multifilament stainless steel - red circuit (3).

The woven structure prototypes (B) (D) are the ones with the best capacity of recovery to the compression effort. The cotton (woven) material (B) together with the multifilament stainless steel - blue circuit (2) is the most susceptible to compression stress.

6.3 CONCLUSIONS | BENDING TESTER

In the first tests carried out without yarn insertion, knitted fabrics were highly flexible, good capacity of recovery to the bending effort (better in the longitudinal direction) and high elasticity; and woven fabrics: more flexible in the longitudinal direction than in the transversal, lower recovery capacity and limited elasticity. This is logical because woven fabrics have a slightly more “rigid"; structure than knitted fabrics, which is more flexible and better adapted to this type of stress.

As the conductive yarns were inserted the bending stiffness (B) is quite similar, it doesn’t influence much. On the other hand, the recovery capacity to the bending effort (2HB) decreases, since, when inserting the yarns a more rigid structure is created that makes, the recovery capacity worse.

The prototype with the worst recovery capacity and the most rigid bending is the cotton (woven) (B), while the prototypes with the best recovery capacity and therefore the least bending are the woven (knitted) (C).

The material with the most variation in properties is cotton (woven) (B) with the insertion of yarns. Although it is necessary to emphasize that when inserting the yarns, the results obtained are not much different between them so the behaviors are similar. The least is still cotton (knitted) (C).

6.4 CONCLUSIONS | SHEAR TESTER

En los primeros ensayos realizados sin inserción de hilo, los tejidos de punto presentaban low shear rigidity and low capacity of recovery to the shear effot (better in cotton-elastane fabric); y los tejidos de calada: low shear force stiffness (in the transverse direction than in the longitudinal direction) and low recovery capacity from shearing effort (in the transverse and longitudinal direction).

As the insertion of the yarns is performed, the shear rigidity (G) increases and the shear recovery capacity (2HG) is lower. Similarly, by presenting a more rigid structure when inserting these types of threads, it makes this happen.

The cotton (woven) material (B) is the one with the greatest alteration of its shear properties. The multiwire stainless steel - red circuit (3) is the one that most alters its properties.

The same happens if we study the materials with respect to the direction of thread insertion, where the cotton (woven) material (B), is still the one that presents the greatest alteration, especially in the WARP direction that the values are higher.

6.5 CONCLUSIONS | TENSILE TESTER

In this case, conclusions will only be drawn from the woven fabrics, since, as indicated above, knitted fabrics (due to their flexible structure) weren't capable of being subjected to this type of stress.

Thus, before the insertion of conductive threads, the woven fabrics had medium capacity of recovery, particularly low stretching capacity and weak medium tension.

As the conductive wires are inserted, with respect to the traction stiffness (LT), results are obtained whose variation between them is very small, therefore it can be said that the traction sitffness (LT) is maintained. The stretching capacity (WT) is better because, as the structure is more firm, it can withstand the stretching effort better. Finally, the recovery capacity (RT), for the same reason, is lower as the structure becomes more rigid.

The prototype whose properties are most altered is cotton-polyester (woven) (B) after insertion of conductive yarns. Featuring a higher traction stiffness (LT) when inserting conductive wires, higher stretch capacity (WT), and lower recovery capacity (RT).

6.6 FINAL CONCLUSION

In summary, this study concludes, after analysing the results obtained, that multifilament yarns alter the textile properties more than monofilament yarns. In addition, the choice of a knitted or woven fabric is also important; for example, if the application is the insertion of these yarns into garments to create a sensor network, knitted fabrics would have to be accompanied by a reinforcement material to insert these yarns, due to their structure, the insertion of these yarns is more complicated than in woven fabrics whose structure is more “rigid".

In addition, it should be noted that monofilament yarns have a higher conductivity and, it has been proven, that to be sewn, they adapt much better than multifilaments; furthermore, with respect to the aesthetic design, with monofilament threads it is better since aesthetically everything is more uniform.

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7. FUTURE LINES OF RESEARCH | ABOUT THE PROJECT

This project has only analyzed few aspects inside a very wide field of research. Therefore, there are many things left to improve and to do in order to create a more detailed project.

If this line of research will continue, more types of wires would have to be studied and characterized.

The types of materials should also be more, varying compositions and ligaments.

In addition, it would be interesting to be able to create the conductive thread embroidery in one step rather than in two, as it has been done in this project. Once embroidered, it would also be interesting to check the maintenance properties of the prototype (washing of the garments, ironing...).

