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M.Sc. in Textile Engineering

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PERFORMANCE OF THE SUSTAINABLE SINGLE JERSEY FABRICS FROM RECYCLED POLYESTER AND ACRYLIC FIBERS CORE-SPUN YARNS

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Supervisor

Assoc. Prof. Dr. Züleyha DEĞİRMENCİ

by

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PERFORMANCE OF THE SUSTAINABLE SINGLE JERSEY FABRICS FROM RECYCLED POLYESTER AND ACRYLIC FIBERS CORE-SPUN YARNS

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

PERFORMANCE OF THE SUSTAINABLE SINGLE JERSEY FABRICS FROM RECYCLED POLYESTER AND ACRYLIC FIBERS CORE-SPUN YARNS

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It is known that with the changing fashion in the textile sector, textile products are produced in large proportions every year. In this sector where production is high, it can be observed that as production increases, raw material consumption, energy consumption, water consumption and the consumption of natural resources such as these increase in direct proportion. While textile products are produced, wastes are formed at every stage, and the reuse of these wastes contributes to sustainability under the name of recycling. In this context, it is very important for the textile industry to produce recycled fiber and to include recycled fiber in the content of the products. The customer base of acrylic, which is among the synthetic fibers, is quite high, it is in high demand especially in winter months due to its similarity to wool fiber. As another example of synthetic fibers, polyester fiber is among the preferred synthetic fibers such as acrylic due to the properties it exhibits. It is very important to recycle both synthetic fiber types and reintroduce them into the production line. In the study, it is aimed to emphasize the importance of sustainability and to emphasize the contribution of recycled fibers. In this study, 7.5 Nm samples were obtained with different combinations of recycled fibers and conventional fibers on core yarns, these samples were converted into knitted fabrics and the effects of the recycled fiber ratio used in the products on the quality of the samples were investigated.

Key Words: Sustainability, Recycled Fibers, Core Yarns, Acrylic, Polyester.

ÖZET

GERİ DÖNÜŞTÜRÜLMÜŞ POLYESTER VE AKRİLİK ÖZLÜ İPLİKLERDEN SÜRDÜRÜLEBİLİR SÜPREM KUMAŞLARIN PERFORMANSI

TURGUT, Edanur
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92 sayfa

Tekstil sektöründe değişen moda ile beraber her yıl yüklü oranlarda tekstil ürünlerine üretim yapıldığı bilinmektedir. Üretimin fazla olduğu bu sektörde üretim arttıkça hammadde tüketimi, enerji tüketimi, su tüketimi ve bunun gibi doğal kaynakların tüketiminin de doğru orantılı olarak arttığı gözlemlenebilmektedir. Tekstil ürünleri üretilirken her aşamada telefler oluşmaktadır ve bu oluşan teleflerin tekrar kullanılabilmesi geri dönüşüm adı altında sürdürülebilirliğe katkı sağlamaktadır. Bu bağlamda geri dönüşüm elyaf üretmenin ve ürünlerin içeriğinde geri dönüşüm elyaf bulundurmanın tekstil sektörü için önemi oldukça büyüktür. Sentetik elyaflar arasında bulunan akriliğin müşteri kitlesi oldukça fazladır, özellikle kış aylarında yün lifine benzerliğinden dolayı oldukça talep görmektedir. Sentetik elyaflara başka bir örnek olarak polyester elyafı da sergilediği özelliklerden dolayı akrilik gibi tercih edilen sentetik elyaflar arasında gelmektedir. Her iki sentetik elyaf çeşidinin de geri dönüştürülmesi ve üretim hattına tekrar dahil edilebilmesi oldukça önem arz etmektedir. Çalışmada sürdürülebilirliğin önemini vurgulamak ve geri dönüşüm elyafların sağlayacağı katkının vurgulanması hedeflenmektedir. Bu çalışmada özlü iplikler üzerinde geri dönüşüm elyafların ve konvansiyonel elyafların farklı kombinasyonlarıyla 7,5 Nm numuneler elde edilmiş, bu numuneler örme kumaşa dönüştürülmüş ve ürünlerde kullanılan geri dönüşüm lif oranının numunelerin kalitesine olan etkileri incelenmiştir.

Anahtar Kelimeler: Sürdürülebilirlik, Geri Dönüşüm Elyaflar, Özlü İplikler, Akrilik,Polyester.

"Dedicated to my family"

"Tolunay TURGUT"

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LIST OF SYMBOLS

α_m	Twist Coefficient
WVP	Water Vapor Permeability
%	Percentage
$\%U_m$	Yarn Unevenness
$\%CV_m$	Yarn Unevenness
Nm	Yarn Count
Ne	Yarn Count
Tex	Yarn Count
Dtex	Yarn Count
m	Metre
cm	Centimeter
mm	Millimeter
m^2	Square meters
cm^2	Square centimeter
tpm	Twist per minute
rpm	Revolution per minute
Pa	Pascal
kPa	Kilopascals
min	Minute
WPC	Wale per centimeter
CPC	Course per centimeter
g	Gram

LIST OF ABBREVIATIONS

R-PET	Recycled Polyethylene Terephthalate
PET	Polyethylene Terephthalate
PAC	Acrylic
PBT	Polybutylene Terephthalate
PVA	Polyvinyl Alcohol
FDY	Fully Drawn Yarn
RECYCLE FDY	Recycle Fully Drawn Yarn
DTY	Drawn Textured Yarn
RECYCLE DTY	Recycle Drawn Textured Yarn
PAN	Polyacrylonitrile
ACR	Acrylic
RE-ACR	Recycled Acrylic

CHAPTER 1
INTRODUCTION

The ready-made clothing and textile sector is among the most important sectors in the world in terms of labor intensive, production capacity and production intensity. In the textile sector, it contributes not only to clothing and apparel, but also to home textiles. The ready-to-wear and textile sector has grown by an average of 60 times in the last 40 years, and it is predicted that the production capacity is more than twice the current demand. When this situation is considered, sustainability is of great importance for the textile industry, as in other sectors. It is very important economically and ecologically for the world to ensure production without any waste, such as the fact that the auxiliary materials and raw materials of the manufactured products are of natural origin and the chemical substances are considerably reduced during fiber production [1].

The textile industry represents a significant part of the manufacturing industry and plays an important role in the economy and social welfare of many regions around the world. The textile industry is not only one of the most important consumer goods industries, but also has a significant impact on the environment. Because it is a very diverse and heterogeneous industry that encompasses a significant number of activities, from the conversion of fibers into yarns and fabrics, to the production of a wide variety of products such as hi-tech synthetic yarns, wool, bedding, industrial filters, geo textiles, clothing produce a variety of significant adverse environmental and social impacts throughout the global lifecycle. Textile waste is not a large waste stream by weight or volume, but has a significant environmental impact associated with textile production [2].

There are many innovations in the recycling of textile waste. Among these innovations, some wastes called plastic bottles, packaging and plastics can be brought to the textile industry. This acquisition is becoming quite popular and widespread. In this way, with the advancement of technology, the number of such recycling applications is increasing in direct proportion. PET bottle wastes are also recycled in different sectors and recycling in textiles is carried out as recycled polyester (r-PET) and its use is becoming very common. In this way, it becomes possible to obtain environmentally friendly and sustainable products [3]. Nowadays, recycling of natural and artificial fibers is common. There are recovery efforts in many fiber types. In the recycling sector, not only PES fiber but also many fibers are recovered. Along with the recycling of cotton fiber, which is among the natural fibers, its use in fabric types such as denim fabrics is widely used in the clothing industry.

The importance of recycling and the contribution of its use to sustainability are very important with an environmental perspective. In this context, based on this, a comparison was made by using recycled fiber and conventional fiber on the yarn structure in core yarns, both in the core and in the covering part. As a result of this comparison, it is aimed to create different options by revealing the difference between the use of recycled and conventional fibers. A study was conducted on the effects of the use of recycled acrylic and conventional acrylic blends in different ratios in covering fibers, and the use of conventional polyester filament and recycled polyester filament in core part on the 7.5 Nm yarn and knitted fabrics obtained.

1.1. Properties of Acrylic (Polyacrylonitrile)

Acrylic, modacrylic, and vinyl fibers are types of fibers that contain cyanide groups as side chains. Acrylonitrile is defined as a comonomer containing a cyanide group. Acrylic fibers generally consist of more than 85% acrylonitrile monomer units. This type of fiber is warm, high-volume, hard to wrinkle, and has a good flexibility ratio. Acrylic fibers are fibers obtained using the wet and dry spinning method of comonomers.

1.1.1. Physical Properties of Polyacrylonitrile Fibers

Acrylic fibers have moderate strength and moderate elongation at break. Although the strength of acrylic fibers varies between (18-36 g/tex), the strength value decreases when wet. Hardness levels are moderate. It has a high flexibility rate and shows the feature of getting rid of bending deformation. They have low specific gravity, and this value range varies between 1.16-1.18. They have a low moisture recovery of 1.0%-2.5%. PAN fibers have good thermal and electrical insulating properties, and in addition, they create a moderate static charge and additionally soften at 190°-250°C. Acrylic fibers are usually round or smooth with dog bone cross-sections. The view of acrylic fibers under the microscope is given in Figure 1.1.

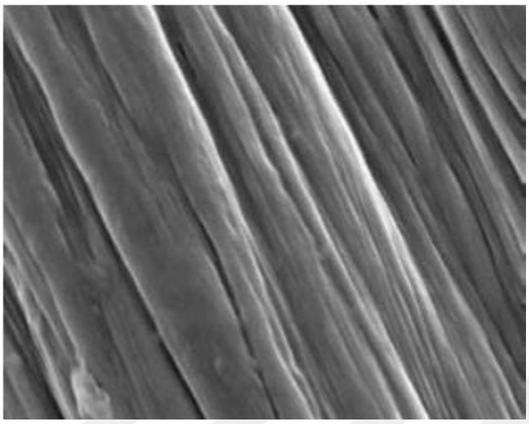

Figure 1.1. View of acrylic fiber under microscope [4]

1.1.2. Chemical Properties of Polyacrylonitrile Fibers

Polyacrylonitrile fibers have good resistance to chemicals and are affected by concentrated acids. At high temperatures, the rate of being affected by oxidizing and reducing agents is very low, apart from hydrochloride solutions. They are not affected by sunlight. Chemical structures of acrylic fibers are given in Figure 1.2.

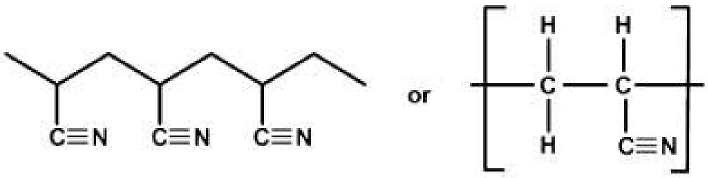

Figure 1.2. Chemical structure of acrylic fiber [5]

1.1.3. Usage Areas of Polyacrylonitrile Fibers

Acrylic fibers have many uses. These usage areas mostly include the clothing sector, home textiles and industrial areas. They are widely used in the clothing industry such as knitwear, socks, plush, circular knitting, sportswear and children's wear. Although it is highly demanded in the field of home textiles, especially in the carpet sector, it is also used in areas such as blankets, rugs, upholstery and velvet fabrics. In outdoor use, they are used in materials such as car ceilings, boat covers, tarpaulin and outdoor furniture [6].

1.2. Properties of Polyester

Polyester fibers are fibers that contain at least 85% of a polymeric ester of aromatic carboxylic acid, including terephthalic acid and p-hydroxybenzoic acid. Polyester obtained as an ester polyethylene terephthalate formed by the gradual growth polymerization of terephthalic acid and diol ethylene glycol is the main product used in the trade. Most polyesters have the same property. They are highly flexible, tangle-resistant, highly durable fibers.

1.2.1. Physical Properties of Polyester Fibers

Although polyester fibers have a high strength value, their elongation at break varies between 15% and 50% depending on the orientation of the crystal structure in the fiber. These fibers are harder than other fibers. It exhibits high flexibility and recovery from bending deformation. The specific gravity of polyester fibers is 1.38 on average. It is a type of hydrophobic fiber and shows moderate thermal conductivity. Polyester fiber softens at 210°-250°C. These fibers melt at 250°-255°C. Polyester fibers are generally straight and rod-like with rounded or trilobal cross-sections. The view of polyester fibers under the microscope is given in Figure 1.3.

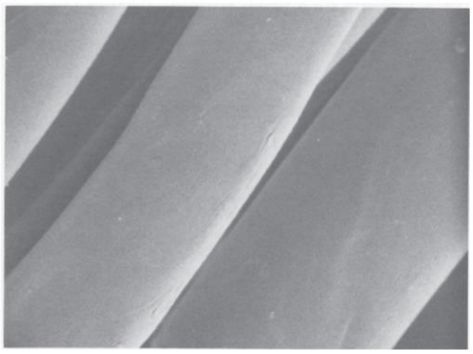

Figure 1.3. View of polyester fiber under microscope

1.2.2. Chemical Properties of Polyester Fibers

Polyester fibers are not affected by bases, acids, reducing and oxidizing agents. They may be affected by hot concentrated acids and bases. Polyester fibers show very high resistance to biological substances. When they are exposed to sunlight, they can be exposed to oxidative attack without any change in the fiber, and this can lead to loss of power. Chemical structures of polyester fibers are given in Figure 1.4.

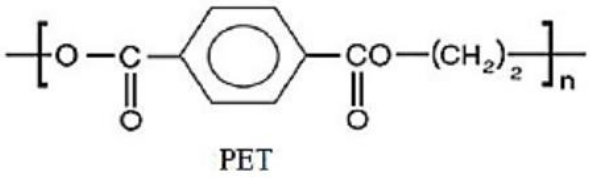

Figure 1.4 Chemical structure of polyester fiber [7]

1.2.3. Usage Areas of Polyester Fibers

Polyester fiber is a type of fiber that is widely used in every sector. Clothing, home textile and industrial usage areas are quite wide and vary. Polyester fiber is widely used in the manufacture of jackets, coats, coats and topcoats in suits, underwear, shirts and outerwear. Polyester fabrics have different usage areas, mainly bedspreads, tablecloths, pillows, duvet covers, curtain fabrics and carpets. Industrial uses include fishing net, automobile tires, rope, sewing thread and sailcloth [8].

1.3. Purpose of the Study

The primary aim of the study is to express the importance of recycled fibers on the basis of sustainability and to investigate the economic and ecological contributions of recycled fibers. Within the scope of the study, comparisons were made between recycled acrylic and polyester and conventional acrylic and polyester. In this context, 16 different core yarns were produced by using recycled fibers at different rates and comparisons were made within themselves. While DTY polyester, FDY polyester, DTY recycled polyester and FDY recycled polyester are used in the core, acrylic and recycled acrylic are used in the covering fibers.

Recycled acrylic and recycled polyester are used in the core and cover part of the sample yarns. It has been adopted as a principle to emphasize the importance of sustainability and to ensure that the selection of recycling in the samples for which a certain sample range is created, becomes widespread. Since the use of polyester fiber, which is very common for recycled, arouses curiosity about what kind of properties it will exhibit on core yarns, recycled polyesters are included in the core of the samples. The reason for using recycled acrylic in the cover part is that there is not much information about recycled acrylic in the literature and this is to ensure that it becomes widespread. It is aimed to obtain a sustainable product by combining polyester and acrylic, which are the most used and preferred among artificial fibers, in the same samples.

1.4. Structure of the Thesis

According to the purpose, the thesis is written in 6 chapters.

➢ In the first chapter, an introduction was made.

➢ In the second part, about sustainability and recycling in textile.

➢ In the third chapter, include literature survey

➢ In the fourth chapter, about material and method.

➢ In the fifth chapter; include result and discussion

➢ In the last conclusion section; include conclusion.

CHAPTER 2
SUSTAINABILITY AND RECYCLING IN TEXTILE

2.1. Sustainability in Textile

Sustainability aims to provide maximum benefit by extending the life span of products. In addition to the technical and economic requirements of sustainability, the need for waste prevention and recycling has been revealed as a result of the studies of economists and environmentalists [9,23]. With the unsustainable use of ready-made clothing and textile products, the damage to the environment will increase. The most important way to prevent this situation is that the production and product are sustainable. However, the process does not end there, in addition to sustainable production and product, it is necessary to change the consumption behavior of consumers and increase their responsibilities towards the environment [9].

Rachel CARSON contributed to the start of the sustainability revolution with she's work "Silent Spring" published in 1962. Rachel Carson, as an American naturalist and writer, argues that pesticides pose serious problems and dangers to humans and animals. It is mentioned for the first time in the literature in the report called "Limits to Growth 2" published by the "Clup of Rome" on the concept of sustainability in 1962. The time when sustainability became famous and described as a turning point began with the widespread use of the internet and computer at the Rio de Janeiro Earth Summit in 1992. At this summit, it brought together 182 world leaders and brought the concept of sustainability to international dimensions [1].

Sustainability is the action of a company by taking steps that will positively affect economic progress, human life and environmental balance from the interaction of these three dynamics, considering its economic, social and environmental dynamics [10]. The report titled "Our Common Future", which was prepared for the first time by the United Nations Commission on Environment and Development (Brundtland Commission), included the most well-known definition of sustainability.

Sustainability is defined as meeting the needs of today in a way that does not prevent future generations from meeting their own needs [11].

It is clearly known that the importance of sustainability in the textile industry has a great place. There are many designers working on sustainability in the fields of Fashion Design and textiles. Focusing on waste and ethics, these designers adopted an emotional approach to second-hand clothes and adopted Kipöz's 'make, break, rip, sew' approach with a metaphorical point of view. With this point of view, they added value to sustainability by making old clothes reusable as a result of the use of certain techniques [12].

Due to the high cost of natural fibers and the long duration of production processes, as well as the high amount of water and energy used in this process, it is seen that synthetic fibers come to the forefront in the choice of raw materials, and it is seen that their use has increased accordingly. In this context, awareness focused on recycling and sustainability has led to the emergence of alternative searches and has led to the development of different raw materials. Thanks to technological developments, new material groups have been developed and started to be used in the textile sector [13].

Mass production, which started with the industrial revolution, caused the unconscious use of resources, and therefore, the wastes thrown into the environment after the production process significantly damaged the ecological structure. Based on this, sustainability, one of the most important senses of obligation, has gained value in terms of protecting resources and transferring them to future generations. As the value of sustainability increased, companies were willing to use sustainable methods not only because of environmental concerns, but also because of the desire to use resources more efficiently. In this way, they aim to become better financially [14].

Especially since the end of the 20th century, environmental problems have emerged with the increase in population and the development of industrialization. The unconscious use of unlimited natural resources has brought up waste and residue problems in the production process and has caused problems that pose global threats such as ozone layer depletion, greenhouse gas emissions, and climate change. Humanity has had to develop new perspectives in order to continue its life cycle without any problems. The concept of sustainability emerged in search of an answer to these problems [15].

2.1.1. Rules of 3R and 4R

The importance of sustainability is of great importance for the textile sector and other sectors. It is thought that 3R and 4R rules should be focused on in order to implement sustainability. The 3R, which has become popular recently, can be defined as reuse, reduce and recycle. The 4R rule is known as a rebuy added to the 3R rule [9].

Reduce: It is defined as reducing the use of natural resources, that is, consumption. In order to reduce the amount of waste generated, it is very important to carefully select the product and ensure its use as long as possible. It has been defined that the best way to manage waste is not to produce it. There are points to be considered for reducing waste [16]. At this point

- Not to prefer disposable products,
- Avoiding overpackaged products,
- Some measures can be taken, such as purchasing bulk products.

Reuse: It means that the products are reused and used for the same use without deviating from the intended use. The economic and environmental aspects of reusing products are very important. For this, it is necessary to follow some rules;

- Reusing products in different ways,
- Products that show continuous use should be directed. Using cloth bags instead of bags and similar packaging,
- Measures such as making, buying or supporting second-hand sales are within the scope of reuse.

Recycling: Recycling a material or material and using it again as a new material is called recycling. There are some things to be done in order to contribute to recycling. These; Buying products made from recycled materials,

- Classifying wastes according to their properties in order to facilitate recycling.

The 3R strategy is likened to an inverted pyramid. According to this pyramid, the more the amount of waste is reduced, the more reuse is required. The more the amount of waste is reused, the more recycling the 3R rule has been compared to the pyramid. The prominent situation in the cycle is that it is thought that the long life of the product by producing high quality products will contribute to this situation [16].

3R strategies are widely adopted by companies. Fiftyrx3, a fashion project developed by Jil Danyelle in New York, is a project on using recycled or reused clothing at a rate of at least 50% every day for approximately 1 year. The goal here is to transform a pre-existing part by not purchasing it. Patagonia, a sportswear manufacturer, uses the waste it has obtained from the consumer for 10 years and obtains high quality recycled clothing. This company is among the companies that attach great importance to the concept of recycling and absorb innovations. Polyester fleece products produced by converting from plastic bottles are an example of a business that can lead social responsibility projects. Looolo Textiles, a Canadian company, produces products with properties that can be lost in nature at the end of their useful life. Like these companies, there are many companies in every corner of the world that adopt a progressive perspective that adopts sustainability and recycling as a principle [17].