Finally, to obtain real sensors and to be able to interconnect them in order to determine if it really works and give it a real application, attending to the main objective of this study, which is the creation of intelligent sensorized garments by means of interconnection of conductive threads maintaining properties of comfort, functionality and ergonomics for people.

8. ANNEX I | SENSOR'S MARKET RESEARCHS

Statex [1]	Very elastic, shiny and extremely electrically conductive silver knitted fabrics.
TT Sensor Plus 4 [2]	TT Sensor Plus 4 sensor as a disposable card that records the temperature to which an item is exposed. *• Minimum application temperature: +5°C* *• Service temperature range: -15°C to +90°C*
Luminary Micro / Texas Instruments - RF430-TMPSNS-EVM [3]	Near Field Communication type.
Lllypad sensor de temperatura MCP9700 [4]	They can be sewn into clothes, even washable. This board is a temperature sensor based on the MCP9700 The MCP9700 is a small thermistor type temperature sensor. This sensor has in the output 0. 5V at 0 ° C, 0. 75 V at 25 ° C and a thermal drift of 10 mV per degree centigrade. Converting from analog to digital on the signal line will allow you to set the local ambient temperature
Clothing PLUS [5]	Entity in charge of developing intelligent textiles. Create e-textile solutions with durability, easy maintenance, refined process and full technical testing. - Sensors - Material technologies - Product design and development - Software application - Testing - Certification and approval - Intelligent textile production - Supply chain management
Sparkfun single lead heart rate [6]	Heart rate sensor. Interface type.
Sensor de respiración X4M200 [7]	The XeThru X4M200 is Novelda's breathing sensor powered by the XeThru X4 system on the chip. Standard sleep and breathing monitoring capabilities are integrated into the sensor and provide advanced breathing and movement tracking during both day and night. The programmable detection range of up to 5 meters is a key feature for the sensor.
Desarrollo de sensores personalizados [8]	Includes all the built-in functionality for your radar sensor project; access to the XeThru X4 UWB Radar's SoC parametric control, the back-end data processing it requires, and communication stacks that connect to host software running on Windows, Mac, Linus, and embedded targets
FLORA - Wearable electronic platform: Arduino-compatible - v2 [9]	Portable electronic platform

Sensor de frecuencia cardiaca – Polar OH1 – Talla M – XXL, Naranja [10]	Polar OH1 records the heart rate with the unique 6-LED POLAR optical heart rate system.
eVu TPS – Sensor fisiológico triple [11]	Compact and lightweight fingertip sensor. Heart rate variability, skin conductance, temperature. eVu Senz Smart App for Android phones and tablets. Easily track customer compliance and progress
Tecnología E-WEBBINGS e-Textile [12]	By combining non-conductive base fibres with a combination of specialised conductive elements, our E-WEBBINGS® electronic textiles offer a customisable base for various smart textile projects. - Metal Stranding - Metal Injection
VitalPach [13]	The most discreet and advanced patient monitoring device possible. State-of-the-art biosensor monitors eight physiological measurements continuously, in real time. - Single-wire ECG, heart rate, heart rate variability, breathing rate, skin temperature, body posture, fall detection and activity
Módulos de detección de signos vitales [14]	The biometric sensor product family has first-class integrated optical sensor modules that include algorithms for heart rate measurement, photoplestimography (PPG) and electrocardiography (ECG).
Semtech Wireless Power [15]	Sensor for evaluation modules. Complete system design solutions for low-power portable applications Leading power scalability. Design flexibility. Applications: HEALTH MONITORS
Plataformas ARDUINO [16]	Platforms that can be used to control devices and read data from all types of sensors. Arduino boards can work at an operating frequency of up to 16 MHz and up to 16 MIPS, so the computational capacity is sufficient for the acquisition, processing and transmission of data from digital and analog sensors for monitoring vital signs.
GENTAG, Inc. [17]	GENTAG, Inc. is a technology development company that focuses on creating innovative, low-cost wireless sensor technologies based on cell phones.