2.2. The Importance of Recycling and Recycled Fibers

Along with the increasing population, the increase in the use of all kinds of materials in the industry causes the amount of waste and waste to increase. Recycling becomes inevitable in order to prevent wastes from mixing with nature and harming the environment, and in terms of contributing to the economy by recycling wastes into production. One of the biggest advantages of recycling is that it contributes to the protection of natural resources. Wastes such as plastics, metals and textile wastes mixed with the nature disrupt the soil acid balance, harming the soil and reducing its productivity. In this context, thanks to recycling, the need for raw materials in terms of production is reduced by protecting nature, protecting natural resources. It is known that the rate of recycling of textile waste in Turkey has increased with the efforts of companies and private institutions. This rate is increasing day by day, reaching 70%. It is thought that optimizing the use of natural resources will provide us and the next generations the opportunity to benefit from natural resources [18].

The concept of waste is a name given to any substance that is not needed and is desired to be removed. Waste, which was insignificant in ancient times, has now become valuable by recycling. Today, recycling of textile waste is of great importance. Among the advantages brought by recycling is also providing mobility to the economy by saving raw materials. There are a number of classifications of waste in the textile sector. These classifications are classified as pre-consumption and post-consumption. It can consist of all kinds of fibres, yarns and fabrics originating from production, while those originating from consumption have a greater variety. Considering that the use of such large amounts of waste will provide a great benefit to the economy, some legal regulations regarding sheathing for the insulation of newly implemented buildings have resulted in an insulation material with good performance by providing flexibility in the use of this type of waste. In this way, it has helped to protect nature by simultaneously contributing to recycling and economy [19].

An average of 1 million tons of textile waste is generated every year around the world. Some of these wastes are textile wastes that come out during fabric and yarn production. It is known that some of them are obtained from fabric pieces and used textile products during the garment. It is clearly known that a large proportion of these wastes are recyclable. While it is known that textile wastes are evaluated in many ways and in different fields, some of them are used in felt production and some are used in yarn production in Turkey. Especially in ring spinning, short fiber spinning and in long fiber spinning, fiber recovery is in question. In a ring mill, the amount of waste that occurs during the production of carded yarn is about 5,5%-10,5%, about 12% in the production of combed yarn, and this rate goes up to 23% in the production of fabric and apparel. Considering these rates, it is clearly seen that the importance of recycling is once again emphasized [20].

In some studies, in the literature, there are many studies that include recycling not only synthetic fibers but also natural fibers. For example, the recycling of waste, fly and ragweed generated during the production of cotton fiber, which is among the natural fibers, is quite common among the textile industries. According to the findings, some of the consumers stated that if textile products made from virgin fibers are priced competitively, they will choose products made from recycled fibers regardless of product classification. This situation is expected to become widespread [21].

Ready-to-wear sectors have been a sector where fabric wastes have been used over years. Recycling of clothes and apparel products after consumer use has become a subject that has been studied in recent years. Ready-made clothing products, which are recycled and recycled after consumer use, start to become interesting for consumers, leading to a tendency towards recycling and previously processed products rather than conventional products. In this way, this situation, which brings together many advantages, brings with it an increase in the usage area in apparel as well as in other sectors [22].

Sustainability can be defined as an environmentally friendly world view that aims to ensure economic development with the principle of using natural resources and environmental values with rational methods. The ready-to-wear and textile industry has started to show a rapid acceleration in the minimization of waste, environmental damage, re-use (re-use, up-cycle, down-cycle) and recycling (re-cycle) studies, especially recently. Textile production processes produce chemicals at rates ranging from 10% to 100% of the product, depending on the weight of the product. 40%-60% of these chemicals are removed by the wastewater stream. In addition to the harmful waste water and chemicals released to the nature during its production, an average of 2700 liters of water is spent for only 1 cotton t-shirt. This fresh water is needed for the future and life cycles of nature and people. While the limited water resources increase the value of water day by day, it is clearly seen that the consumption of water in this service for textile products will have a great negative effect for the future. Considering that 20,000 liters of water is required to produce only 1 kg of cotton, it is of vital importance in every sense that textile products can be recycled and reintroduced into production [23].

In the textile industry, a number of waste materials in different types and forms are formed as a result of ribbon, fiber, yarn and weaving and similar processes. It is clearly seen that the per capita fiber consumption in the world is growing steadily depending on the income level and population growth. It is predicted that fiber consumption per capita reached an average of 13 kg in 2016, and this figure may reach up to 20 kg in the following years. Accordingly, textile consumption and production increase in direct proportion to this. In this case, it gives signals to consumers and producers that environmental damage should be minimized. In this age where the global economy is important, it is necessary to produce environmentally friendly products at the production stage, whether the products of the desired quality are within the scope of the textile sector or not [24].

In ancient times, textile products were used only for covering and protection, but in our current age, it is becoming a sector where consumption is excessively with the developing and changing fashion understanding. In this context, a serious recycling uprising has started in our country. The repercussions of sustainability are also quite large in different countries. There are approximately 500 operating facilities in the USA for the recycling of textile wastes. It is known that there are more than 300 of these recycling facilities in Germany. With the increase in the complacency of the world's giant brands towards recycling products, the orientation of the companies is moving in the same direction and they are making intense efforts for product supply and production. This situation, on the other hand, excites the consumer by contributing to the fashion of products with recycling content in the changing and developing fashion [25].

Packaging wastes constitute 30% of solid wastes in Turkey and 50% by volume. The amount of plastic packaging put on the market in 2008 is approximately 500 thousand tons, and the recovered amount is known as 200 thousand tons. It is seen that the recovery rate has thus reached 40%. The fact that the textile industry is among the usage areas of recycled plastic packaging is important for the sustainability of textile fibers. It is known that PET bottles, which are used as composite materials by obtaining PET polymer from PET bottles, are easily used in textile products when life cycle analysis is provided. It has created a situation where all forms of recycling are accepted for the protection of petroleum and petroleum-based non-renewable energy sources [26].

Sustainability refers to a systemically developing team concept that ensures the continuity of the economic, environmental and social impacts of the society. Institutions, together with their economic, environmental and social parameters, positively affect economic development, human life and environmental balance through the interaction of these parameters. Today, 3R and 4R rules need to be assimilated in order to implement sustainability for the textile industry. The expansion of 3R covers the 4R rule when rebuy is added as recycling, reduction and reuse [13].

Circular economy and sustainability address all phases from start to finish, including the production processes of products. In this context, it is very important to be able to recycle and reuse textile materials. It is known as one of the easiest and most common applications in the field of recycling to obtain a new product by mixing a product with different materials in certain proportions [27].

According to the researches, PET plastic is among the most suitable materials for recycling. When the life cycle of PET is under investigation, it is among the polymers with the highest consumption and production. This polymer, which is easily recycled, can find more usage areas with less loss of properties compared to others. If it is recycled, it can also find a place in the market as a new raw material. For this reason, its use in the textile industry is increasing day by day [28].

Textile wastes contain chemicals that are defined as hazardous waste at low rates. Apart from this, there are some wastes such as yarn, cotton fly and cut fabric. Some of these wastes are included in the production by making yarn again. Some of them can be used as insulation materials. Although the recycling of wastes is achieved to a large extent, some of them take their place in landfills. It is known that the rate of textile waste in landfills increases every year. In the waste stream in textile, the wastes consisting of natural yarns and fibers are completely recycled by applying mechanical separation processes to obtain short fiber. In textile products consisting of a mixture of natural fibers and synthetic fibers, the separation process is applied and the natural fibers are recovered. Although recycling of textile waste is possible at a rate of 50%, the rate of textile waste is 25% in the UK [29].

Today, the transformation of cotton into products with higher added value is one of the criteria for both environmental and economic benefits. However, wastes in terms of cotton fiber are generally used in landfills and sound insulation. The recycling of cotton fibers has not yet reached the synthetic level. Studies on the recycling of cotton in the literature have often focused on the importance and sustainability of this fiber [30].

Increasing population, increasing market demand, fast fashion trends, developments in production technology etc. In recent years, fiber consumption has increased rapidly. According to the Preferred Fibers and Materials Market Report, total fiber production in 2019 was 119 million metric tons, doubling over the last 20 years. It is also estimated to grow by 30% to 146 million metric tons in 2030. Polyethylene terephthalate (PET) alone dominates the market and has about half of the market in fiber production combined. However, this amount (r-PET) is recycled. The share of polyethylene terephthalate was only 14% in 2019 [31].

Recently, much attention has been given to forward recycling as well as recycling. In some studies, many different ideas and thoughts on back-and-forth recycling have been put forward. In these studies, it is thought that it will contribute to sustainability, which is a process done by removing second-hand clothes in back-and-forth recycling and redesigning them with various techniques and studies. Recycling of the clothes that the designers have not been successful in recycling brings with it many advantages. In this way, it is thought that the recycling of products that cannot be obtained by forward recycling will contribute to reducing the rates of textile waste to the minimum level [12].

Synthetic fiber types, which are among the fiber types, are among the non-renewable fibers. The raw material of these fibers is petroleum. In natural fiber types, this is the opposite. For example, cotton and natural fibers such as these are among the renewable fiber types. Even natural fibers require chemicals and energies based on non-renewable resources during the production. For this reason, it is very difficult to conclude which fiber type is environmentally friendly by providing advantage [9].

In a study carried out by MADE-BY, a comparison was made to address the effects of the most used fibers in the textile industry against nature. In this study, the process from the raw material stage to the yarn stage of natural fibers and synthetic fibers was examined. According to the data they obtained, it was observed that natural and synthetic fibers obtained by conventional production methods were left behind in terms of sustainability. It has been concluded that recycled or organic fibers are the most environmentally friendly fibers compared to others [9].

There are many reasons for waste generation in the textile industry. Some of these reasons are the change in raw materials within the enterprise, the variability of the number of orders taken to the production line, the variability of the air conditioning conditions, the decrease in the amount of orders from the customers and the increase in their variety may cause an increase in the amount of waste. In addition, inefficient work schedule, inadequate controls and even operator variability have serious effects on the amount of waste. Measures should be taken to increase waste generation within the enterprise. Measures to be taken for this situation; First of all, it is necessary to raise awareness of the employees by taking certain trainings on the minimization of waste generation. It is very important to categorize and classify the wastes generated within the company. Categorizing different properties such as fiber quality, fiber fineness or fiber length of fibers with the same properties can be a good step towards increasing the quality of the product for the next recycling process [32].

It creates employment opportunities at every stage of the textile waste recycling life cycle (i.e., collection, separation, transport, recycling) and offers opportunities for small or family businesses. On top of that, textile recycling is not considered an end in itself, but a way to implement the circular economy, that is, the closed-loop production system. It can become one of the solutions that helps companies in their progress towards sustainable business performance. Textile recycling directs product manufacturing to lower production costs, due to the fact that recyclable materials are a low-cost, efficient and low-environmental impact alternative. For example, ECOSIGN (2017) found that recycling second-hand clothing can reduce greenhouse gas emissions by 53%, reduce pollution associated with chemical processing by 45%, and reduce water eutrophication levels by 95% [33].

Minimizing the carbon footprint in the textile and apparel supply chain is a tedious process due to the complexity of the supply chain link. The recycling process is one of the most promising approaches to minimizing the carbon footprint in the textile industry. Recycling the wastes in the production process throughout the supply chain, consumer behavior in terms of reuse, recycling of the material and recycling at the end of its life can be seen as carbon footprint reduction areas [34].

A recycled product or item refers to products that are recovered or separated from solid waste after the manufacturing process or use. In addition, any product containing any proportion of recycled product must be specified for the customer. There are different methods for textile recycling; such as mechanical, chemical and thermal recycling. Considering the diversity of textile materials waste and forms, various waste recycling technologies and techniques must work in an integrated manner to achieve a noticeable impact on recycling [35].

Today, climate change poses a serious problem for the whole world. To overcome this problem, some attempts have been made by governments to minimize waste generation or reuse waste. Polyethylene terephthalate (PET) bottles are produced from raw petrochemical products, and post-use wastes do not have a direct impact on the environment. On the other hand, if the PET bottle wastes that increase in volume are not recycled, they cause economic and environmental problems [36].

The best way to economically reuse PET waste is through recycling processes, which can be either mechanical or chemical. In addition, although the recycling process does not reduce the cost, it is important in terms of maintaining the ecological balance. PET bottles can be easily separated from other waste, so some additional processing is needed. Crushing, washing, drying to obtain PET flakes. r-PET fibers to be used in the textile industry are produced from PET flakes by melt spinning system. This recycled product can be easily adapted to textile production instead of pure PET. The fact that about 60% of the recycled PET polymer is used in the production of PET filament and staple fiber shows how important the textile industry is [36].

There is regulatory interest in increasing textile reuse and recycling, which will move the treatment of textile waste higher up the waste hierarchy in line with the EU's waste directive (European Commission (EC), 2008). Increased textile reuse and recycling can potentially reduce the production of virgin textile fibers and, in the case of reuse, can also avoid engineering processes later in the textile product's life cycle, thereby reducing environmental impact. The potential environmental benefits of various textile reuse and recycling systems have been evaluated in the academic literature using methods such as life cycle assessment [37].

Comparing the raw material energy consumption with the recycled material energy consumption, it can be concluded that the reuse of 1 ton of polyester clothing uses only 1.8% of the energy required to produce these products from virgin materials. Reusing 1-ton cotton clothing uses only 2.6% of the energy needed to manufacture it from virgin materials. For this reason, the estimation of textile wastes after production and consumption is very important for recycling facilities. Turkey is among the top ten textile and apparel exporters in the world. Therefore, textile waste and recycling rates in Turkey will contribute significantly to global figures [38].

Recycling processes can be divided into different categories according to the degree of processing involved in the operation. In the operation, there is product recycling in which the chemical and physical structure of waste materials does not change, the use of fibers as filling material is an example of this. In addition, there is material recycling, where the physical but chemical nature of the waste material is not changed, polyester textiles are melted and then re-spinned into new fibers can be categorized as such. Finally, there is raw material recycling, in which both the chemical and physical structure of the waste material is altered, polymerization of fiber materials into monomers will be the main application regarding this category of fiber [39].

Global textile fiber production, textile consumption and the amount of textile waste are constantly increasing. Global fiber production was around 85.5 million tons in 2013 and is predicted to increase to 130 million tons by 2025. Household clothing expenditures in the EU were 4.2% of total household expenditures in 2012 and 2.5% in Finland. There are strong indications that Europeans are consuming much more clothing today than they did two decades ago. When adjusted to reflect changes in the price of clothing, the household expenditure data shows that the volume of EU clothing purchases actually increased by 40% over 1996–2012 and by 26% for Finland. Clothing consumption in Finland is smaller in terms of both money and weight than in Europe and other Scandinavian countries. However, in Finland, too, the number of clothes consumers seems to have doubled since the 1990s. Clothing consumption creates resource demands and environmental impacts at each life cycle stage of the textile production and consumption chain. The environmental impacts of textiles across the entire value chain are case specific and depend on the types and blends of fibers used and the respective production, use and disposal methods. Vander Velden concluded that the environmental load of textiles is a function of not only the basic materials (cotton, polyester, nylon, acrylic and elastane), but also the thickness of the yarn and textile fabric [40].

Any garment or textile material is defined as sustainable when it provides maximum benefit to people and minimum impact on the environment in every sense. In basic terms, every piece of clothing has an environmental footprint at every stage of its creation. This is why there is an innate logical inconsistency between the fast fashion business model and the idea of environmental sustainability. The fast fashion industry portrays society's enthusiasm for industrious use. This creates an unsustainable demand, meaning that even big brands are forcing manufacturers to cut costs and deliver large quantities at low prices. These prerequisites are clearly conceivable thanks to inexpensive synthetic fibres, chemicals and dyes. This results in higher environmental impact [41].

As the textile, apparel, fashion and retail industries become more sustainable, the use of recycled fibers, yarns, fabrics and product ingredients in the development and production of new products has become one of the areas of interest. The decision to use recycled materials in products should be made during design and product development and should continue throughout the manufacturing processes. There are two stages in the collection and processing of recycling. Recycled materials used in textiles and apparel products can be recovered along the textile and apparel supply chain and through post-consumer collection methods. The use of recycled raw materials is in line with the greater movement of global industries towards a circular economy (linear) and closed-loop production [42].

All of the textile production process steps such as fiber growing-manufacturing, spinning, weaving, knitting, nonwoven surface, wet processing and ready-made product manufacturing cause different levels of environmental impact. Textile products are produced using fiber, which is the basic material that defines the processing technology, application area, lifetime and sustainability feature of a textile product. Textile products and the textile sector itself are an inevitable sector in our daily life, which is constantly expanding from medical applications to civil engineering applications, from nanofabrication technologies to space technologies. With the increasing consumption of textile products in the developed and developing countries of the world, the fiber demand in the sector has increased and reached approximately 95.6 million tons in 2015 [43].

There are many innovations in the recycling of textile waste. Among these innovations, some wastes called plastic bottles, packaging and plastics can be brought to the textile industry. This acquisition is becoming quite popular and widespread. In this way, with the advancement of technology, the number of such recycling applications is increasing in direct proportion. PET bottle wastes are also recycled in different sectors and recycling in textiles is carried out as recycled polyester (r-PET) and its use is becoming very common. In this way, it becomes possible to obtain environmentally friendly and sustainable products [3].

2.2.1. Recycled Polyester

Today, polyester polymer has many uses. It is a polymer used in the introduction of liquid foods such as soft drinks and water. It is quite possible to recycle polyester polymer, and recycled polyester is among the highly demanded polymers. There are different ways to transform the PET polymer. One of these recycling ways is to recover PET chips in the recycling facility. These PET chips are converted into fibers by using the melt fiber spinning method. There are businesses in Turkey for this recycling method. PET fiber is obtained from chips in two ways. These; Fiber is obtained by mass/material or chemical methods. Chips can be separated down to the molecular level by chemical treatment and can be repolymerized. Even though these processes are high in cost, the fiber quality increases, and the fiber can reach a usable fiber level. PET bottle wastes are selected among all other wastes and primarily sorted out, and then PET shavings can be obtained by crushing, washing, drying and similar processes [26].

It has been obtained as a result of worldwide research that PET plastic is the most suitable polymer for recycling. Considering the life cycle of PET, it is one of the polymers with the highest consumption rate. Due to the chemical structure of the polymer, it can be easily recycled and can find a new area of use as a raw material without losing its properties compared to many other polymers. In order to increase the quality of the R-PET fibers, chemical cleaning before the recycling process has a significant positive effect on the quality of the obtained r-PET. One of the advantages of R-PET fibers is that they release less carbon compared to other fibers [28].

2.2.2. Recycled Acrylic

Although there is not much information in the literature about recycling acrylic, recycling acrylic fibers and the recycling of these fibers are very important for the textile industry. Wool fiber, which is among natural fibers, is considered as the equivalent of synthetic fibers. It is among the preferred fibers in knitwear and similar products due to its heat retention and many advantages it provides for the winter season [63]. The high demand of the customers is directly proportional to the increase in the waste rate during the production of acrylic yarns. Therefore, recycling acrylic yarns and mixing them with the product in a recycled state provides great advantages both economically and ecologically. When we look at the literature, although there are not many studies related to recycling acrylic fibers, there are few tangible studies.

In one of the studies conducted in the literature, the examination of the performance characteristics of sweaters produced with open-end recycled acrylic yarn is discussed. A comparison was made between the effects of recycled and conventional sweaters and PBT, gimped yarns in these sweaters. In the results, recycled acrylic fiber blended fabrics showed higher thickness, thermal resistance, pilling, abrasion resistance and lower bursting strength results than conventional ones. In this case, it has been concluded that recycled acrylic gives acceptable results, and it will be more advantageous to use it with yarns such as PBT and gipe [44].

2 patents have been obtained in the literature related to the recycling of acrylic. The first patent relates to the invention of a method for recycling waste dops generated during spinning of acrylic (Cummings and Mogensen, 1958). The second patent is the invention of a method for the recovery of acrylic waste (Omid and Abbas, 2013). In the second patent, until the waste acrylic waste becomes fiber again; It includes the steps of dissolving acrylic in a suitable solvent, filtration, precipitation with alcohol, washing with water, vacuum filtration, drying, granulating, pulverizing, resolving with solvent and producing fiber from solution. In the first patent, the waste acrylic dope goes through all the other processes except precipitation, granulation and powdering with alcohol [45,46]. It is suggested that it is possible to recycle acrylic with these methods and it can be reused.