Etiqueta NFC Textil Flexible Ntag212 [18]	The only stretchable NFC label, which can be sewn, ironed, folded and creased. Completely waterproof, resistant up to 150 ° C. Universal compatibility.
20 Tags NFC etiquetas NTAG203 Circus [19]	Purchase of NFC patches.
6-Axis Sensor [20]	6-axis magnetometer and accelerometer products offer extremely high resolution, low power performance that is compatible with our eCompass software. These solutions address high-precision electronic compass functionality for augmented reality, e-readers, medical applications, home appliances, portable navigation devices, smart phones and tablets.
LIBRO SMART TEXTILES FOR MEDICINE AND HEALTHCARE	
BEKINTEX [22]	Sale of conductive materials used in a project for monitoring vital signs in children.
MICROCONTROLADOR PIC [23]	Used in the same project for the collection of information.
Textile Sensor EVALUATION KIT [24]	This kit contains evaluation samples of the following sensors: - Analogue pressure sensor PW073 - High load textile pressure button PW073 - Analogue pressure sensor in the form of PW074 - Sensor de tela PR PW109 GSR - TACRACPS1X0404GY Single textile snap button - Temperature sensor
SMARTEX [25]	Entity in charge of the production of interactive, multifunctional, flexible and conformable fabrics for the human body that represents a cutting-edge tool promoting innovation, sustainable development and competitiveness in many disciplines.

**Note: The web reference page for each sensor can be found by clicking on the number in brackets. A hyperlink has been created with the corresponding link for each one.*

9. ANNEX II | SUMMARY TABLE OF THE RESULTS OBTAINED FOR EACH PROTOTYPE

SURFACE TESTER												
	MIU				MMD				SMD (um)			
	WARP		WEFT		WARP		WEFT		WARP		WEFT	
	“A”	“B”	“A”	“B”	“A”	“B”	“A”	“B”	“A”	“B”	“A”	“B”
COTTON - ELASTANE FABRIC (**KNITTING**)	0.183	0.257	0.230	0.201	0.0001	0.0001	0.0001	0.0001	1.070	1.905	1.990	1.450
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.508	0.579	0.364	0.608	0.0310	0.0412	0.0242	0.0400	7.500	4.015	7.760	3.840
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.414	0.400	0.516	0.243	0.0178	0.0186	0.0304	0.0098	9.195	6.165	8.935	5.300
COTTON – ELASTANE FABRIC – (monofilament with conductive covered)	0.312	0.593	0.336	0.269	0.0160	0.0292	0.0191	0.0192	3.875	4.340	4.635	4.710

COMPRESSION TESTER		
	WC (gf / cm^2)	RC (%)
COTTON - ELASTANE FABRIC (**KNITTING**)	0.221	48.87
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.878	26.20
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	1.002	29.14
COTTON – ELASTANE FABRIC – (monofilament with conductive covered)	0.287	30.66

BENDING TESTER				
	B (gf.cm^2 / cm)		2HB (gf.cm^2 / cm)	
	WARP	WEFT	WARP	WEFT
COTTON - ELASTANE FABRIC (**KNITTING**)	0.0486	0.0178	0.0325	0.0143
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.2760	0.2799	0.3497	0.3525
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.1035	0.3219	0.2013	0.2700
COTTON – ELASTANE FABRIC – (monofilament with conductive covered)	0.0415	0.1350	0.0738	0.3111

SHEAR TESTER				
	G (gf/cm.degree)		2HG (gf/cm.degree)	
	WARP	WEFT	WARP	WEFT
COTTON - ELASTANE FABRIC (**KNITTING**)	0.32	0.38	0.93	0.98
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.15	0.17	0.45	0.43
COTTON – ELASTANE FABRIC – (multifilament stainless steel)	0.17	0.10	0.48	0.35
COTTON – ELASTANE FABRIC – (monofilament with conductive covered)	0.14	0.16	0.50	0.38

TENSILE TESTER						
	WT (%)		RT (%)		LT	
	WARP	WEFT	WARP	WEFT	WARP	WEFT
COTTON - ELASTANE FABRIC (**KNITTING**)						
COTTON – ELASTANE FABRIC – (multifilament stainless steel)						
COTTON – ELASTANE FABRIC – (multifilament stainless steel)						
COTTON – ELASTANE FABRIC – (monofilament with conductive covered)						

SURFACE TESTER												
	MIU				MMD				SMD (um)			
	WARP		WEFT		WARP		WEFT		WARP		WEFT	
	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"
COTTON FABRIC (**KNITTING**)	0.184	0.204	0.227	0.192	0.0003	0.0004	0.0001	0.0001	1.105	1.185	1.630	1.145
COTTON FABRIC – (multifilament stainless steel)	0.256	0.284	0.416	0.245	0.0308	0.0303	0.0375	0.0316	6.015	7.335	7.850	6.970
COTTON FABRIC – (multifilament stainless steel)	0.252	0.269	0.456	0.322	0.0328	0.0207	0.0236	0.0284	9.940	8.545	8.630	4.960
COTTON FABRIC – (monofilament with conductive covered)	0.290	0.247	0.376	0.434	0.0345	0.0325	0.0337	0.0210	5.675	3.875	5.415	3.905