CHAPTER 3
LITERATURE SURVEY

3.1. Core Spun Yarns

There are many studies in this field in order to emphasize the importance of core yarns. In the studies, the advantages of core yarns are mentioned and the effects of the gains on the final product are emphasized.

In their study, Baykuş D. and Oğulata R. (2019) conducted a study on denim fabrics in order to obtain high elasticity, and in this study, permanent elongation and elasticity values were examined. In the content of the study, core yarns with cotton/elastane, cotton/T400/elastane, cotton/PBT/elastane, and cotton/Sustans/elastane blends were used as weft yarn in denim fabrics. In the study, elastane was used as the core, other fibers are also included in the covering fiber, and detailed comparisons are available. As a result of this study, they observed that as the number in elastane increases, the final yarn exhibits flexibility and its elasticity value increases. In the study, it is observed that the effects of the changes in the reed number are observed, and accordingly, as the warp density increases, the warp density increases and this situation reduces the movement of the yarns in the weft direction, thus reducing the permanent elongation value. They examined the effect of the covering fiber by obtaining that the values of cotton/T400/elastane are higher than those of cotton/PBT/elastane and the values of cotton/sustans/elastane ones are higher than those of cotton/sustans/elastane. Within the scope of this study, the effect of elastane when used in essence and the effects of the differences in the coat on denim fabrics were examined [47].

In his study, Öner E. (2019) produced eight elastane core cotton yarns in four different yarn counts and two different twist coefficients. Cotton rovings were used in the covering fiber part of the yarns and Lycra was used as elastane in the core part with Figure 3.1. The fineness value of the filament used in core is Ne 0.75 and 78 dtex elastane. Within the scope of the study, the behavior of core yarns was discussed by keeping the elastane number constant and changing the twist coefficient and yarn number. They observed an increase in yarn strength with the increase of twist coefficient in the samples they produced. In addition, they observed that thick place and neps errors increased at Ne 30 and thinner numbers. They observed that the yarn evenness increased, the Ne 30 yarn count for the examined elastane core cotton yarns formed a threshold value in terms of yarn faults, and it positively affected the elongation property of the elastane contained in the core [48].

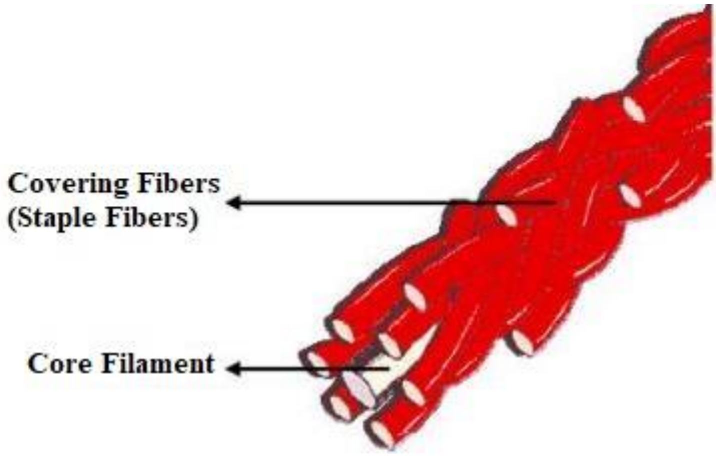

Figure 3.1 Core yarn structure [48]

Yılönü S. and Ünal B. (2018) produced core yarns with different coats and compared them in their study. It has produced core yarn by using cotton, viscose, bamboo, modal, polyester in the covering fiber and 75 denier polyester in the core. By producing conventional yarns consisting of the same fiber types and not using core, a total of 10 different yarns have been tested and tested both the effect of fiber difference in the covering fiber and the same yarn with yarns produced without using core. They provided a comparison of the performance characteristics of the concise form. In the results obtained by the researchers in the study, results were obtained in the form of an increase in hairiness values in cotton, bamboo, and modal with the use of core, and a decrease in polyester. In the results of yarn tenacity and breaking elongation, an increase was observed in the breaking strength values of the polyester yarns used in the core when the conventional ring yarns were compared with the same kind of core yarns in other yarn types, except polyester and modal. In this study, it has been found that the polyester used in the core contributes significantly to the yarn performance properties [49].

Aydoğdu S. and Yılmaz D. (2019) used 100% cotton, 100% viscose and 50/50% cotton/Tencel on the covering fiber in the study they carried out, and it has 3 different yarn counts by using elastane (lycra) with 2 different fineness values. The yarn and fabric properties of the samples produced by producing 18 core yarns were examined. It has been observed that the viscose covering fiber of the core yarns produced using mantos viscose, cotton and cotton/Tencel blended fibers exhibits significantly smoother and less hairiness. It has been observed that the core yarns used in cotton coat have uneven, high density, high nep content and high hairiness values. It has been observed that cotton/Tencel blended core yarns report better yarn strength, fabric strength and elongation at break compared to other yarns. From here, the importance of the fiber type used in the covering fiber is clearly seen [50].

In this study, Samah M E Elrys et al. (2022) used elastic core/T400, elastic core/Lycra, dual core, and tri-core yarns in order to examine the effect of yarn structure and yarn count on core yarn properties. They investigated by producing different yarn counts. Measured parameters include mechanical properties, yarn evenness and yarn hairiness. As a result, maximum strength was observed in ring-spun yarn and minimum strength in tri-core yarn. Elastic core/Lycra has the highest value in terms of wear resistance, ring-spun yarn has the lowest value. Statistical analysis showed that yarn count only had a significant effect on yarn hairiness, but yarn structure and bidirectional interaction (yarn count* yarn structure) had no significant effect on yarn hairiness [51].

Yılönü S. and Ünal B. (2018) produced polyester core yarn using 5 different raw materials in their study. The fibers used in the covering fiber are cotton, viscose, modal, bamboo, polyester. The properties of 10 samples, produced and obtained from the same fibers in conventional yarns without using core, were examined according to core and covering fiber. In the unevenness tests applied to conventional ring yarn and core yarns, it was observed that there was not much change in the unevenness values based on raw materials. When conventional ring yarns in yarn types other than modal and polyester yarns are compared with the same kind of core yarns, an increase in the breaking strength values of the polyester yarns used in the core is obtained. It is also clearly seen in the research in the literature that the core yarns provide significant strength to the product and improve the breaking elongation values by giving flexibility [52].

In one of their studies, Ünal B. and Yılönü S. (2018) examined the fast-drying properties of towel material by using core yarns. Within the scope of the study, 5 (modal, cotton, polyester, bamboo, viscose) different fiber types were used, and towels were produced. The yarns obtained are produced in the ring machine and the yarns obtained are located in the weft direction of the towel. The samples were tested for softness, durability, fast drying and durability properties. As a result of the study, better faster drying was observed in polyester core yarn compared to other yarn types [53].

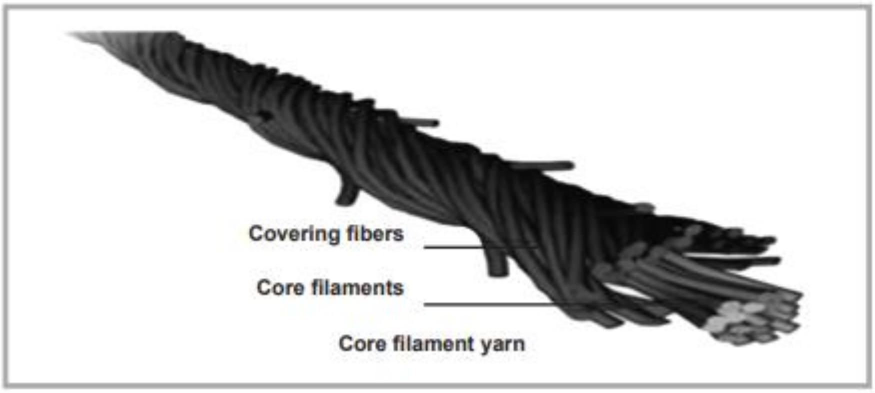

Figure 3.2 Multifilament core yarn structure [53]

Unal P., Üreyen M. and Aslan C. (2015) carried out a study on testing this product in the form of knitted fabric by producing core yarn in order to be used and popularized in sportswear in their project. In the first stage of the study, 11 fabric structures that are widely used in the market were selected and the comfort and mechanical tests of these fabrics were carried out. In the second phase of the project, as an alternative to these fabrics, yarns in 3 different numbers were produced by using hollow yarns, cotton in the covering fiber, viscose and acrylic core PVA fiber in the ring spinning machine. In the results obtained, it was observed that there were serious performance differences between core yarns and fabrics [54].

Öğüt T., Özden K. and Nacarkahya T., (2021), in their study, 6 different core yarns were produced by using vortex yarn spinning system. In the core part, 3 different filaments (Polyvinyl Alcohol (PVA), Textured Filament Polyester, Viscose (CV)) and in the covering fiber (wrap) part, 3 different fiber strips are knitted by using viscose, Polyester and Polyester / Viscose (65/35)) analysis of permeability properties are provided. In the results obtained, it was observed that the air permeability value of the product with polyvinyl alcohol in the core part and polyester in the winding part gave the highest results compared to the others, and it was determined that the fineness value of PVA was due to its thinness compared to other core yarns [55].

Vuruşkan D. (2019) studied the effect of double core yarns on quality parameters in his research. Within the scope of the study, 2 different yarn counts, and 3 different coat fibers were used. Types of covering fiber are 100% cotton, 60/40% cotton/polyester and 100% polyester, and PET/PTT bicomponent filament + elastane, polybutylene terephthalate (PBT) + elastane and polyethylene terephthalate (PET) + elastane are used in the double core. As a result of the study, an increase in yarn breaking strength was obtained with the increase of synthetic fiber in the covering fiber. It has been obtained as a result of this study that the variability of the winding fiber has a significant effect on the yarn evenness [56].

Celik N. and Kavuzlu M. (2021), in their research, core yarns were produced in denim and sportswear with different parameters with or without PBT. Yarns containing Ne 8, 10, 12, 16 CO/PBT/EL as content, as well as yarn containing CO/PES/EL as Ne 18, were produced in a double core yarn (dual core method) in a ring spinning machine. Physical analyzes were provided in the study and it was obtained that positive effects were observed in the permanent elongation values of PMUK/PBT/ELASTAN blended yarn compared to cotton/elastane-containing yarns [57].

Çelikkan S. and Yılmaz D. (2017) examined the study of core yarns consisting of double and single elastane in their study. In the study, the properties of the fabrics obtained from the yarns were examined in detail by producing Ne 20/1 double core yarns using 2 different fiber types and two different core finenesses. By comparing the results obtained in the study with single core yarns, the effect of the number of filaments on the core is emphasized [58].

In this study, the use of some technical core yarns in protective textile products was examined by Ertekin M. and Kırtay E. It has been stated that these core yarns can give various high performances in the field of protective textiles. In these studies, the data obtained from the tensile test and the effect of sheath, core and core-sheath ratio on the tensile properties were statistically analyzed. The results revealed that the tensile properties of core yarns show different trends according to fiber type in core, sheath and different core/sheath ratios. Higher tensile strength is noticeable in core yarns with para-aramid sheath fibers followed by PES Trevira® and meta-aramid and vice versa in case of elongation. Dyneema® and Technora® core yarns exhibit the highest and PES-Trevira® the lowest tensile strength values. It was stated that the highest elongation values were observed in PP filament core yarns [59].

In the study of Babaarslan O. and Kurban N. (2019), it is observed that they carried out a comprehensive study to improve the properties of denim fabrics and to conduct a detailed literature search on super stretch denim fabrics. The study focuses on the elasticity properties of core yarns [60].

In the study, core yarns were produced. On the structure of the produced core yarns, the use of recycled fiber and the use of conventional fiber in both the core and the covering fiber part (stable) were made and a comparison was made. Contrary to what is known, it is thought that yarns with recycling additives will contribute to the literature by considering that they will exhibit as good properties as yarns produced from conventional fiber.

CHAPTER 4
MATERIAL AND METHOD

4.1. Material

4.1. Production of Sample Fabrics

Within the scope of this study, a total of 16 sample yarns were produced with different core and different covering fibers ratios. For the production, primarily, rovings were produced in 4 different mixing ratios. The first roving mix is 52% acrylic/35% recycled acrylic/ 13% polyamide, the second roving mix is 61% acrylic/26% recycled acrylic/ 13% polyamide, the third roving mix is 70% acrylic/ 17% recycled acrylic/ 13% polyamide, and the last roving was determined as 87% acrylic / 13% polyamide. Rovings and mixing ratios are given in Table 4.1 below.

Table 4.1 Roving mixing ratio (sheat fibers)

	Roving Mixing Ratio (Sheat Fibers)
1.	52% acr/ 35% re-acr/ 13% pa
2.	61% acr/ 26% re-acr/ 13% pa
3.	70% acr/ 17% re-acr/ 13% pa
4.	87% acr/ 13% pa

Acrylic fiber is used in different proportions in the covering fibers. There is also a mixture of these conventional acrylic fibers used. There are mixtures of 2 different acrylic fibers, relax and un-relax. The shrinkage rates of relax and unrelax fibers vary, and based on this situation, more voluminous yarns (high bulk) can be produced with the provision of their mixture The relax and unrelax ratios of the samples are given in Table 4.2.

Table 4.2 Mixing ratio of sheat fibers

	Mixing Ratio of Sheat Fibers	**%**
1.	2.75 DTEX SEMI-MATT UNRELAX ACR	37
	2.75 DTEX SEMI-MATT RELAX ACR	15
	3.3 DTEX SEMI-MATT POLYAMIDE	13
	2.75 DTEX SEMI-MATT RECYCLED ACR	35
2.	2.75 DTEX SEMI-MATT UNRELAX ACR	38
	2.75 DTEX SEMI-MATT RELAX ACR	23
	3.3 DTEX SEMI-MATT POLYAMIDE	13
	2.75 DTEX SEMI-MATT RECYCLED ACR	26
3.	2.75 DTEX SEMI-MATT UNRELAX ACR	36
	2.75 DTEX SEMI-MATT RELAX ACR	34
	3.3 DTEX SEMI-MATT POLYAMIDE	13
	2.75 DTEX SEMI-MATT RECYCLED ACR	17
4.	2.75 DTEX SEMI-MATT UNRELAX ACR	40
	2.75 DTEX SEMI-MATT RELAX ACR	47
	3.3 DTEX SEMI-MATT POLYAMIDE	13

By combining each of the produced rovings separately with 4 different cores, a total of 16 different core yarns were obtained. The 4 different cores (filaments) identified are given in Table 4.3.

Table 4.3 Core properties and denier

	Core Properties (Filaments)	**Denier**
1.	Fully Drawn Yarn (FDY)	70 denier polyester
2.	FDY Recycled	70 denier recycled polyester
3.	Drawn Textured Yarn (DTY)	70 denier polyester
4.	DTY Recycled	70 denier recycled polyester

16 samples of 7.5 Nm were obtained by combining the obtained 4 rovings with the specified 4 different core filaments separately. The naming of the produced samples and the detailed sample table are given in Table 4.4.

Table 4.4 Name of samples and final content of core yarns

NAME OF SAMPLES	CONTENT OF ROVING	FINAL CONTENT OF COREYARNS
ARD32	52% acrylic/ 35% recycled acrylic/ 13% polyamide	48% acrylic/ 32% recycled acrylic/ 12% polyamide/ [8% polyester (RECYCLE DTY)]
ADT32		48% acrylic/ 32% recycled acrylic/ 12% polyamide/ [8% polyester (DTY)]
ARF32		48% acrylic/ 32% recycled acrylic/ 12% polyamide/ [8% polyester (RECYCLE FDY)]
AFD32		48% acrylic/ 32% recycled acrylic/ 12% polyamide/ [8% polyester (FDY)]
BRD24	61% acrylic/ 26% recycled acrylic/ 13% polyamide	56% acrylic/ 24% recycled acrylic/ 12% polyamide/ [8% polyester (RECYCLE DTY)]
BDT24		56% acrylic/ 24% recycled acrylic/ 12 % polyamide/ [8% polyester (DTY)]
BRF24		56% acrylic/ 24% recycled acrylic/ 12% polyamide/ [8% polyester (RECYCLE FDY)]
BFD24		56% acrylic/ 24% recycled acrylic/ 12% polyamide/ [8% polyester (FDY)]
CRD16	70% acrylic/ 17% recycled acrylic/ 13% polyamide	64% acrylic/ 16% recycled acrylic/ 12% polyamide/ [8% polyester (RECYCLE DTY)]
CDT16		64% acrylic/ 16% recycled acrylic/ 12% polyamide/ [8% polyester (DTY)]
CRF16		64% acrylic/ 16% recycle acrylic/ 12% polyamide/ [8% polyester (RECYCLE FDY)]
CFD16		64% acrylic/ 16% recycled acrylic/ 12 % polyamide/ [8% polyester (FDY)]
DRD0	87% acrylic/ 13% polyamide	80% acrylic/ 12% polyamide/ [8% polyester (REYCLE DTY)]
DDT0		80% acrylic/ 12% polyamide/ [8% polyester (DTY)]
DRF0		80% acrylic/ 12% polyamide/ [8% polyester (RECYCLE FDY)]
DFD0		80% acrylic/ 12% polyamide/ [8% polyester (FDY)]

4.2. Method

4.2.1. Manufacturing System

Yarn production consists of two stages. Preparation processes and final processes. The yarns used in the study were produced in accordance with the steps in Figure 4.1.

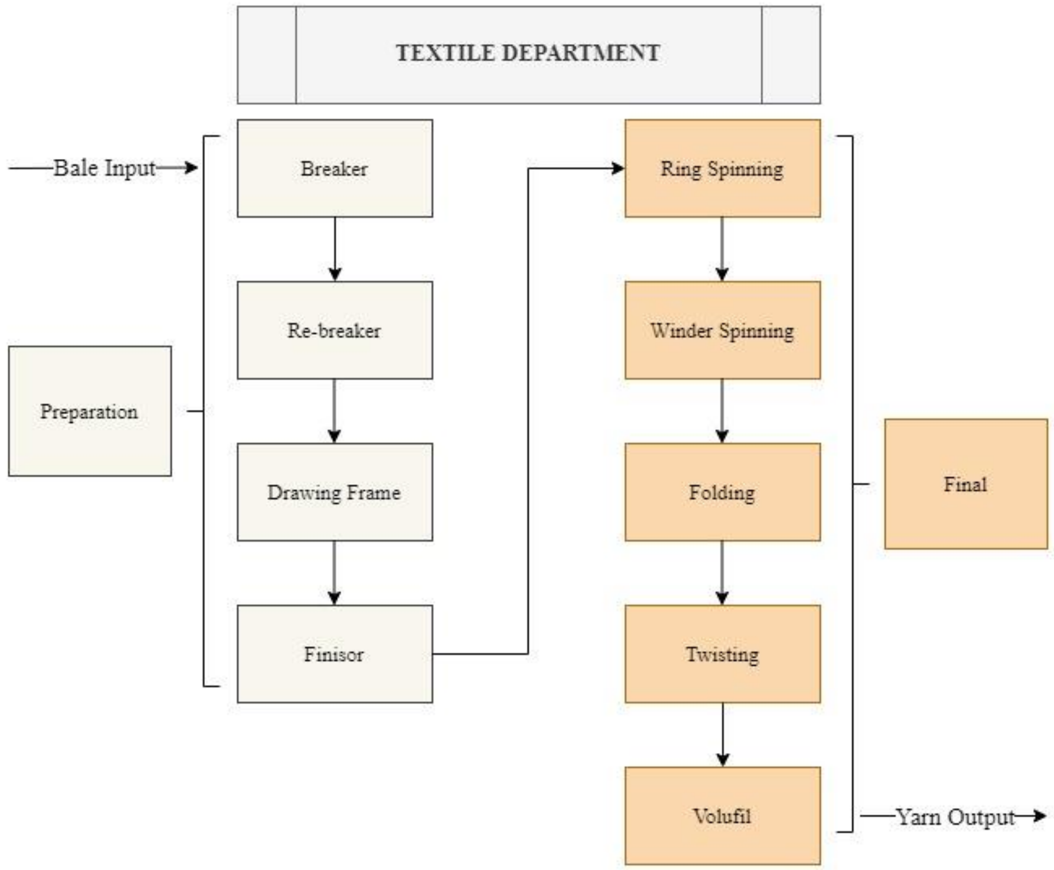

Figure 4.1 The production process of samples production.

4.2.1.1. Breaker

Endless filaments are obtained by turning polymers into endless filaments. These endless filaments are filaments obtained from synthetic or artificial polymers. In order to convert the filaments into yarn form, certain processes are required. The breaking process performs the first breaking process by applying a certain tension and drawing process to the endless filaments.

This process is the first step necessary for the filaments to turn into yarn form. Endless filaments are broken and converted into shorter fibers, allowing them to elongate and break. This process is included in the preparation process. Figure 4.2. shows the image of the breaker machine.

Figure 4.2 Breaker machine

4.2.1.2. Re-breaker

It is the second process of the re-breaker preparation process. At this stage, it is applied to provide different fiber combinations. For example, it helps to form mixtures by combining different fiber types such as acrylic/wool or acrylic/wool/polyamide by means of needle-tipped cylinders and printed cylinders. At this stage, ensuring the homogeneity of the fibers, paralleling the fibers helps the lubrication process and obtaining the desired weight. In addition, blends of melage-style yarns are also made in this section. As a result of this process, a smoother, softer, and thinner product is obtained. Figure 4.3. shows the image of the re-breaker machine.

Figure 4.3 Re-breaker machine

4.2.1.3. Drawing Frame

It is among the drawing frame preparation process. The drawing frame consists of 3 stages in itself, these are; are drawing-1, drawing-2, drawing-3. In this process, the fibers are subjected to 3 drawing processes, respectively, in order to reduce fiber unevenness and ensure smoothness. Its fiber is thinner, smoother, and it is ensured to take its most homogeneous form by preventing fish formation. Thanks to the discs inside, it prevents variation by shaving thick and thin parts. In this way, by providing smoothness between the fibers, reducing the number of fibers in the cross-section, ensuring increased material compatibility for unit weight, reducing fiber hooks, reducing the thickness of the fiber are among the main objectives and duties. Figure 4.4. shows the image of the drawing frame.

Figure 4.4 Drawing frame machine

4.2.1.4. Finisor

The main purpose of the finisor is to make the fibers ready for spinning. It increases the material length per unit weight with the help of rollers without applying the twisting process according to the desired weight. It is the last operation in the preparation process. After this process, the fibers are directed to the final process. Figure 4.5. shows the image of the finisor machine.

Figure 4.5 Finisor machine

4.2.1.5. Ring Spinning

It is a process carried out by feeding the rovings coming from the finisor machine to the machine. Staple is the process of thinning the yarn by subjecting the fibers to twisting and drawing. The fiber weight coming from the roving is reduced by the drafting unit. The desired yarn number is determined by the drafting and twisting applied at this stage. Figure 4.6. shows the image of the ring spinning machine.

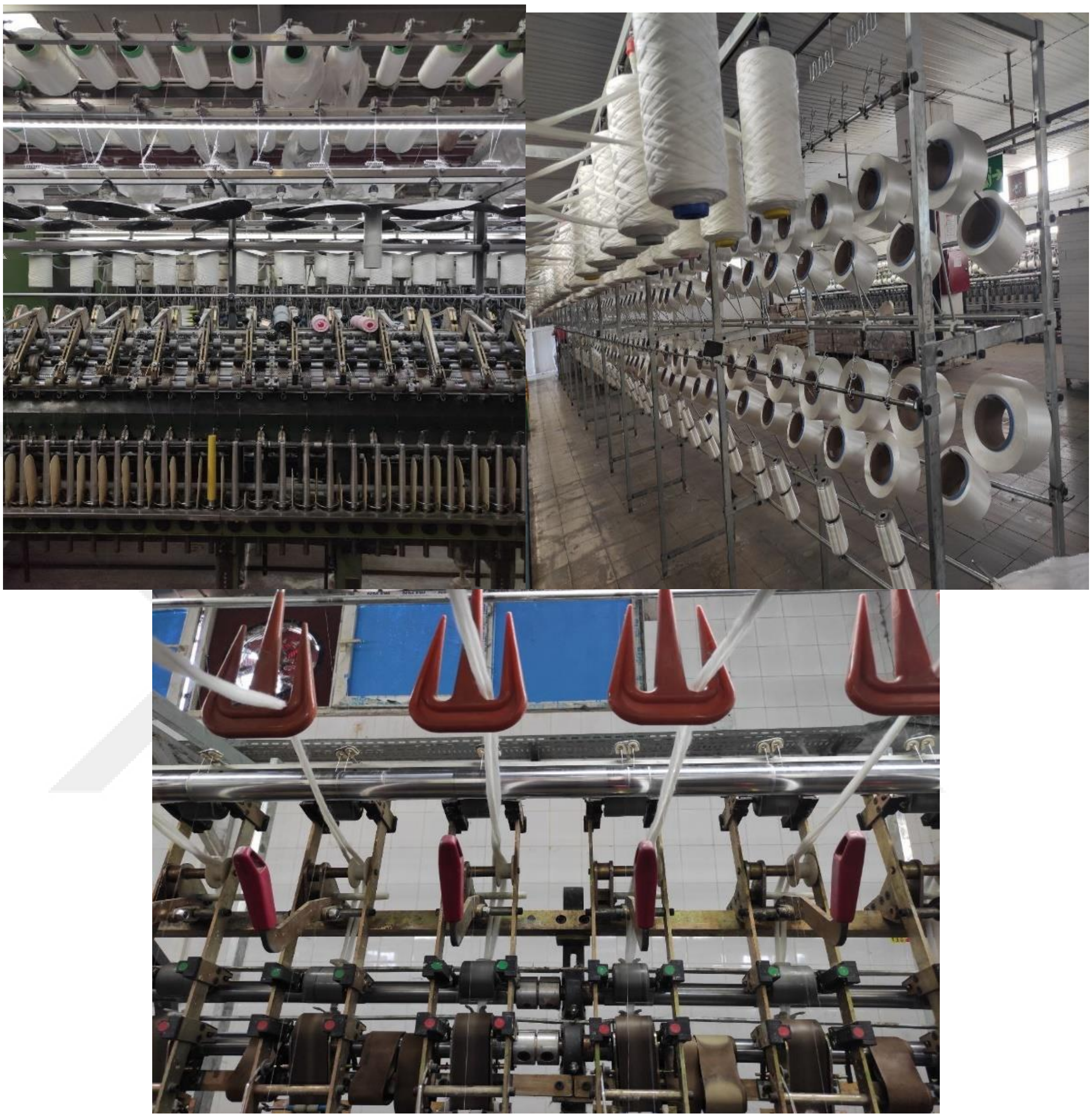

Figure 4.6 Ring spinning machines

4.2.1.6. Winder Spinning

It is a process performed after the ring machine. It is a process that is carried out by adding the cops (bobbins) coming from the ring spinning machine end to end and turning them into a single large bobbin. In this process, at the same time, a more homogeneous structure is provided by eliminating the thick or thin places determined by the machine. In some machines, the operator manually feeds the cops, while in some machines the system advances automatically, but the process is the same. This process directly affects the yarn quality in a positive way.

4.2.1.7. Folding

In this process, it is a process in which more than one yarn or more than one yarn of different kinds is wrapped and brought together without being subjected to the twisting process. Breaks may occur during the process. When breaks occur, the machine stops automatically, but also stops the winding process. This process provides preparation for the next process.

4.2.1.8. Twisting

It provides twisting of the yarns coming from the folding machine. They are similar to each other with the folding process. The difference between them is that the twisting process is not performed in the folding machine, while the twisting process is carried out in the twisting machine. Thanks to this process, the strength of the yarn obtained is increased and irregularity is reduced, thus providing the opportunity to create different effects.

4.2.1.9. Volufil

In this process, it is the process of giving volume to the yarn by inflating the yarns coming from the twisting machine with the help of hot grids. Its main purpose is to obtain a softer surface by giving the yarn a more voluminous structure with the help of heat. Grill temperatures and machine speed vary according to the type of material [61].

4.2.2. Production of Core Yarn

There are many different methods of producing core yarn. Core yarn production is possible in most spinning systems. There may be differences between systems. The most important differences are that it is possible to combine the core fiber and the covering fiber with a different method. As a result of all methods, core yarn production can be achieved.

Spinning systems commonly used in core yarn production;

- Core Yarn Production in Ring Spinning System
- Core Yarn Production in Friction Spinning System

- ➢ Core Yarn Production in Air-Vortex Spinning System
- ➢ Core Yarn Production in Open-End Rotor Spinning System

It can be listed as [49].

Within the scope of the study, ring spinning system was used as the core yarn production system. The scheme of the system used is given in Figure 4.7.

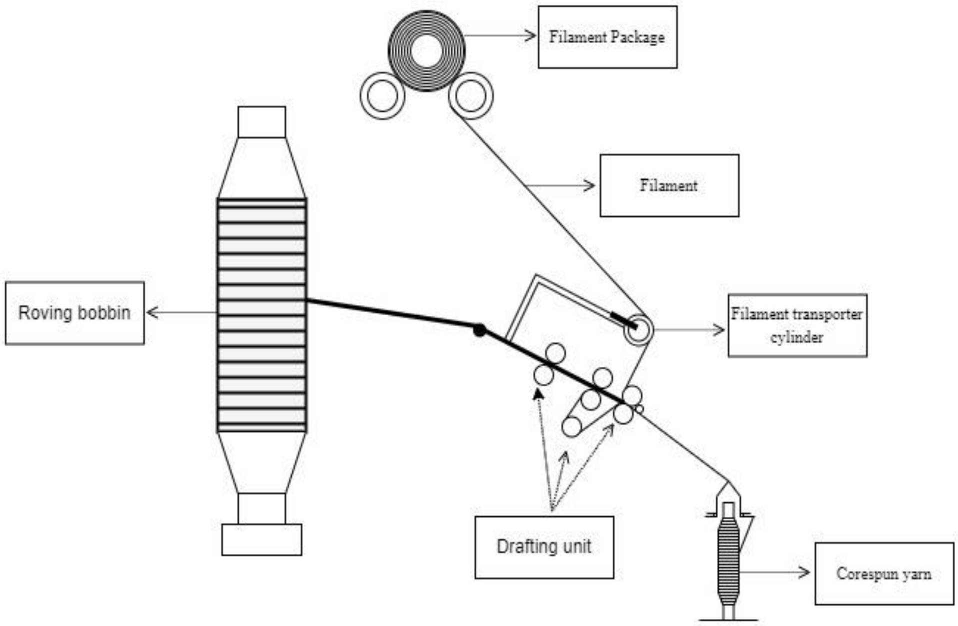

Figure 4.7 Diagram of the ring spinning machine in which core yarn samples are produced

4.2.2.1. Features of Core Yarns Producing Machine

Ring spinning machine was used in the study. The production parameters, twist factor, twist, spindle speed, delivery speed and total draft used to produce 7.5 Nm core yarn of this machine, which uses the core spinning method, are indicated on the Table 4.5.

Table 4.5 Production parameters of the samples in the ring machine

Production Parameters of The Samples in The Ring Machine	
αm (twist factor/coefficient)	40
Twist (Tpm)	120 T/m
Spindle Speed (rpm)	4000

Table 4.5 Continued

Delivery Speed (m/min)	30
Total Draft	8,14

It is known that the machines used in production have a great impact on the yarn quality. As the brand and model change, the yarn quality increases or decreases. All machines used in this study are given in Table 4.6 along with their models and production years.

Table 4.6 Model and brand of machines

Machine	Model And Brand
Breaker	Seydel Bielefeld (2000 Model)
Re-breaker	N. Schlumberger (2002 Model)
Drawing Frame (1. passage)	N. Schlumberger GC-15 (2002 Model)
Drawing Frame (2. passage)	N. Schlumberger GC-15 (2002 Model)
Drawing Frame (3. passage)	N. Schlumberger GC-15 (2002 Model)
Finisor	N. Schlumberger FM-41 (2002 Model)
Ring Spinning	ZINSER RM451 (2006 Model)
Winder Spinning	Orion Plus (2017 Model)
Folding	Mettler Toledo (2002 Model)
Twisting	Savio Geminis (2018 Model)
Volufil (bloating)	Savio Espero (2002 Model)

4.2.3. Structural Properties of Samples

The fabrics produced were produced by using different mixing ratios in the covering fiber and different filaments in the core. The comparisons were made on the basis of raw materials, and it was investigated how the variability of both the covering fiber and the variability of the filament used in the core affected the results. It is known that the variability in the raw material of the yarns is an effective parameter on the yarn. It is known that the variety of yarn made is a parameter that has a direct effect on both the yarn and the fabric. The tests applied were carried out in accordance with international standards. All of the samples were conditioned for 24 hours before the test and the tests were carried out. The yarns were knitted in a manual flat knitting machine (number E12) (size of E12). Figure 4.8 shows the machine on which the samples were knitted.

Figure 4.8 Samples knitting machine

- Unit Weight: The samples were cut as 10x10 cm and weighed. Measurement determinations were obtained using TS EN 12127:1999 test standards. It was measured by taking the test average of these 3 samples by testing 3 of each sample.
- Thickness: Samples were measured in the HANS SCHMIDT D-2005 device. During the test, DIN EN ISO 5084 standards were used and 3 measurements were taken from each sample and the average value was determined in mm. In Figure 4.9, there is the device in which the thickness was measured.

Figure 4.9 Sample thickness gauge machine

- Stitch Yarn Length: Stitch length is an important parameter for knitted fabrics. The loop thread length is measured by unwinding a certain row with an appropriate tension without stretching the knitted fabric. The length of the thread is obtained, and the length found is divided by the number of available loops to determine the loop length. The loop length is the length of the thread in the knitted loop in mm [62].

- Stitches and sticks are measured in an area of 1 cm with the help of loupes from 5 different points of the samples. This measurement provides the values of CPC (course/cm) and WPC (wale/cm).
- The tests were carried out in a conditioned laboratory environment (at 20º C and 65% relative humidity) in accordance with the standards.

4.2.3.1. Yarn Strength Test

Yarns have been tested in accordance with standards. During the measurements, using the BS 1932 Part 2 (250mm 250mm/min) standard, 20 measurements were taken from each sample and the average of the test results was included. Titan yarn and fabric strength test device was used during the tests. Yarn strength tester is shown in Figure 4.10.

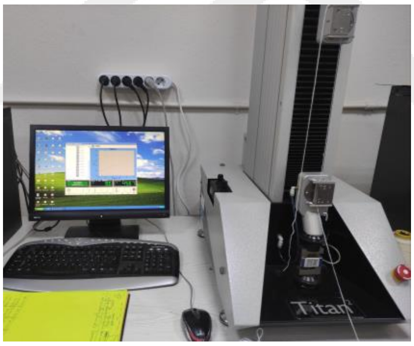

Figure 4.10 Yarn strength measurement tester

4.2.3.2. Yarn Evenness Test

Uster Tester 4 device was used to measure the unevenness and hairiness values of the yarns. The tests were carried out in accordance with the standards and yarn unevenness, thin places, thick places, neps, hairiness measurements were determined. It is used for objective determination of statistical analyzes such as standard deviation and coefficient of variation.

4.2.3.3. Air Permeability Test

The samples were tested in accordance with the standards. In the measurements, 10 measurements were taken from each sample using the TSE 391 EN ISO 9237 standard. SDL Atlas air permeability tester was used while performing the tests. The test area is 20 cm² and was carried out by applying a pressure drop of 100 Pa. Air permeability tester is shown in Figure 4.11.

Figure 4.11 Air permeability measurement tester

4.2.3.4. Water Vapor Permeability Test

The water vapor permeability test was carried out in accordance with the standards. Two measurements were obtained from each sample. Measurements were determined in accordance with test standards. The BS 7209:1990 test standard has been applied. The tests were performed in a conditioned laboratory environment (at 20º C and 65% relative humidity). Water vapor permeability tester is shown in Figure 4.12. While determining the results, the results of the water vapor test were calculated with the help of Formula 4.1. M in the formula; mass loss in the fabric after the test in grams, t; test time in hours and A; gave the area of fabric exposed to the test.

$$\boldsymbol{WVP}(\boldsymbol{g}/\boldsymbol{m}^2/\mathbf{24h}) = \frac{\mathbf{24*M}}{(\boldsymbol{A*t})} \qquad \mathbf{(4.1)}$$

Figure 4.12 Water vapor permeability measurement tester

4.2.3.5. Bursting Strength Test

In bursting tests on samples using a James Heal TruBurst bursting strength tester were determined by the standard of TS 393 EN ISO 13938-2. For the bursting test, 50 cm test material was used, and 5 measurements were taken from each fabric sample. Bursting strength tester is shown in Figure 4.13.

Figure 4.13 Bursting strength measurement tester

4.2.3.6. Abrasion Resistance Test

In the abrasion resistance test, the periods at which the samples were torn were determined in accordance with the TS EN ISO 12947-3 standard by using the Martindale 2000 Abrasion Tester. Abrasion resistance tester is shown in Figure 4.14.

Figure 4.14 Abrasion Resistance measurement tester

4.2.3.7. Pilling Resistance Test

In the pilling test, 4 pieces of each sample were taken from each sample, 2 in the weft direction and 2 in the warp direction and tested in accordance with the test standards. During the tests, the pilling value was evaluated by many operators and averaged. The test standard applied is TS EN ISO 12945-1 and the process was carried out at 7200 cycles. During the tests, the test results are obtained through the gray scale by numbering from 1 to 5 as 1 worst 5 no change. Pilling resistance tester is shown in Figure 4.15.

Figure 4.15 Pilling resistance measurement tester

4.2.3.8. Dimensional Stability Test

Dimensional stability test is performed by washing each sample. After each washing, the samples are dried and measured, and their dimensional strength is tested by proportioning them according to their initial size. Samples of 25x25 cm dimensions were used in the samples. During the washing process, each wash was treated at 40 °C for 1 hour and 1000 cycles. A household washing machine was used during the tests.

Dimensional change was determined after washing. Values are given as percentages. Measurements are provided in the lengthwise and widthwise directions. While determining the results, the formula specified in Formula 4.2 was used. The test standard is ASTM D 1776.

$$Dimensional\ Stability\ Value = \frac{[(Pre\ process - post\ process\ measurement) * 100]}{Pre\ process\ measurement} \qquad (4.2)$$

CHAPTER 5
RESULT AND DISCUSSION

The structural properties of the knitted fabrics obtained from the yarns were measured in accordance with the standards. The results with the structural properties are given in Table 5.1.

Table 5.1 Structural properties of knitted fabric samples

Raw Material	**Unit Weight (g/m^2)**	**Thickness (mm)**	**Stitch Yarn Length**	**Course/ cm**	**Wale/ cm**	**Stitch Density** (wpc*cpc)	**Loop Shape Factor** (cpc/wpc)
ARD32	205	1,89	0,32	9	7	63	1,29
ADT32	211	1,76	0,30	9	7	63	1,29
ARF32	216	1,61	0,32	8	6	48	1,33
AFD32	213	1,58	0,32	9	6	54	1,50
BRD24	221	1,75	0,32	8	6	48	1,33
BDT24	221	1,92	0,32	8	6	48	1,33
BRF24	208	1,50	0,28	8	5	40	1,60
BFD24	214	1,41	0,30	8	6	48	1,33
CRD16	213	1,67	0,30	8	6	48	1,33
CDT16	219	1,57	0,34	8	6	48	1,33
CRF16	209	1,82	0,30	8	6	48	1,33
CFD16	207	1,80	0,32	8	6	48	1,33
DRD0	225	1,86	0,32	8	6	48	1,33
DDT0	224	1,89	0,32	8	6	48	1,33
DRF0	201	1,83	0,36	8	6	48	1,33
DFD0	214	1,89	0,34	9	6	54	1,50

The (unit weight), (thickness), (Stitch yarn length), (course), (wale), (Stitch density) and (loop shape factor) values of the samples are given in Table 5.1 in detail. Although it is observed that the values are close to each other, it is seen that the increase and decrease in the ratio of recycled acrylic fiber do not create big differences between the obtained values.

5.1. Yarn Test Results

- Yarn Tenacity Test Results: A graph was used to determine the test results of core yarns consisting of covering and core containing different raw materials. The tenacity results of the produced core yarns are shown in Figure 5.1.