COMPRESSION TESTER		
	WC (gf / cm²)	**RC (%)**
COTTON FABRIC (**KNITTING**)	0.254	40.55
COTTON FABRIC – (multifilament stainless steel)	0.794	30.23
COTTON FABRIC – (multifilament stainless steel)	0.781	42.97
COTTON FABRIC – (monofilament with conductive covered)	0.251	29.88

BENDING TESTER				
	B (gf.cm² / cm)		**2HB (gf.cm² / cm)**	
	WARP	WEFT	WARP	WEFT
COTTON FABRIC (**KNITTING**)	0.0142	0.0286	0.0030	0.0112
COTTON FABRIC – (multifilament stainless steel)	0.1879	0.0327	0.4024	0.0889
COTTON FABRIC – (multifilament stainless steel)	0.2284	0.0590	0.3424	0.1126
COTTON FABRIC – (monofilament with conductive covered)	0.1368	0.0549	0.1983	0.0538

SHEAR TESTER				
	G (gf/cm.degree)		**2HG (gf/cm.degree)**	
	WARP	WEFT	WARP	WEFT
COTTON FABRIC (**KNITTING**)	0.40	0.43	0.90	0.78
COTTON FABRIC – (multifilament stainless steel)	0.45	0.27	1.30	0.58
COTTON FABRIC – (multifilament stainless steel)	0.85	0.73	2.70	4.00
COTTON FABRIC – (monofilament with conductive covered)	0.95	0.43	1.78	0.35

TENSILE TESTER						
	WT (%)		**RT (%)**		**LT**	
	WARP	**WEFT**	**WARP**	**WEFT**	**WARP**	**WEFT**
COTTON FABRIC (**KNITTING**)	59.80		20.40		0.744	
COTTON FABRIC – (multifilament stainless steel)	26.60	33.50	12.97	13.43	0.379	0.432
COTTON FABRIC – (multifilament stainless steel)	33.60	37.80	10.57	13.10	0.402	0.400
COTTON FABRIC – (monofilament with conductive covered)	37.10	49.50	10.65	11.01	0.451	0.471

SURFACE TESTER												
	MIU				MMD				SMD (um)			
	WARP		WEFT		WARP		WEFT		WARP		WEFT	
	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"
COTTON FABRIC (**WOVEN**)	0.174	0.141	0.188	0.204	0.0179	0.0139	0.0148	0.0206	4.730	3.130	4.875	4.460
COTTON FABRIC – (multifilament stainless steel)	0.272	0.280	0.255	0.466	0.0295	0.0348	0.0279	0.0381	7.010	15.135	9.645	11.025
COTTON FABRIC – (multifilament stainless steel)	0.331	0.386	0.280	0.269	0.0242	0.0460	0.0301	0.0519	9.110	11.215	5.735	10.555
COTTON FABRIC – (monofilament with conductive covered)	0.375	0.384	0.215	0.170	0.0461	0.0566	0.0201	0.0404	8.450	7.075	4.080	8.725

COMPRESSION TESTER		
	WC (gf / cm^2)	**RC (%)**
COTTON FABRIC (**WOVEN**))	0.154	59.09
COTTON FABRIC – (multifilament stainless steel)	1.840	42.45
COTTON FABRIC – (multifilament stainless steel)	1.954	43.19
COTTON FABRIC – (monofilament with conductive covered)	0.504	37.50

BENDING TESTER				
	B (gf.cm^2 / cm)		**2HB (gf.cm^2 / cm)**	
	WARP	WEFT	WARP	WEFT
COTTON FABRIC (**WOVEN**)	0.4590	0.4116	0.3703	0.3326
COTTON FABRIC – (multifilament stainless steel)	0.4590	0.3075	0.3703	0.3497
COTTON FABRIC – (multifilament stainless steel)	0.3158	0.0139	0.4649	0.3398
COTTON FABRIC – (monofilament with conductive covered)	0.4841	0.0610	0.3611	0.3073

SHEAR TESTER				
	G (gf/cm.degree)		**2HG (gf/cm.degree)**	
	WARP	WEFT	WARP	WEFT
COTTON FABRIC (**WOVEN**)	0.87	1.28	1.35	1.80
COTTON FABRIC – (multifilament stainless steel)	2.37	2.27	8.95	5.83
COTTON FABRIC – (multifilament stainless steel)	3.1	2.97	6.15	9.55
COTTON FABRIC – (monofilament with conductive covered)	4.44	2.21	15.58	9.18