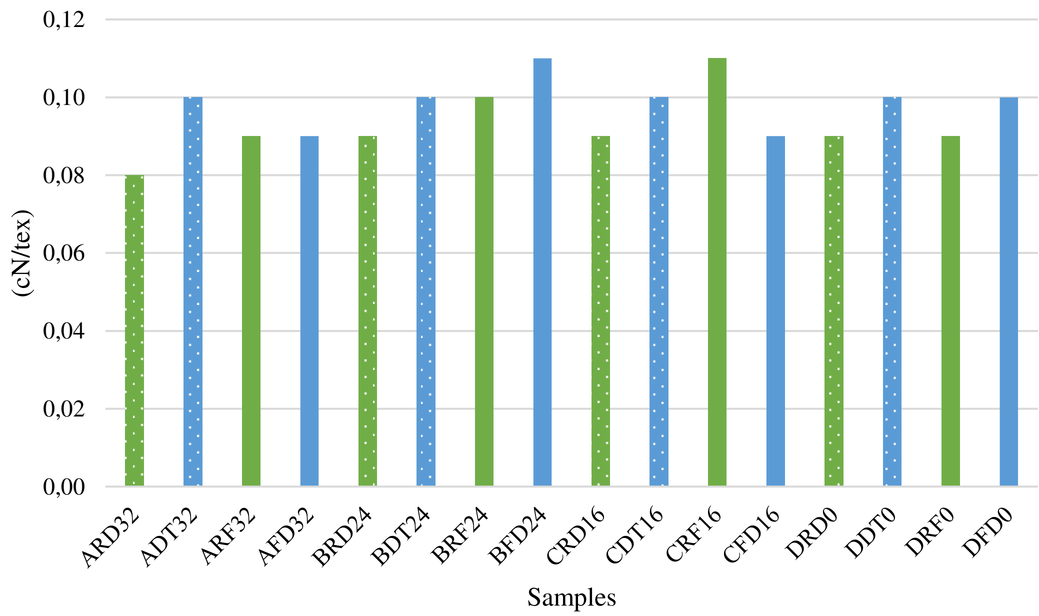

Figure 5.1 Yarn tenacity test results

Looking at the Yarn tenacity test results, it is observed that the highest values are in BFD24 and CRF 16. The lowest yarn tenacity value was found to be ARD32. In addition to the use of recycled acrylic ratio of 32% in the ARD32 sample, although it is obtained from the use of recycled drawn textured yarn in the core of the yarn, in other yarn samples (BRD24, CRD16 and DRD0) where RECYCLED DTY was used, when looking at their own groups, ARD32' It is seen that yarn tenacity gives low results, as in Considering this situation, it can be said that the use of RECYCLE

DTY in the yarn core has a negative effect on the tenacity values on the yarn. In addition, it is observed that the change in the rate of recycle acrylic used in the covering fibers does not have a negative effect on the results.

- Yarn Extensibility Test Results: The yarn extensibility results of the obtained samples are given in Figure 5.2.

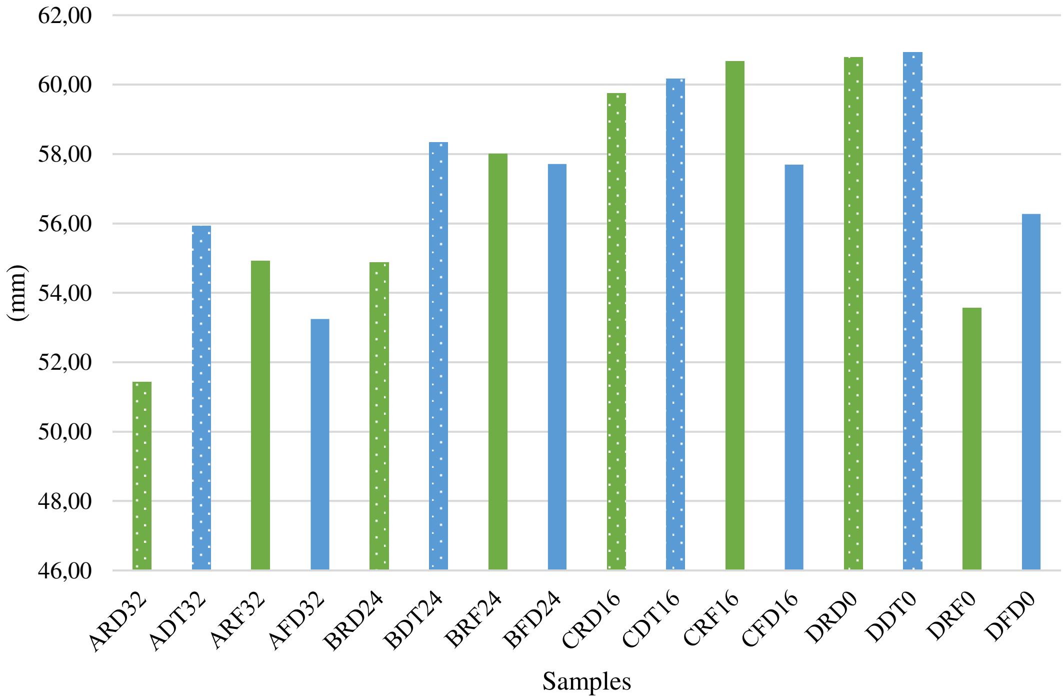

Figure 5.2 Yarn extensibility test results

When the Yarn extensibility test results are examined, a related proportion between recycling and extensibility is observed in the sample contents. As the ratio of recycled acrylic fiber increases, yarn extensibility results decrease. As an exception to this situation, the results of the DRF0 and DFD0 samples claim the opposite, but it is observed that the increase in the recycling acrylic ratio in the majority of the samples negatively affects the yarn flexibility. Considering that the highest extensibility value is in DRD0 and DDT0 samples, it is clearly seen that the low extensibility value in DRF0 and DFD0 samples is affected by the polyester used in the yarn core. When the results are examined in general, it is among the findings that the increase in the recycling acrylic rate gives negative results in yarn extensibility.

➢ Yarn Unevenness Test Results: Yarn evenness (U) test results are given in Figure 5.3 and yarn evenness CV test results are given in Figure 5.4.

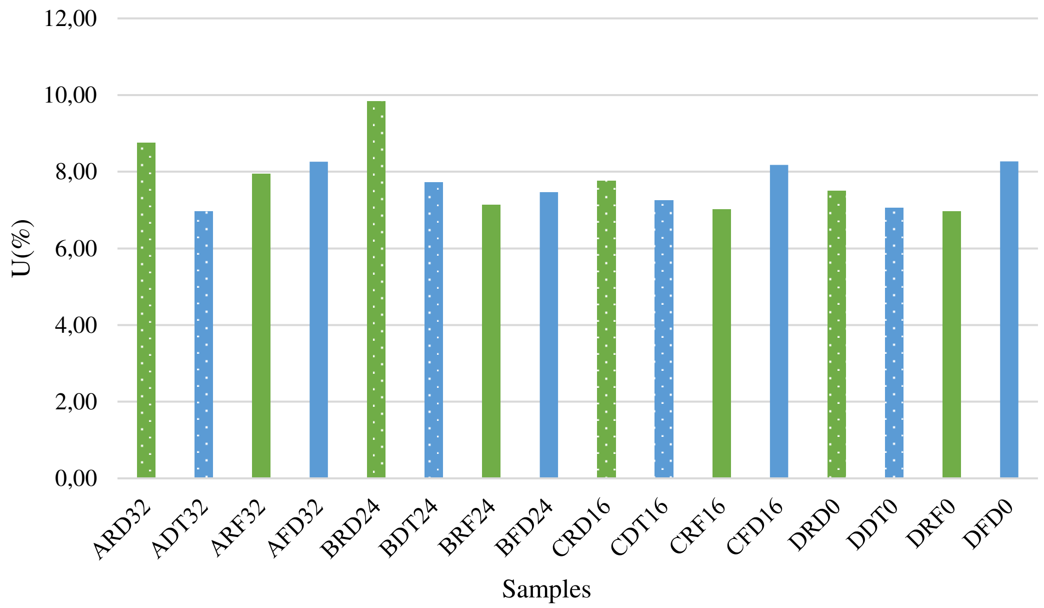

Figure 5.3 Yarn unevenness test results (U)

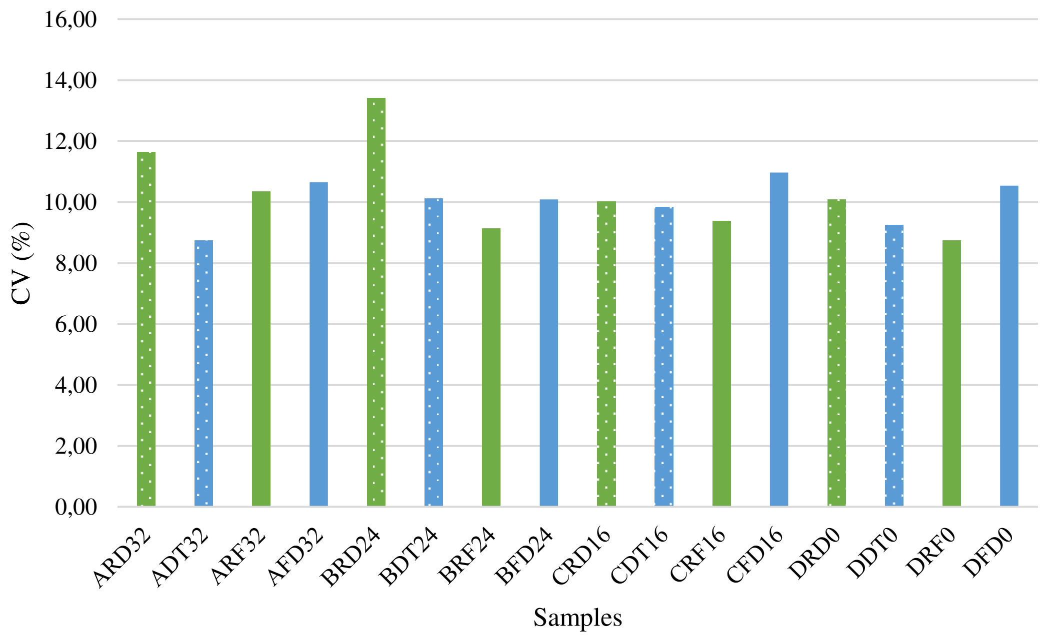

Figure 5.4 Yarn unevenness test results (CV)

When the test results are examined in detail, it is seen that the worst yarn evenness result is in the BRD24 sample. 24% recycled acrylic was used in the covering part of this sample, and RECYCLE DTY was used in the core part. It can be concluded that this sample gives the lowest values due to the use of completely recycled acrylic in both the cover and core. The best yarn evenness value was observed in ADT32 and DRF0 samples. Among these samples, ADT32 has 32% recycled acrylic on its cover, while DRF0 has 0% recycled acrylic on its cover.

5.2. Knitting Test Results

- Air Permeability Test Results: Air permeability test results are given in Figure 5.5.

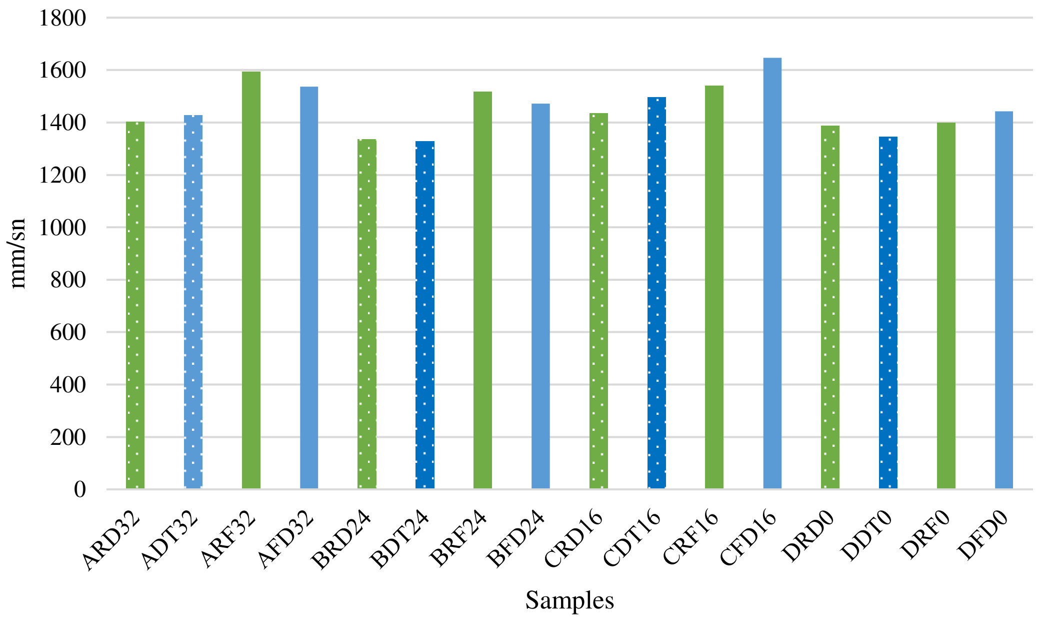

Figure 5.5 Air permeability test results

There is no big difference between the results of the air permeability test results. When the results are examined in detail, it is observed that the filaments of RECYCLE DTY and DTY used in the core of the yarn for all of the samples show slightly less air permeability than the other samples. It was observed that FDY and RECYCLE FDY used in the core part had a positive effect on air permeability. The fact that the core yarn has been textured causes slight differences in air permeability, causing a decrease in air permeability. As the reason for this, it can be said that the polyester, which is texturized in RECYCLE DTY and DTY samples, retains the air because it has a more curved structure compared to other polyester cores. In addition to these, it has been observed that the recycled acrylic fiber in the yarn mixture does not have a negative effect on air permeability, while the fact that the polyester used in the core has been texturized creates slight differences between the results.

- Water Vapor Permeability Test Results: The results of water vapor permeability are given in Figure 5.6.

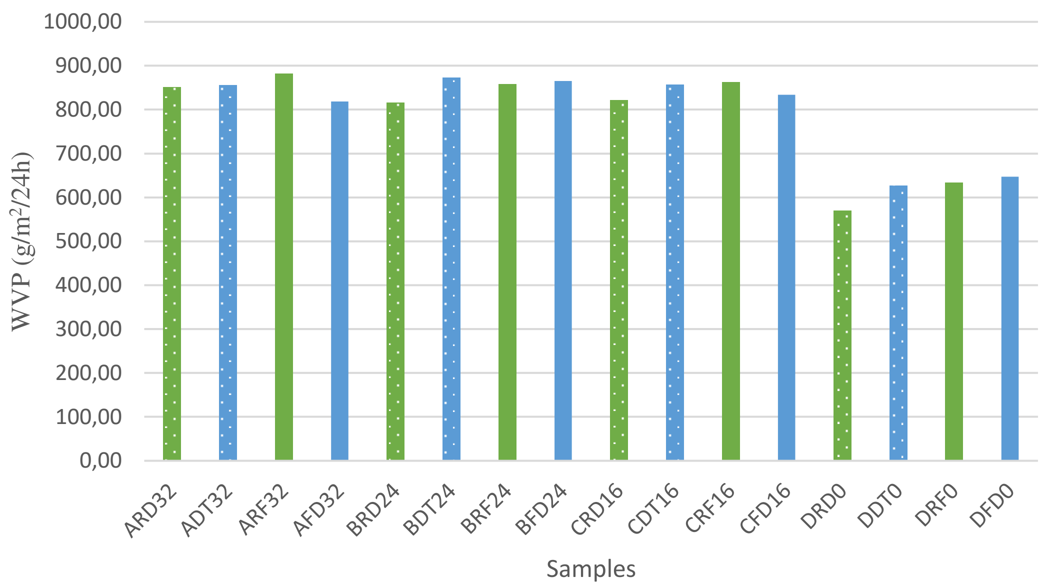

Figure 5.6 Water vapor permeability test results

There was no big difference between the groups in the water vapor permeability test results. The group with 0% recycle acrylic content shows slight differences compared to other groups. The group with the lowest water vapor permeability value is seen as the group without recycle acrylic (DRD0, DDT0, DRF0 and DFD0). Yarns with recycled acrylic content give higher results. It is clearly known that recycled fibers undergo changes in their physical and chemical structures due to being recycled and re-spinned by mechanical and chemical processes before. It is obtained from the test results that the yarns with recycled content have a high-water vapor permeability value due to the processes they have undergone before and that they pass water vapor at a higher rate than conventional acrylic yarns.

- Bursting Strength Test Results: Bursting strength test results of the samples are given in Figure 5.7.

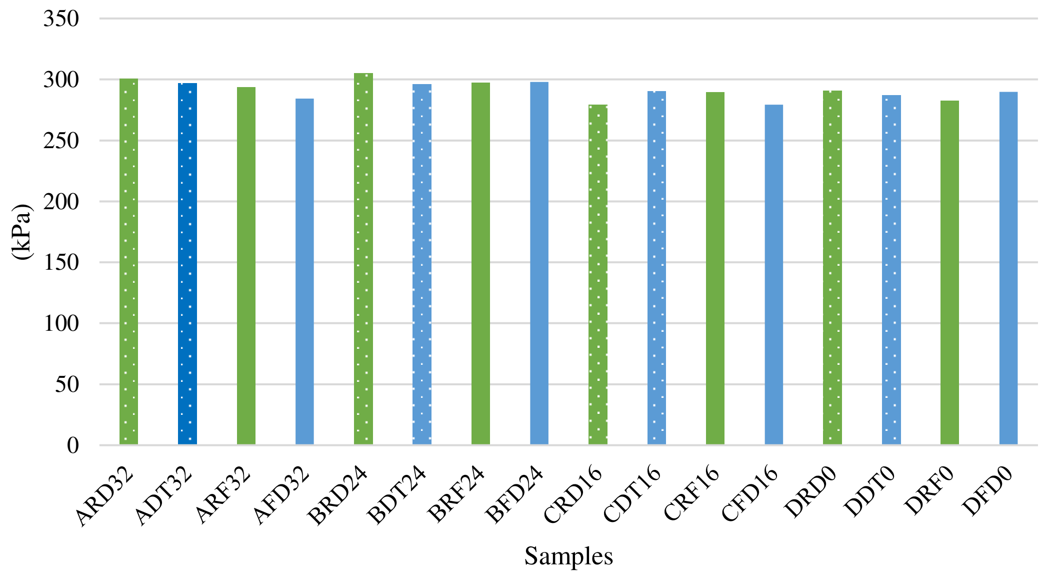

Figure 5.7 Bursting strength test results

When the results of the bursting test are examined, it is observed that the results give very close values. There are no big differences between the samples containing recycled acrylic and conventional acrylic fibers in the content of the covering fibers. The same situation is observed when the test results are compared according to the core. It is observed that the use or non-use of recycled polyester in the core, as well as whether the polyester used is textured or not, does not have a great effect on the bursting strength.

➢ Abrasion-Hole Detect Test Results: The abrasion-hole strength test results of the samples are given in Figure 5.8.

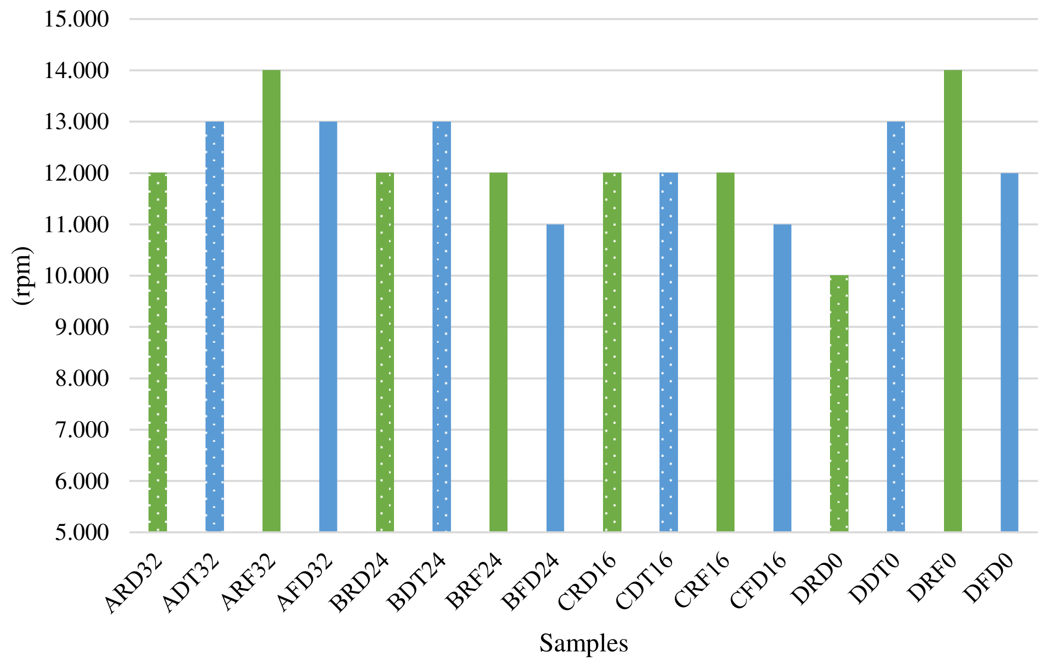

Figure 5.8 Abrasion resistance test results

The results obtained from the abrasion- hole strength test is observed in Figure 5.8. In the test results, it was observed that the highest abrasion- hole speed was in ARF32 and DRF0. Both of these samples contained RECYCLE FDY in the core. On the other hand, while there is 32% recycled acrylic in ARF32 in the covering, the recycling acrylic rate in DRF0 is 0%. In other samples, samples containing 0% recycled acrylic and 32% recycled acrylic yielded results close to each other and gave average results in the samples in between. The lowest tearing speed was observed in the DRD0 sample. It is known that DRD0 has RECYCLE DTY in its core and 0% recycled acrylic in the covering part. According to the test results, the use of recycled polyester or conventional polyester in the core part of the yarn and the use of recycled acrylic or conventional acrylic in the covering part did not have a significant effect.

➢ Pilling Resistance Test Results: Figure 5.9 shows the pilling test results of the samples.