TENSILE TESTER						
	WT (%)		**RT (%)**		**LT**	
	WARP	**WEFT**	**WARP**	**WEFT**	**WARP**	**WEFT**
COTTON FABRIC (**WOVEN**)	1.10	2.05	86.36	65.85	0.419	0.488
COTTON FABRIC – (multifilament stainless steel)	**5.50**	**3.00**	**28.19**	**33.33**	**0.141**	**0.469**
COTTON FABRIC – (multifilament stainless steel)	**4.50**	**1.10**	**31.11**	**40.91**	**0.353**	**0.192**
COTTON FABRIC – (monofilament with conductive covered)	**3.05**	**4.90**	**39.34**	**30.61**	**0.434**	**0.482**

SURFACE TESTER												
	MIU				MMD				SMD (um)			
	WARP		WEFT		WARP		WEFT		WARP		WEFT	
	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"	"A"	"B"
COTTON - POLYESTER FABRIC (**WOVEN**)	0.183	0.240	0.171	0.200	0.0190	0.0190	0.0243	0.0196	3.490	3.760	3.385	4.585
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.264	0.217	0.468	0.381	0.0336	0.0217	0.0419	0.0447	4.305	6.555	4.710	7.245
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.402	0.252	0.323	0.492	0.0561	0.0339	0.0321	0.0605	10.395	7.165	9.710	13.315
COTTON - POLYESTER FABRIC – (monofilament with conductive covered)	0.216	0.200	0.354	0.371	0.0380	0.0226	0.0437	0.0447	8.125	7.550	10.170	5.705

COMPRESSION TESTER		
	WC (gf / cm^2)	RC (%)
COTTON - POLYESTER FABRIC (**WOVEN**))	0.166	59.04
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.788	60.15
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.357	51.54
COTTON - POLYESTER FABRIC – (monofilament with conductive covered)	0.397	53.90

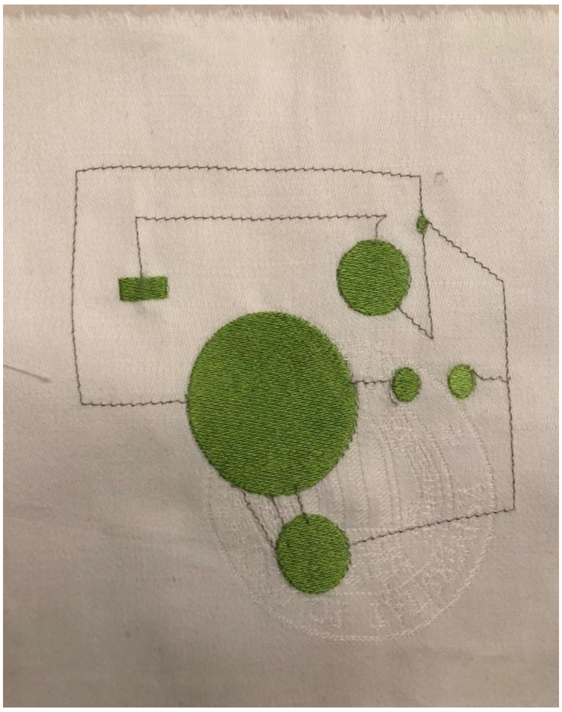
BENDING TESTER				
	B ($gf.cm^2$ / cm)		2HB ($gf.cm^2$ / cm)	
	WARP	WEFT	WARP	WEFT
COTTON – POLYESTER FABRIC (**WOVEN**)	0.0705	0.3011	0.2851	0.2270
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.0684	0.0075	0.0485	0.1102
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	0.0623	0.0048	0.2006	0.1602
COTTON - POLYESTER FABRIC – (monofilament with conductive covered)	0.0351	0.0703	0.0929	0.1901

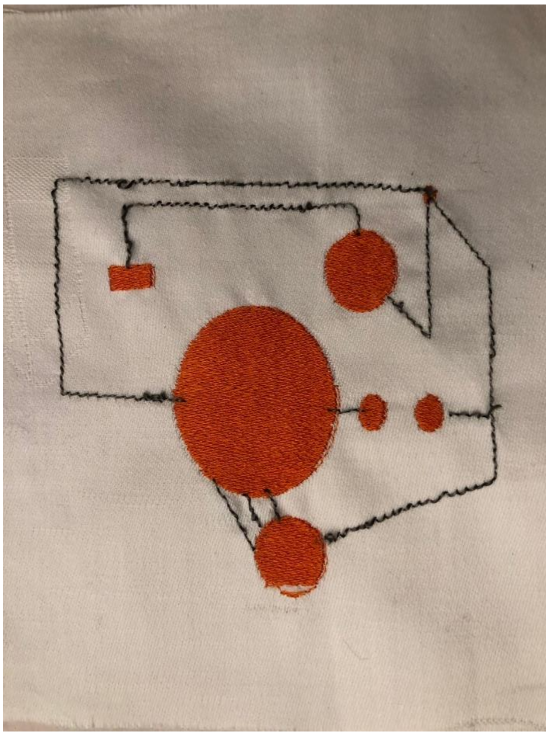
SHEAR TESTER				
	G (gf/cm.degree)		2HG (gf/cm.degree)	
	WARP	WEFT	WARP	WEFT
COTTON - POLYESTER FABRIC (**WOVEN**)	0.49	0.92	0.53	1.08
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	2.05	1.45	4.25	2.58
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	1.84	1.74	4.33	3.18
COTTON - POLYESTER FABRIC – (monofilament with conductive covered)	1.43	2.81	3.03	6.98

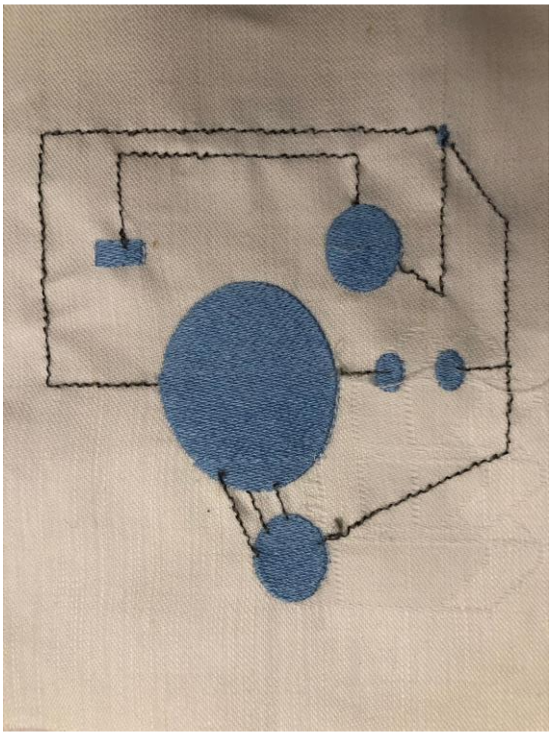
TENSILE TESTER						
	WT (%)		RT (%)		LT	
	WARP	WEFT	WARP	WEFT	WARP	WEFT
COTTON - POLYESTER FABRIC (**WOVEN**)	10.50	10.27	50.00	53.66	0.435	0.431
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	4.35	15.30	36.78	15.30	0.437	0.461
COTTON - POLYESTER FABRIC – (multifilament stainless steel)	7.30	5.20	38.36	45.19	0.378	0.499
COTTON - POLYESTER FABRIC – (monofilament with conductive covered)	5.45	15.10	32.11	36.78	0.436	0.580