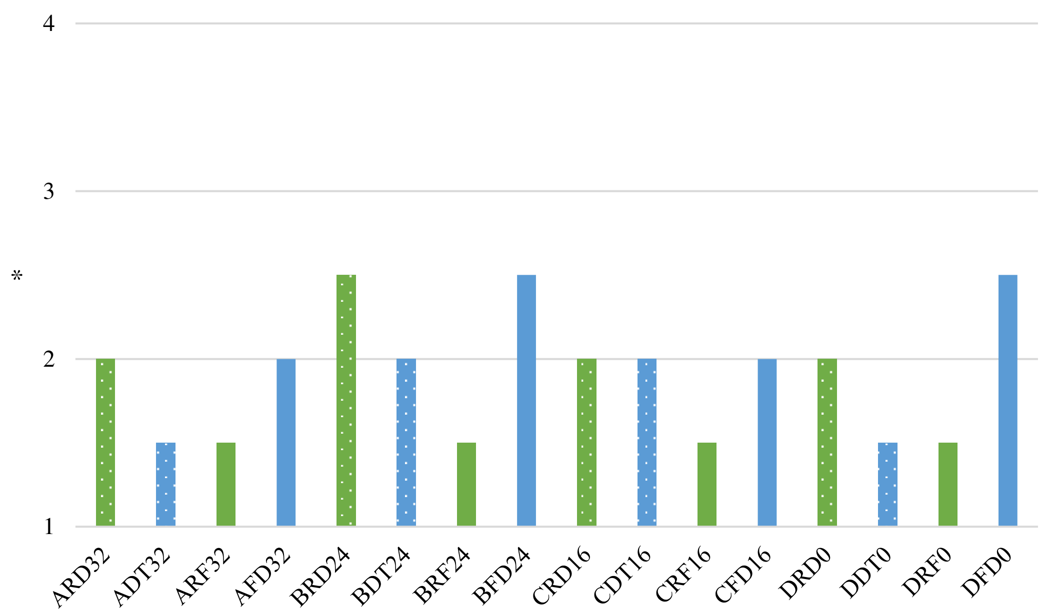

Figure 5.9 Pilling test results (**1 worst, 5 no change)*

Pilling test results are shown in Figure 5.9. According to the test results, the samples with better pilling value than the other samples are BRD24, BFD24 and DFD0. These samples contain 24% recycled acrylic in the covering fiber of BRD24 and BFD24. In the DFD0 sample, there is 0% recycled acrylic in the covering part. BRD24, BFD24 and DFD0 samples give the same pilling results despite the presence of different proportions of conventional acrylic in their covering fiber. In addition, it is concluded that the use of RECYCLE DTY and FDY in the core of the BRD24, BFD24 and DFD0 samples does not have a negative effect on the sample, whether they use recycling or not. It is observed that there is no significant relationship between the test results. Although it is observed that using or not using recycling in the covering fiber or core fiber does not have a significant effect on the test results, it is obtained that the use of recycling in textile products will create better results.

- Dimensional Stability Test Results: Dimensional strength test results are given in Table 5.2 and Table 5.3. Table 5.2 contains the data obtained from the dimensional change results in the widthwise direction of the samples.

Table 5.2-Dimensional stability test results (widthwise)

Widthwise, %					
	1.Washing	2.Washing	3.Washing	4.Washing	5.Washing
ARD32	0	0	0	2	4
ADT32	0	0	0	0	2
ARF32	0	0	0	0	4
AFD32	2	4	8	6	8
BRD24	2	2	6	4	6
BDT24	8	6	8	6	8
BRF24	0	0	2	0	4
BFD24	0	0	4	0	4
CRD16	4	4	6	4	8
CDT16	2	6	6	4	8
CRF16	4	4	6	6	8
CFD16	4	4	4	4	8
DRD0	4	4	4	4	6
DDT0	4	8	8	6	8
DRF0	6	0	2	2	4
DFD0	4	4	2	2	4

When we look at the data obtained from the dimensional strength test results, it can be observed that the increase in the recycled acrylic ratio from the first wash to the last wash affects the dimensional strength. As the recycling acrylic ratio increases, it is observed that the dimensional strength of the samples decreases, and the fabric is more stable. It has been obtained by the obtained data that small shrinkage is observed on the fabric from the second wash in the change between washes. In the 5th wash, maximum shrinkage is observed compared to other washes.

- Table 5.3 contains the data obtained from the dimensional change results in the lengthwise direction of the samples.

Table 5.3-Dimensional stability test results (lengthwise)

Lengthwise, %					
	1.Washing	2.Washing	3.Washing	4.Washing	5.Washing
ARD32	10	12	14	12	14
ADT32	10	12	8	8	10
ARF32	8	8	8	10	12
AFD32	10	10	8	8	10
BRD24	10	12	8	6	8
BDT24	10	10	8	8	10
BRF24	10	10	8	8	8
BFD24	8	10	8	6	8
CRD16	6	8	6	6	8
CDT16	10	10	8	10	12
CRF16	8	10	8	4	6
CFD16	8	8	6	8	10
DRD0	10	8	8	8	12
DDT0	10	8	8	4	8
DRF0	6	6	8	6	10
DFD0	8	10	8	10	12

When we look at the data obtained from the dimensional strength test carried out in the lengthwise direction, a maximum of 14% and a minimum of 4% are seen in the size of the sample weaves. When the results of each washing are examined, it is observed that whether the sample content is recycled acrylic in the covering fiber or whether recycled polyester is used in the core of the yarn does not create significant differences.

In this test, which is carried out in the lengthwise and widthwise directions, it is observed that the fabric shrinkage rate in the widthwise direction is much less than the lengthwise.

5.3. Statistical Analysis

Statistical analysis was applied to all test results. Statistical analysis was made using the Design Expert 13 program. With Design Expert 13, the rate of recycled acrylic in the covering fibers, the effect of texturing the yarn used in the core and the effect of recycling the yarn used in the core were evaluated together. According to the test result obtained, the level of significance was analyzed through the ANOVA test. Test results were analyzed at a confidence interval of 0.95 (at a significance level of 0.05). Structural properties (weight, thickness and loop length) and performance properties (yarn tenacity, yarn extensibility, unevenness, thin place, thick place, neps, abrasion-hole detect, bursting, air permeability, water vapor permeability, pilling, widthwise change first washing, widthwise change fifth washing, lengthwise change first washing, lengthwise change fifth washing) is explained by drawing graphs by looking at all factors.

- **ANOVA Variance Analysis Test**

Analysis of variance is used to test hypotheses about whether the difference between the means of two or more groups is significant. Within the scope of this study, a model consisting of 3 groups was established. It has been analyzed whether the yarn used in the yarn core part is textured or not, whether the yarn used in the core is recycled or not, and whether the variation of the recycling rate of the fiber used in the covering part of the yarn has a significant effect on its structural and performance properties. With the Design Expert program, the effect of the change in the core and the cover part was tested with variance analysis. This result is statistically significant by accepting the test results with a p value less than 0.05 as significant when tested with a 95% confidence interval. Otherwise, the test result is considered meaningless. Analyzes were made for all tests. Statistical analysis results are given in Table 5.4.

Table 5.4 ANOVA analysis chart on the impact of structural and performance characteristics.

Responses	Source	Sum of Squares	df	Mean Square	F-value	p-value	
Weight	Model	0,0326	5	0,0065	1,67	0,2289	not significant
	A-no recycle	0,0041	1	0,0041	1,04	0,3321	
	B-texture	0,0211	1	0,0211	5,41	0,0423	
	C-recycle ratio	0,0074	3	0,0025	0,6335	0,6101	

Table 5.4 Continued

	Residual	0,0390	10	0,0039			
	Cor Total	0,0716	15				
Thickness	Model	0,1538	5	0,0308	1,40	0,3047	not significant
	A-no recycle	0,0007	1	0,0007	0,0323	0,8610	
	B-texture	0,0455	1	0,0455	2,07	0,1812	
	C-recycle ratio	0,1076	3	0,0359	1,63	0,2445	
	Residual	0,2203	10	0,0220			
	Cor Total	0,3741	15				
Loop Length	Model	0,1538	5	0,0308	1,40	0,3047	not significant
	A-no recycle	0,0007	1	0,0007	0,0323	0,8610	
	B-texture	0,0455	1	0,0455	2,07	0,1812	
	C-recycle ratio	0,1076	3	0,0359	1,63	0,2445	
	Residual	0,2203	10	0,0220			
	Cor Total	0,3741	15				
Yarn Tenacity	Model	0,0004	5	0,0001	1,53	0,2639	not significant
	A-no recycle	0,0002	1	0,0002	2,78	0,1265	
	B-texture	0,0001	1	0,0001	1,0000	0,3409	
	C-recycle ratio	0,0002	3	0,0001	1,30	0,3289	
	Residual	0,0006	10	0,0001			
	Cor Total	0,0010	15				
Yarn Extensibility	Model	77,20	5	15,44	2,84	0,0756	not significant
	A-no recycle	2,47	1	2,47	0,4541	0,5157	
	B-texture	6,41	1	6,41	1,18	0,3033	
	C-recycle ratio	68,32	3	22,77	4,18	0,0369	
	Residual	54,46	10	5,45			

Table 5.4 Continued

	Cor Total	131,66	15				
Unevenness	Model	1,41	5	0,2830	0,3681	0,8592	not significant
	A-no recycle	0,1892	1	0,1892	0,2461	0,6305	
	B-texture	0,1560	1	0,1560	0,2030	0,6620	
	C-recycle ratio	1,07	3	0,3565	0,4638	0,7139	
	Residual	7,69	10	0,7688			
	Cor Total	9,10	15				
"Thin Place	Model	2450,00	5	490,00	1,57	0,2545	not significant
	A-no recycle	400,00	1	400,00	1,28	0,2843	
	B-texture	25,00	1	25,00	0,0800	0,7831	
	C-recycle ratio	2025,00	3	675,00	2,16	0,1560	
	Residual	3125,00	10	312,50			
	Cor Total	5575,00	15				
Thick Place	Model	7225,00	5	1445,00	0,9538	0,4885	not significant
	A-no recycle	100,00	1	100,00	0,0660	0,8025	
	B-texture	400,00	1	400,00	0,2640	0,6185	
	C-recycle ratio	6725,00	3	2241,67	1,48	0,2788	
	Residual	15150,00	10	1515,00			
	Cor Total	22375,00	15				
Neps	Model	1525,00	5	305,00	1,07	0,4316	not significant
	A-no recycle	100,00	1	100,00	0,3509	0,5668	
	B-texture	100,00	1	100,00	0,3509	0,5668	
	C-recycle ratio	1325,00	3	441,67	1,55	0,2620	
	Residual	2850,00	10	285,00			
	Cor Total	4375,00	15				

Table 5.4 Continued

Abrasion Hole Detect	Model	3,750E+06	5	7,500E+05	0,5660	0,7248	not significant
	A-no recycle	3,725E-09	1	3,725E-09	2,812E-15	1,0000	
	B-texture	2,500E+05	1	2,500E+05	0,1887	0,6732	
	C-recycle ratio	3,500E+06	3	1,167E+06	0,8805	0,4836	
	Residual	1,325E+07	10	1,325E+06			
	Cor Total	1,700E+07	15				
Bursting Strength	Model	585,18	5	117,04	4,31	0,0237	significant
	A-no recycle	18,32	1	18,32	0,6745	0,4306	
	B-texture	60,53	1	60,53	2,23	0,1663	
	C-recycle ratio	506,33	3	168,78	6,21	0,0118	
	Residual	271,59	10	27,16			
	Cor Total	856,77	15				
Air Permeability	Model	1,110E+05	5	22200,34	11,62	0,0007	significant
	A-no recycle	455,95	1	455,95	0,2386	0,6357	
	B-texture	61571,97	1	61571,97	32,22	0,0002	
	C-recycle ratio	48973,79	3	16324,60	8,54	0,0041	
	Residual	19107,74	10	1910,77			
	Cor Total	1,301E+05	15				
Water Vapor Permeability	Model	1,608E+05	5	32151,08	45,02	< 0.0001	significant
	A-no recycle	423,96	1	423,96	0,5936	0,4588	
	B-texture	1114,60	1	1114,60	1,56	0,2400	
	C-recycle ratio	1,592E+05	3	53072,27	74,31	< 0.0001	
	Residual	7141,84	10	714,18			
	Cor Total	1,679E+05	15				
Pilling	Model	0,4531	5	0,0906	0,5472	0,7376	not significant

Table 5.4 Continued

	A-no recycle	0,1406	1	0,1406	0,8491	0,3785	
	B-texture	0,0156	1	0,0156	0,0943	0,7650	
	C-recycle ratio	0,2969	3	0,0990	0,5975	0,6310	
	Residual	1,66	10	0,1656			
	Cor Total	2,11	15				
Widthwise change first washing,	Model	37,00	5	7,40	1,48	0,2791	not significant
	A-no recycle	1,00	1	1,00	0,2000	0,6643	
	B-texture	1,00	1	1,00	0,2000	0,6643	
	C-recycle ratio	35,00	3	11,67	2,33	0,1357	
	Residual	50,00	10	5,00			
	Cor Total	87,00	15				
Widthwise change fifth washing	Model	31,25	5	6,25	1,71	0,2193	not significant
	A-no recycle	2,25	1	2,25	0,6164	0,4506	
	B-texture	2,25	1	2,25	0,6164	0,4506	
	C-recycle ratio	26,75	3	8,92	2,44	0,1245	
	Residual	36,50	10	3,65			
	Cor Total	67,75	15				
Lengthwise change first washing	Model	15,25	5	3,05	1,85	0,1910	not significant
	A-no recycle	2,25	1	2,25	1,36	0,2700	
	B-texture	6,25	1	6,25	3,79	0,0802	
	C-recycle ratio	6,75	3	2,25	1,36	0,3094	
	Residual	16,50	10	1,65			
	Cor Total	31,75	15				
Lengthwise change fifth washing	Model	25,25	5	5,05	1,19	0,3804	not significant
	A-no recycle	0,2500	1	0,2500	0,0588	0,8133	

Table 5.4 Continued

	B-texture	2,25	1	2,25	0,5294	0,4835	
	C-recycle ratio	22,75	3	7,58	1,78	0,2136	
	Residual	42,50	10	4,25			
	Cor Total	67,75	15				

When Table 5.4 is examined in detail, it is seen that the variability in core and cover part has a statistically significant effect on the fabric in bursting strength, air permeability and water vapor permeability tests of knitted fabrics obtained from these yarns. On the other hand, change of weight, thickness, loop length, yarn tenacity, yarn extensibility, unevenness, thin place, thick place, neps, abrasion hole detects, pilling, widthwise with the first washing, and change of widthwise with fifth washing, change of lengthwise with the first washing and change of lengthwise with fifth washing were determined that the results of the tests were not significant. In this case, it was observed that the textured or recycle yarn used in the core and the ratio of recycled fiber used in the covering part affected only 3 properties, and it was concluded that this situation was not effective for other properties.

- **Multiple Graphs View (factor profiler)**

The "Multiple Graphs View (factor profiler)" chart type is a chart type used to analyze the interactions of multiple variables. This type of chart is a chart in which multiple line charts are displayed together and visualizes the effect of different combinations of factors on variables. In this chart type, each line represents a different factor level.

On the graph, factor levels are placed on the horizontal axis and the measurement unit of the variable is located on the vertical axis in order to analyze the interactions of the variables with respect to different factor levels. The intersections of the line graphs show the interaction between certain factor levels and variables.

Multiple graph view was created in Design Expert for all test results. Significant responses in the test results were evaluated, and the multiple graph view of those that were not significant is included in the appendices.

Bursting strength: These graphs show the relationship between actual factors with bursting strength. Multiple graph's view seeing effects from input variables side by side shouts out their relative impacts. Thus, it is tried to determine whether the effect of the variability in the core and the covering fiber on the bursting strength is strong or weak with the help of Figure 5.10.

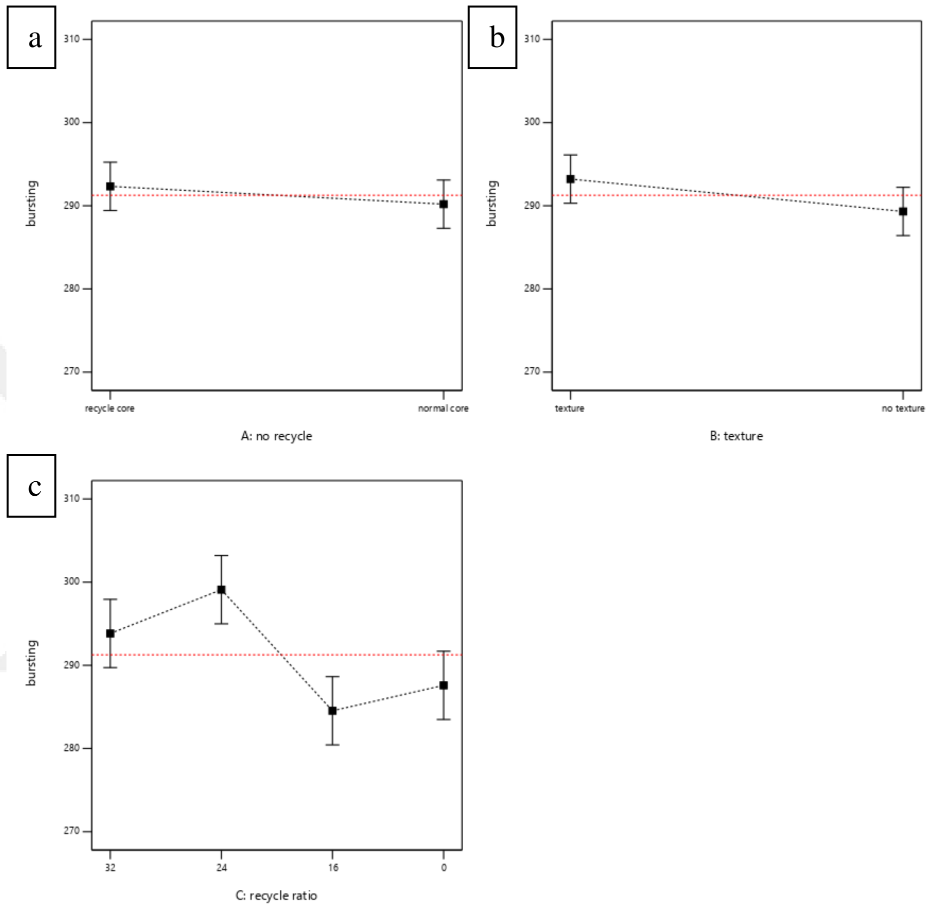

Figure 5.10 Multiple graphical view visual of bursting strength.

When the data of the bursting strength test was taken into consideration and evaluated, the findings were obtained in the analysis of variance. Figure 5.10 (a) shows the effect of the material used in the core of the yarn on the bursting strength. Figure 5.10 (a) shows that there are very small differences between using recycled yarn in core and using conventional yarn. Figure 5.10 (b) shows the effect of textured or non-textured yarn used in the core part of the yarn on bursting strength. According to Figure 5.10 (b), it is observed that the textured yarn gives higher values in the bursting strength test. In Figure 5.10 (c), the effect of the recycled acrylic ratio used in the covering fiber part of the yarn on the bursting strength is observed. According to Figure 5.10 (c), samples with 24% recycled acrylic content showed the highest bursting strength, in the second place 32% recycled acrylic additive yarns, third place recycled acrylic additive-free yarns and lastly 16% recycled acrylic yarns. This situation shows that, contrary to what is thought, fabrics made from recycled acrylic-added yarns give better results than conventional ones when the graphics are examined.

Air Permeability: These graphs show the relationship between actual factors with air permeability. Multiple graph's view seeing effects from input variables side by side shouts out their relative impacts. Thus, it is tried to determine whether the effect of variability in core and covering fiber on air permeability is strong or weak with the help of Figure 5.11.