10. ANNEX III | PHOTOS OF THE PROTOTYPES

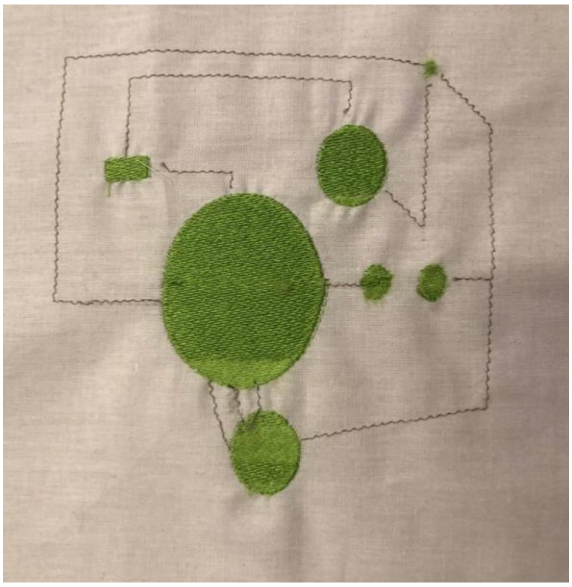
COTTON WOVEN FABRIC | PROTOTYPES

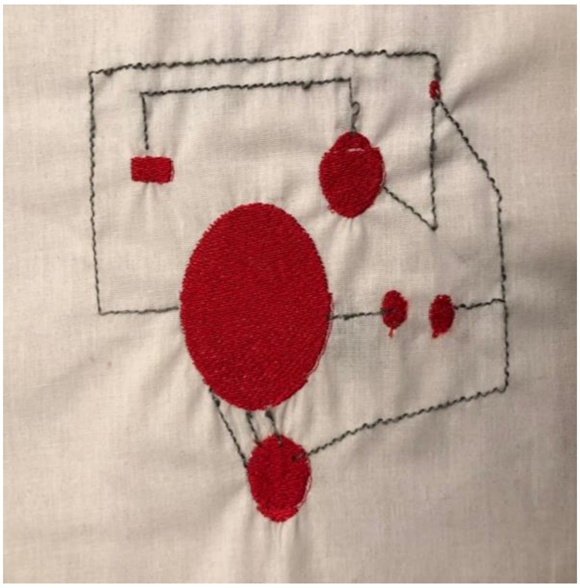


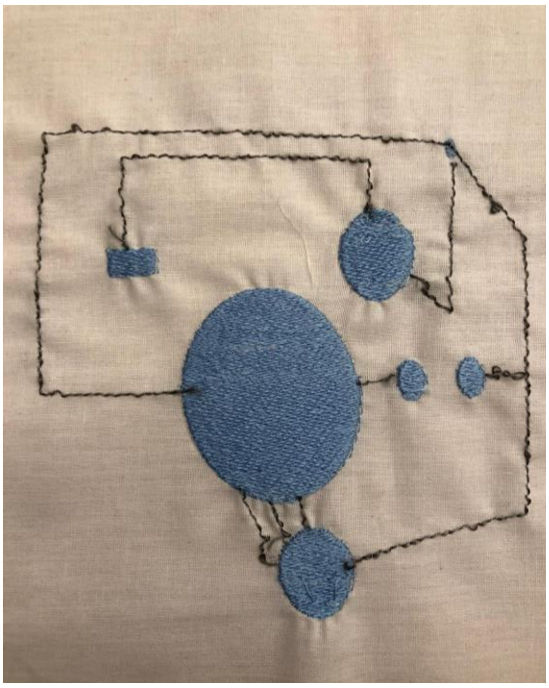


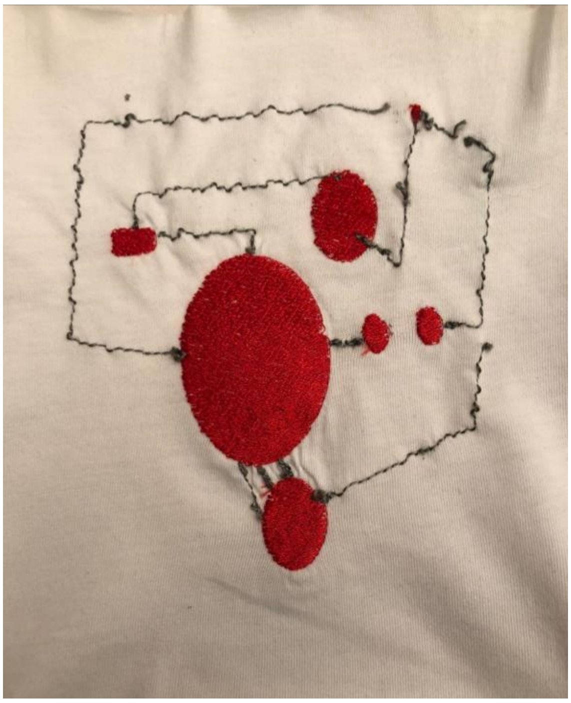


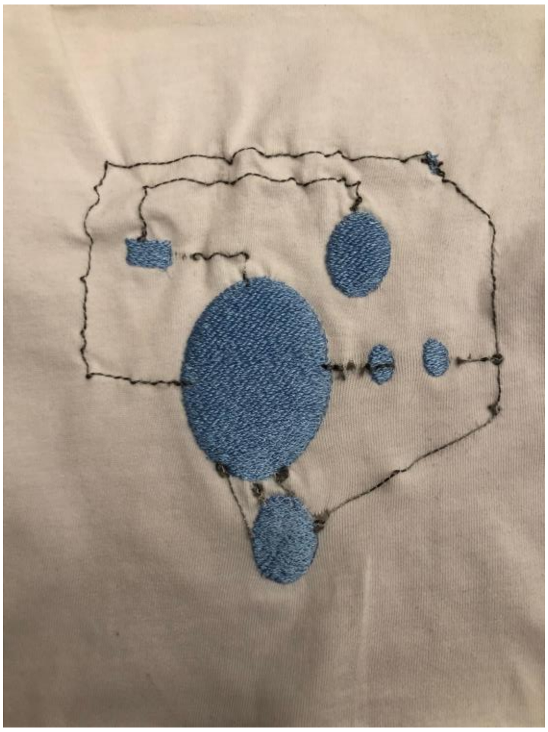