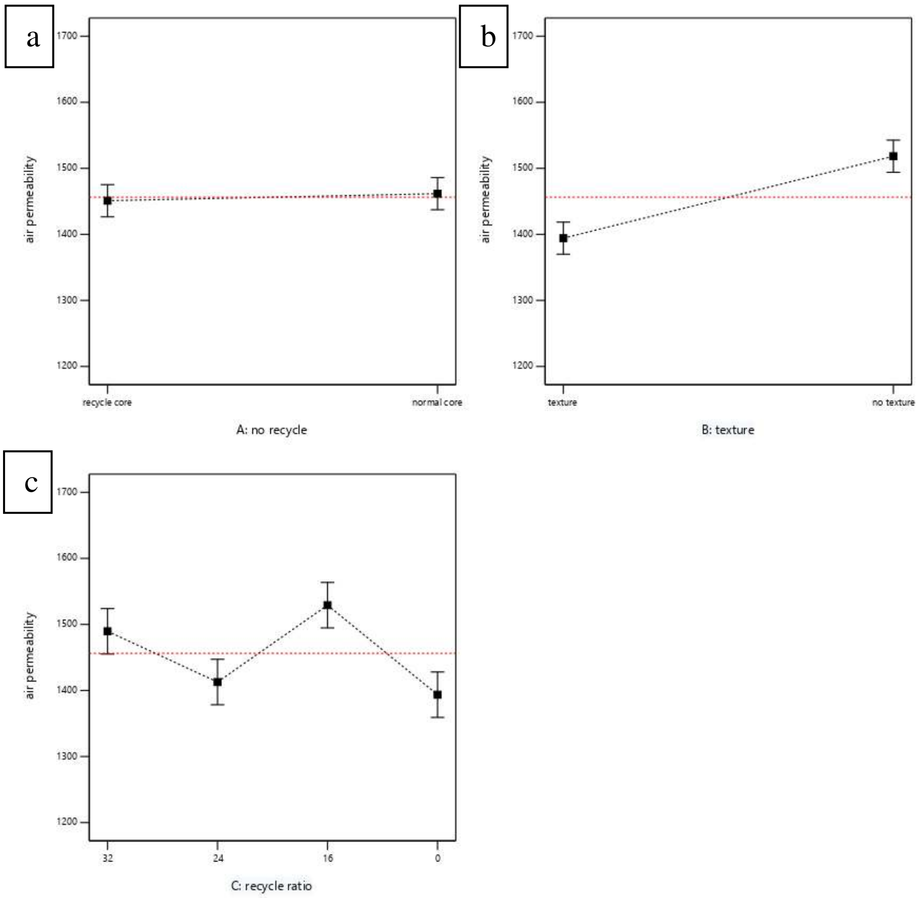

Figure 5.11 Multiple graphical view visual of air permeability.

When the air permeability test was evaluated by considering the data, the findings in the analysis of variance were obtained significantly. Figure 5.11 (a) shows the effect on the air permeability used in the core part of the yarn. Figure 5.11 (a) shows that the recycled or conventional core yarn used in the core of the yarns has almost no effect. Figure 5.11 (b) shows the effect of texturing the yarn used in the core of the yarns on air permeability. According to Figure 5.11 (b), it is observed that the use of texture in the core reduces the air permeability as expected. In Figure 5.11 (c), the effect of the recycled acrylic ratio used in the covering fiber part of the yarn on the air permeability is observed. According to Figure 5.11 (c), it is observed that yarns containing 16% recycled acrylic give the best air permeability value, while yarns that do not contain recycled acrylic in their content give the lowest value.

Water Vapor Permeability: These graphs show the relationship between actual factors with water vapor permeability. Multiple graph's view seeing effects from input variables side by side shouts out their relative impacts. Thus, it is tried to determine whether the effect of variability in core and covering fiber on water vapor permeability is strong or weak with the help of Figure 5.12.

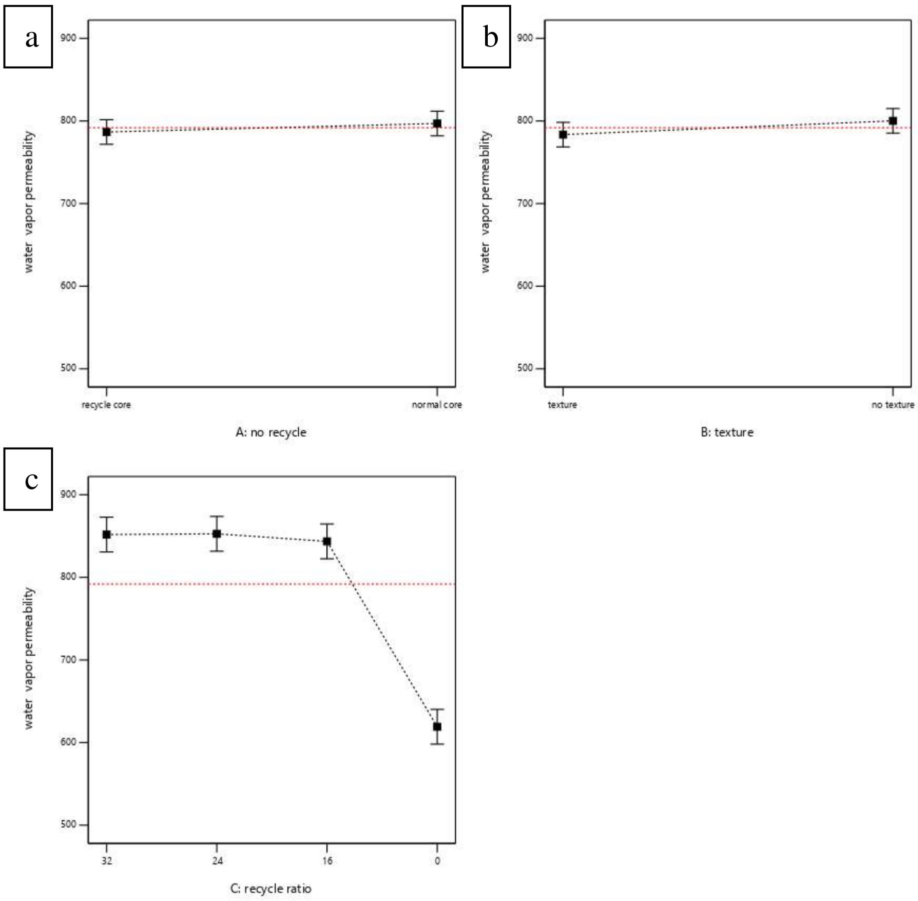

Figure 5.12 Multiple graphical view visual of water vapor permeability.

When the water vapor permeability test was evaluated by considering the data, the findings were obtained in the analysis of variance. Figure 5.12 (a) shows the effect on the water vapor permeability used in the core part of the yarn. Figure 5.12 (a) shows that the recycled or conventional core yarn used in the core of the yarns has almost no effect. Figure 5.12 (b) shows the effect of texturing the yarn used in the core of the yarns on water vapor permeability. Figure 5.12 (b) shows that the textured or non-textured core of the yarn used in the core of the yarns has almost no effect. In graphic c, the effect of the recycled acrylic ratio used in the covering fiber part of the yarn on the water vapor permeability is observed. According to Figure 5.12 (c), it is observed that there are samples containing 32%, 24% and 16% recycled acrylic fiber in their covering fibers with the highest water vapor permeability values. As the lowest water vapor permeability value is estimated in Figure 5.12 (c), it has been determined that there are knitted fabrics that do not contain recycled acrylic fiber.

CHAPTER 6
CONCLUSION

6.1 Conclusion

In the study, structural changes were made in the core and covering parts of the core yarns. The structural properties of the yarn, the performance properties on the yarn and the performance properties on the knitted fabrics were examined. While 4 polyester yarns that are FDY, RECYCLED FDY, DTY and RECYCLED DTY are used in core, yarns with 0% recycled acrylic, 16% recycled acrylic, 24% recycled acrylic, 32% recycled acrylic fiber in the cover part are used. 16 core yarns were obtained. These yarns are weight, thickness, loop length, yarn tenacity, yarn extensibility, unevenness, thin place, thick place, neps, and knitted fabrics obtained from these yarns are abrasion detect hole, bursting, air permeability, water vapor permeability, pilling, widthwise change first washing, widthwise change fifth washing, lengthwise change first washing, lengthwise change fifth washing tests results were evaluated by applying. The tests were carried out in a conditioned laboratory environment in accordance with the standards (at 20º C and 65% relative humidity.) The results were evaluated by applying ANOVA Variance Analysis Test and Multiple Graphs View (factor profiler) in Design expert 13 to the obtained results.

- When the weight values of the samples are examined, it is seen that the yarns used in the core are not an effective parameter for the weight. It was concluded that the rate of recycled acrylic used in the cover part is not a determining parameter for the weight, and no differences were observed between the yarns made with conventional acrylic in the cover part and the other yarns. In this case, it is seen that the use of core yarns made from recycled core and recycled fiber yarns does not pose a disadvantage when viewed on a weight basis.

- Considering the thickness values, it is observed that these values do not create a significant difference between the yarns, just like the weight, but it does not have a negative effect on the yarns.
- In the loop length test results, when the samples are looked at as a group, it is observed that the material used in the core has no effect on the loop length, but there are slight differences compared to the fiber used in the covering fiber. It is observed that the loop length is higher with small differences in yarns produced from conventional acrylic compared to those with recycled content in the covering part.
- Yarn tenacity test results show that the core part is not an effective parameter for yarn tenacity, as in the others, and yarn tenacity increases as the recycled acrylic ratio in the covering fiber increases. However, as a result of the obtained data, it is seen that the yarn tenacity of the yarns produced with 32% recycled acrylic is lower than the other 3 groups. In this case, it can be said that the recycled acrylic fiber has a certain limit and this rate increases negatively on yarn tenacity. Although the difference in the test results is not much, it is obtained that as the recycled acrylic ratio increases, it can have a negative effect on the yarn quality.
- The sample group that gave the lowest values in yarn extensibility test results was the yarn group containing 32% recycled acrylic in its cover part. As in yarn tenacity, the sample group with the highest recycling acrylic ratio gives the lowest values in yarn extensibility. Although there are differences in yarn extensibility as in yarn tenacity, these differences are not very large numerically.
- In the unevenness test results, although the type of yarn used in the core does not make an effective difference, it is seen as a result of the analyzes that the unevenness gives close results when evaluated according to the recycled acrylic ratio in the cover part. The same is true for thick places, thin places and neps.
- In the abrasion-hole detect test, the period in which the 32% recycled acrylic was used sample group ruptured, contrary to what was expected, showed the highest cycle compared to other sample groups.
- When the bursting strength test of knitted fabrics is examined, statistical analysis results were obtained as significant. Knitted fabrics have no effect on

the strength of the core in bursting strength. It is observed that the ratio of recycled acrylic used in covering fiber has a significant effect. It is observed that the sample groups with the highest strength values are respectively 24%, 32%, 0% and 16% recycled acrylic additive yarns. While the strength is expected to be low in products with recycling additives, it is observed that yarns with recycling additives exhibit preferable results when the advantage of core yarn is taken into account.

- The air permeability properties of the samples were found to be significant as a result of statistical analysis. When the air permeability properties of knitted fabrics were examined, it was concluded that the textured core yarn groups exhibited less air permeability as expected compared to the non-textured ones. When the air permeability of the samples was considered according to the recycled acrylic ratio used in the cover fiber, it was observed that the sample group with 16% recycling acrylic added had the highest air permeability.
- Statistical analysis of the water vapor permeability test was found to be significant. As a result of this test, it was found that the samples showing the highest water vapor permeability were the samples with 32%, 24% and 16% recycling acrylic additives, respectively. It is seen that the results of the sample group, which does not contain recycled acrylic, remained below the average and gave the lowest water vapor permeability. In this case, it can be said that the products with recycling additives show better water vapor permeability compared to the conventional ones.
- According to the pilling test results, the yarn group using 24% recycled acrylic exhibited better pilling than the other sample groups. In addition, it is observed that the yarn group with 32% recycled acrylic gives the worst pilling value. Here, as in other tests, it can be deduced that if the recycling acrylic rate exceeds 24%, it exhibits negative results.
- In the dimensional strength test, the analysis of the first and last washings were provided in the washing tests performed in widthwise and lengthwise directions. When the widthwise change of knitted fabrics is examined closely, it can be concluded that the yarn used in the core is not an effective parameter. It can be observed by the test results that the recycled fiber used in the covering fiber affects with small differences. Although it is not a self-

effective parameter in the measurements provided in the lengthwise direction, as in the widthwise, it has also been obtained as a result of statistical analyzes that the fiber used in the cover part does not have great effects.

When all the test results are considered in general within the scope of the study, it is seen as a result of the data that the use of the core (Fully Drawn Yarn (FDY), FDY Recycle, Drawn Textured Yarn (DTY) or DTY Recycle) among the polyesters used in the core does not show significant negative results. It is observed that the acrylic fibers used in the cover part (Fully Drawn Yarn (FDY), FDY Recycle, Drawn Textured Yarn (DTY) or DTY Recycle) are recycled or not, and even the change in the recycling acrylic ratio does not give negative results in the test results. The variance analysis and multiple graphic analysis images made as a result of the findings obtained confirm these.

Worse results are generally expected with recycled products compared to conventional products. The reason for this is that it is thought that recycling products will be returned as a disadvantage if they are subjected to many processes before. In this study, core yarns were produced together with recycled fibers. When the structural properties, yarn performance and fabric properties are examined in the obtained data, it has been found that there are no significant differences between the conventional yarns and the recycled yarns. Considering the analyzes and test results, recycled products can be preferred completely depending on meeting the supply and demand of the customer mass. It is thought that the preference of products with recycling additives will contribute to the country in ecological and economic terms and will positively affect the sustainability of non-renewable energy resources. In this context, such products can become a good option for sustainability.

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APPENDIX

Multiple Graphical Views of the test results of yarn and knitted fabrics produced within the scope of the Thesis Study on Design Expert 13 (those that are not significant in the variance analysis) are included in this section.

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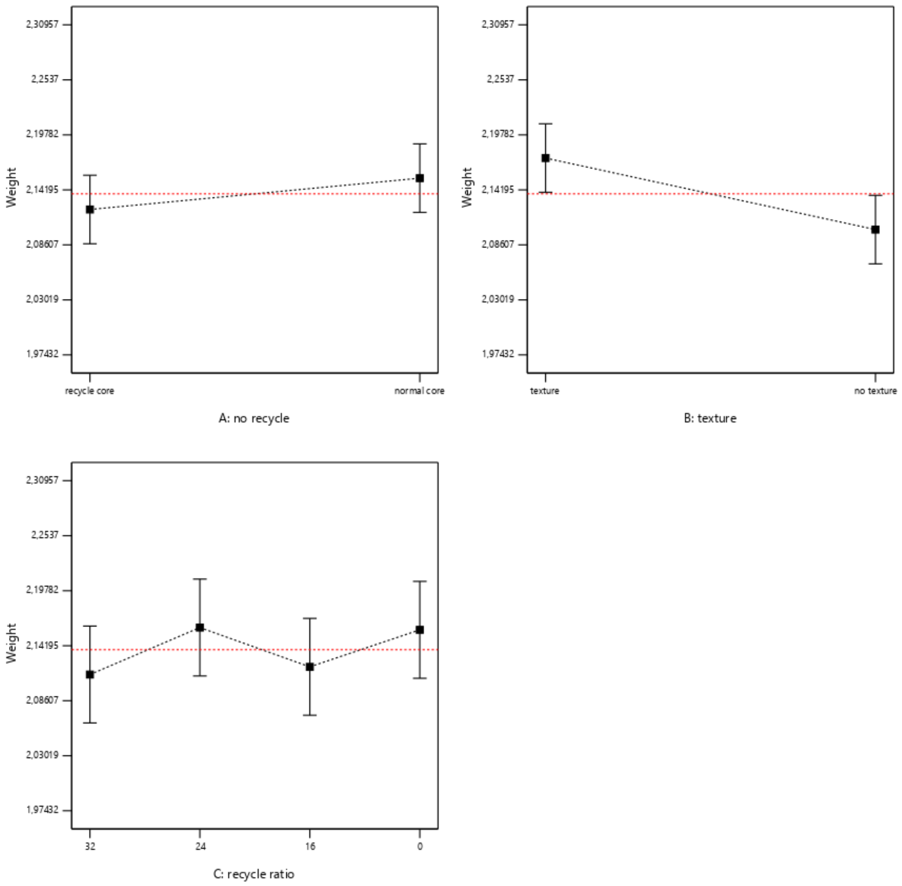
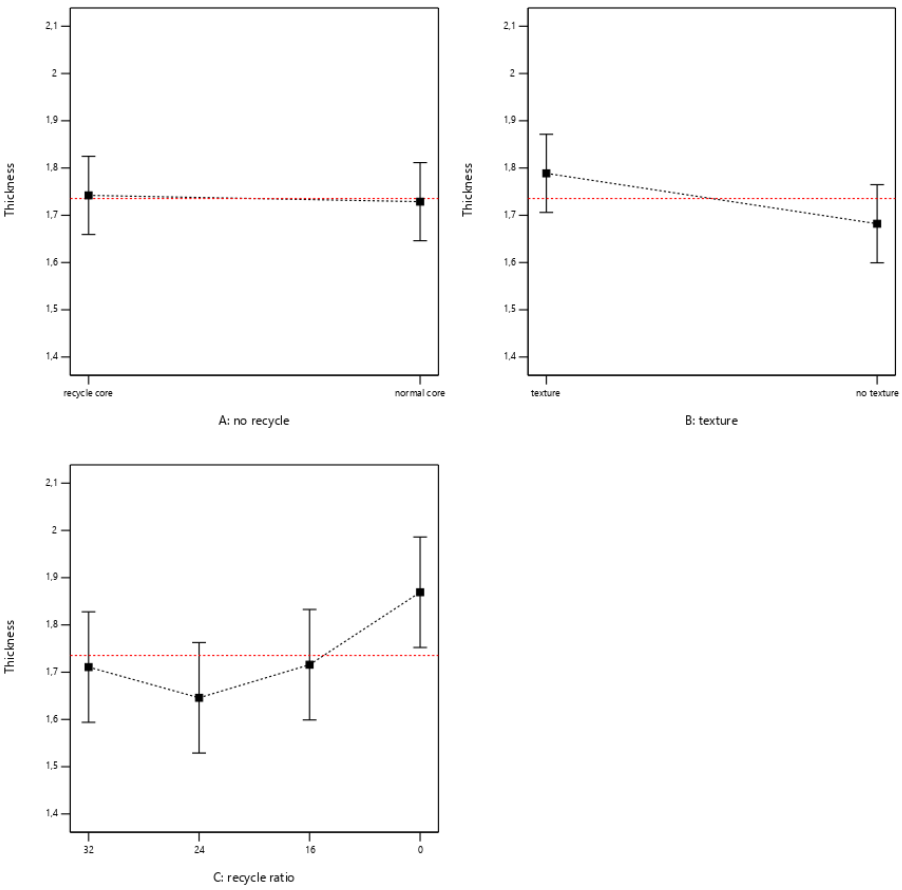
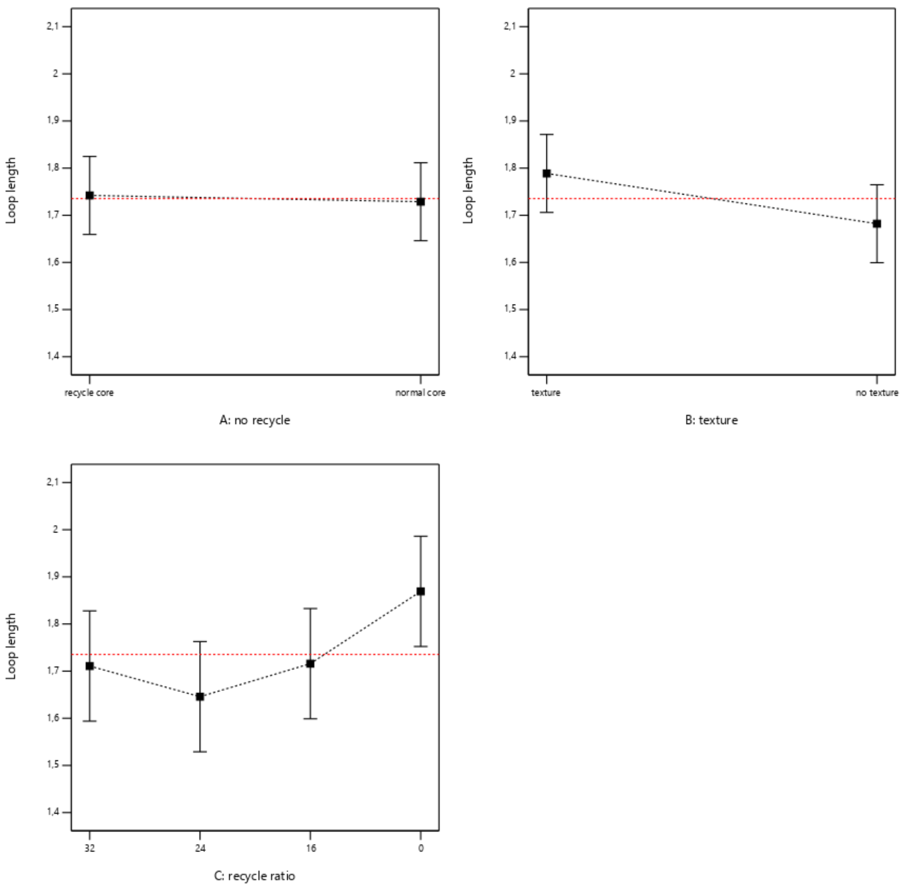