COTTON - POLYESTER WOVEN FABRIC | PROTOTYPES



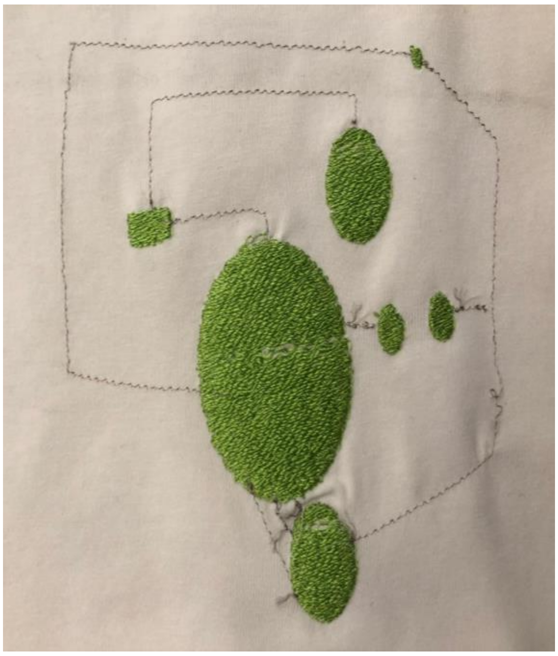


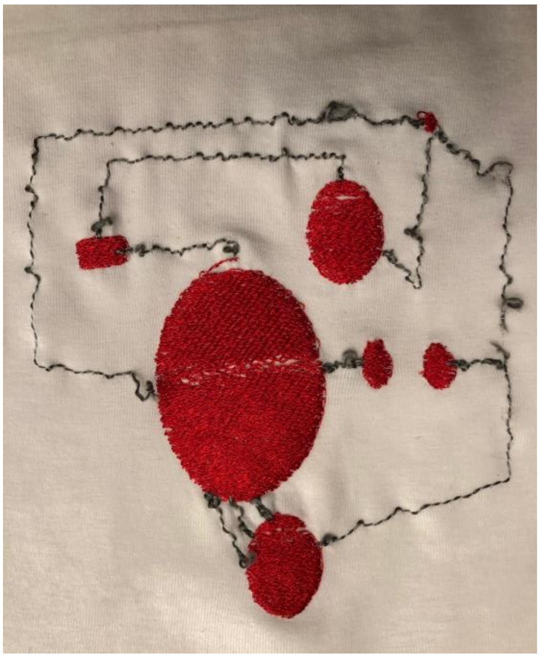


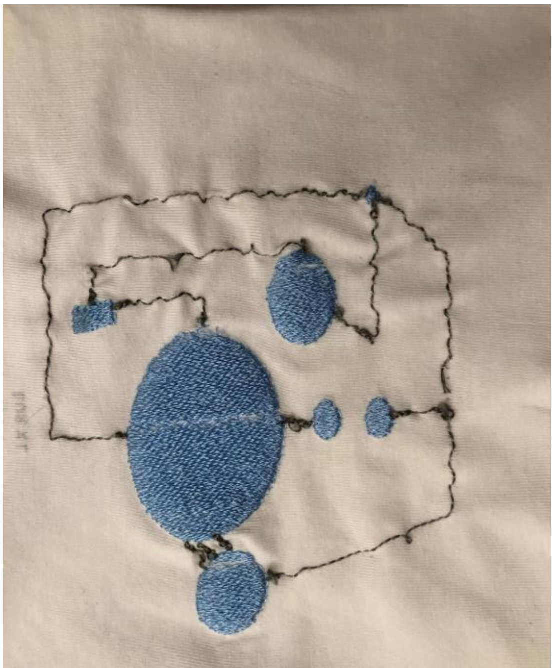




COTTON - ELASTANE KNITTED FABRIC | PROTOTYPES







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