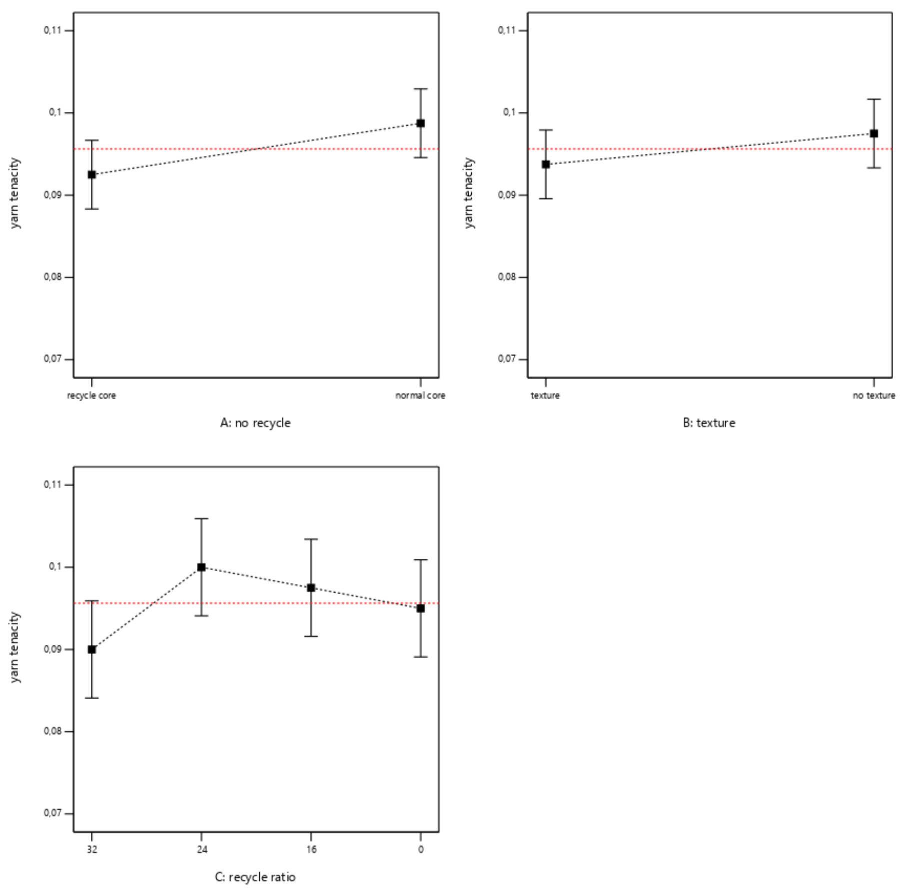
App. 1 Multiple graphical view visual of weight



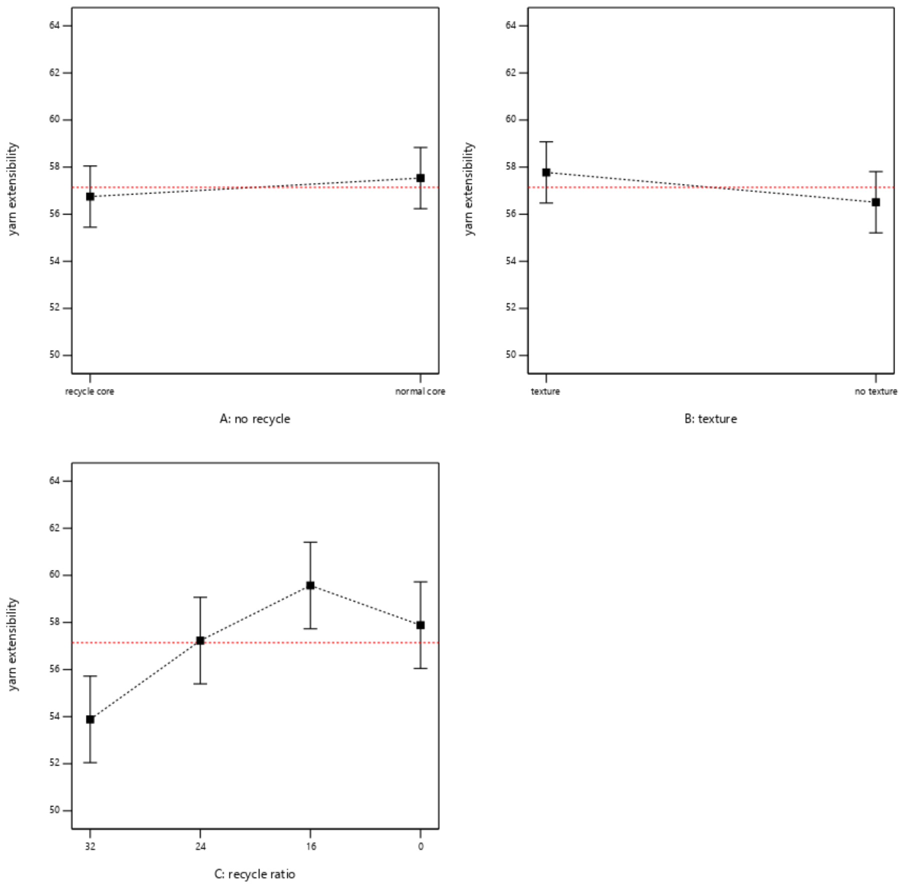
App. 2 Multiple graphical view visual of thickness.



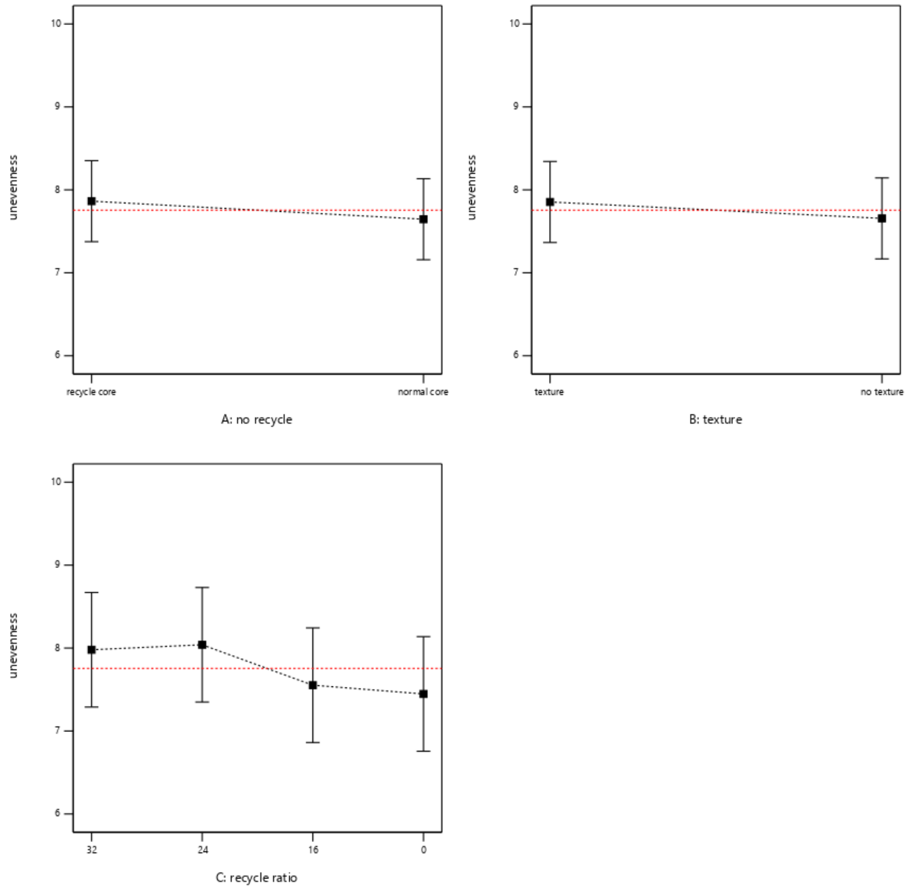
App. 3 Multiple graphical view visual of loop length.



App. 4 Multiple graphical view visual of yarn tenacity.



App. 5 Multiple graphical view visual of yarn extensibility.



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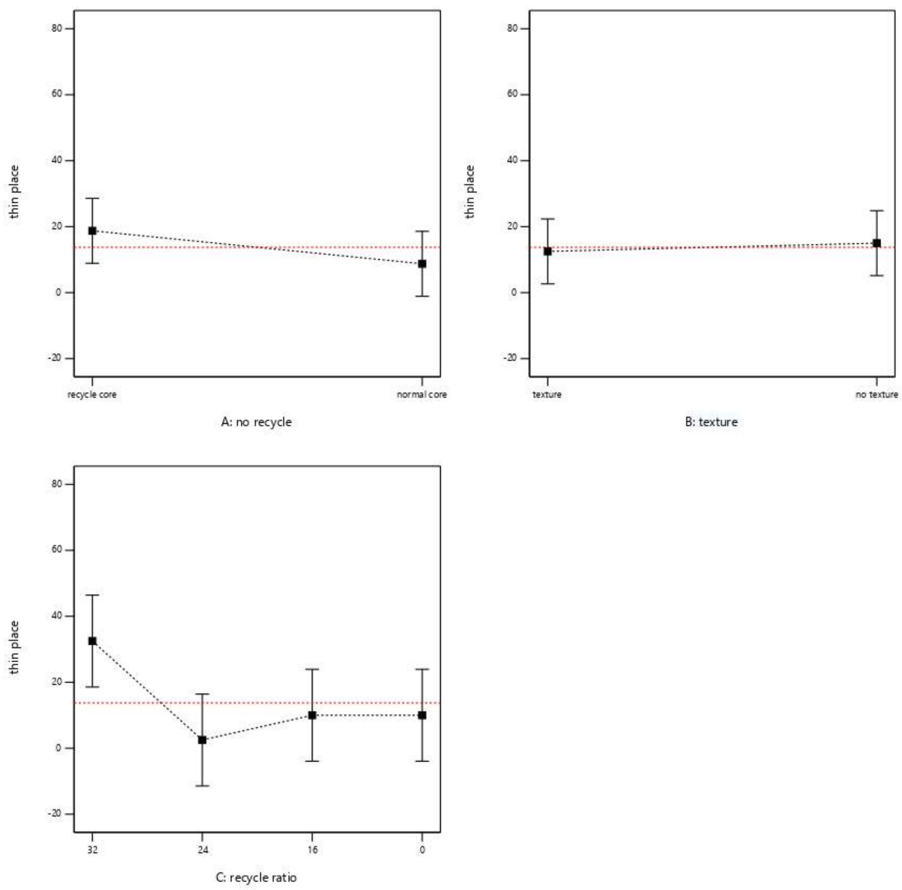
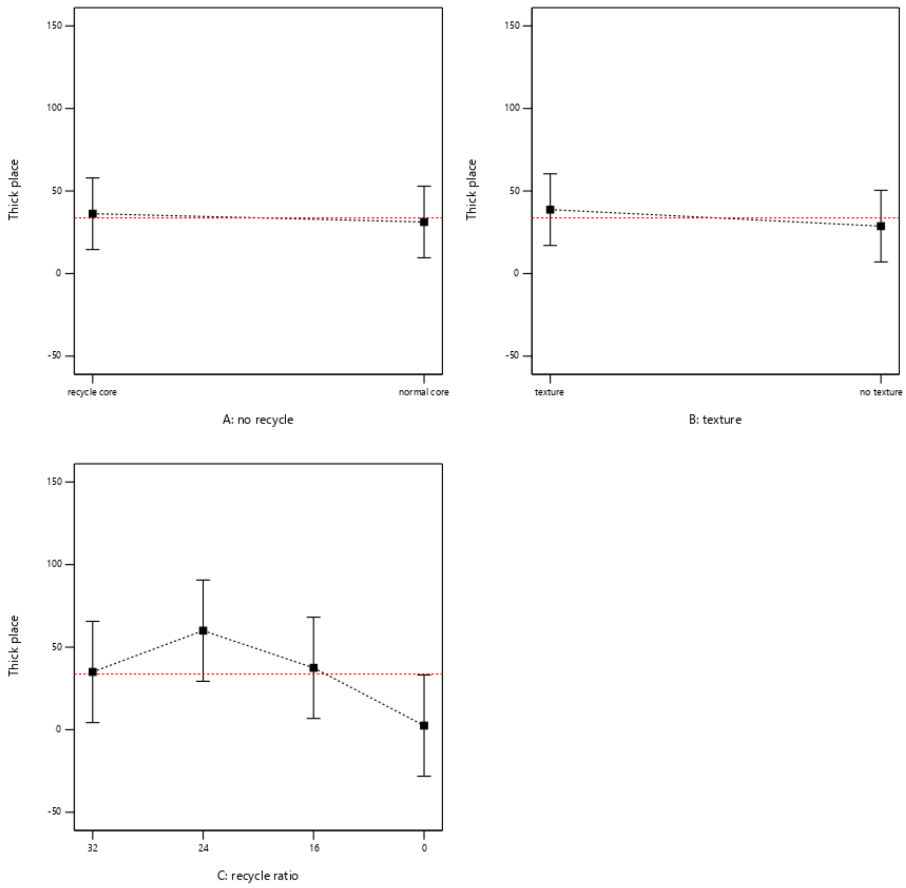
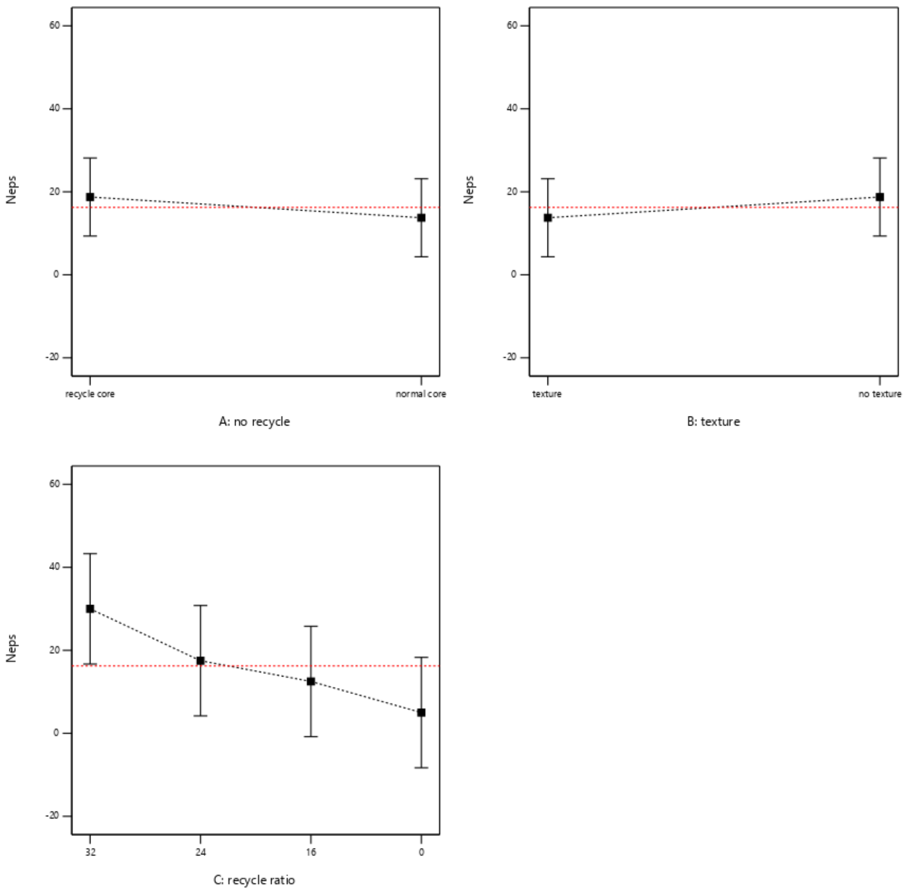


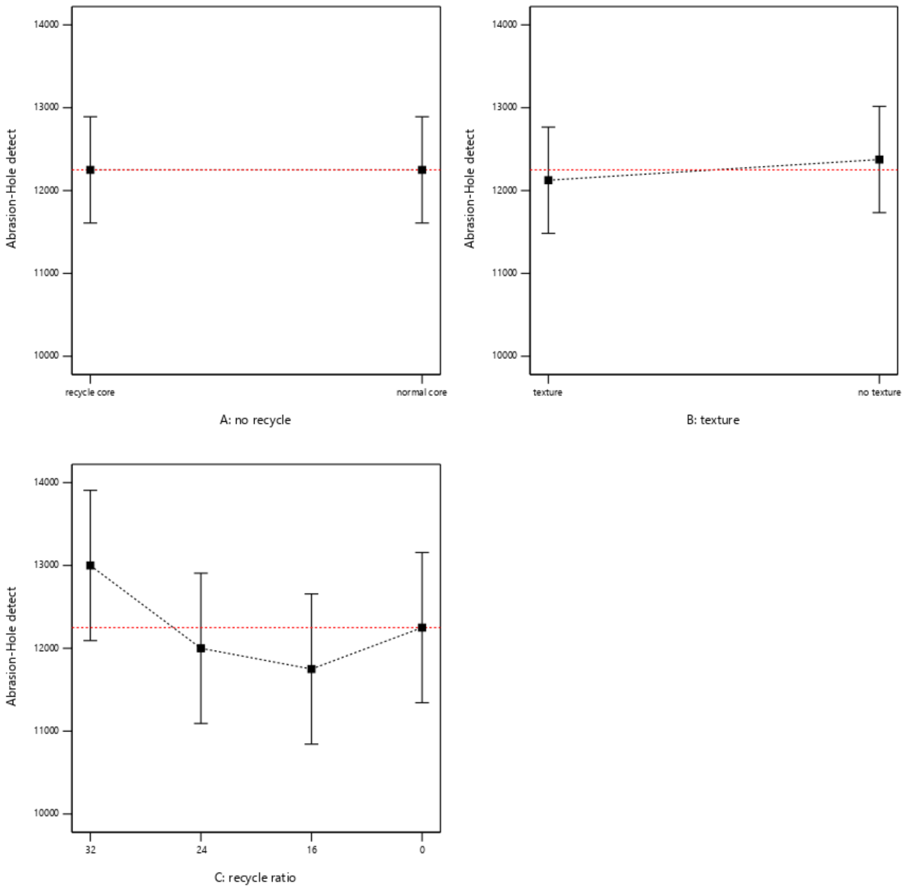
App. 7 Multiple graphical view visual of thin place.



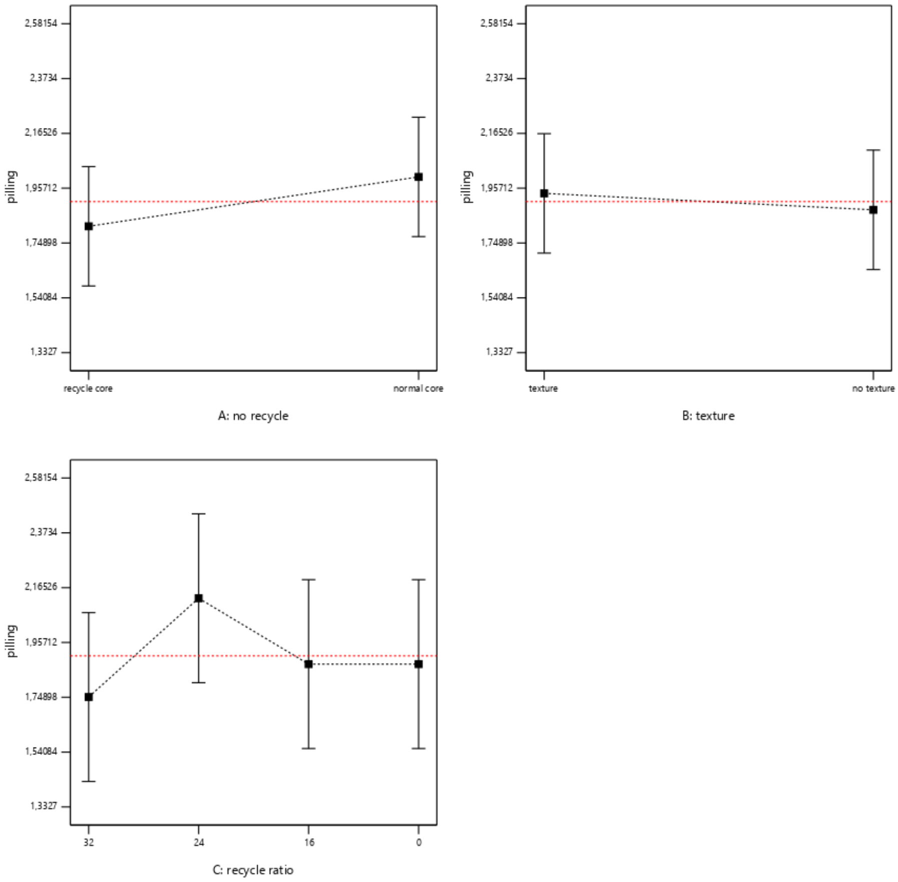
App. 8 Multiple graphical view visual of thick place.



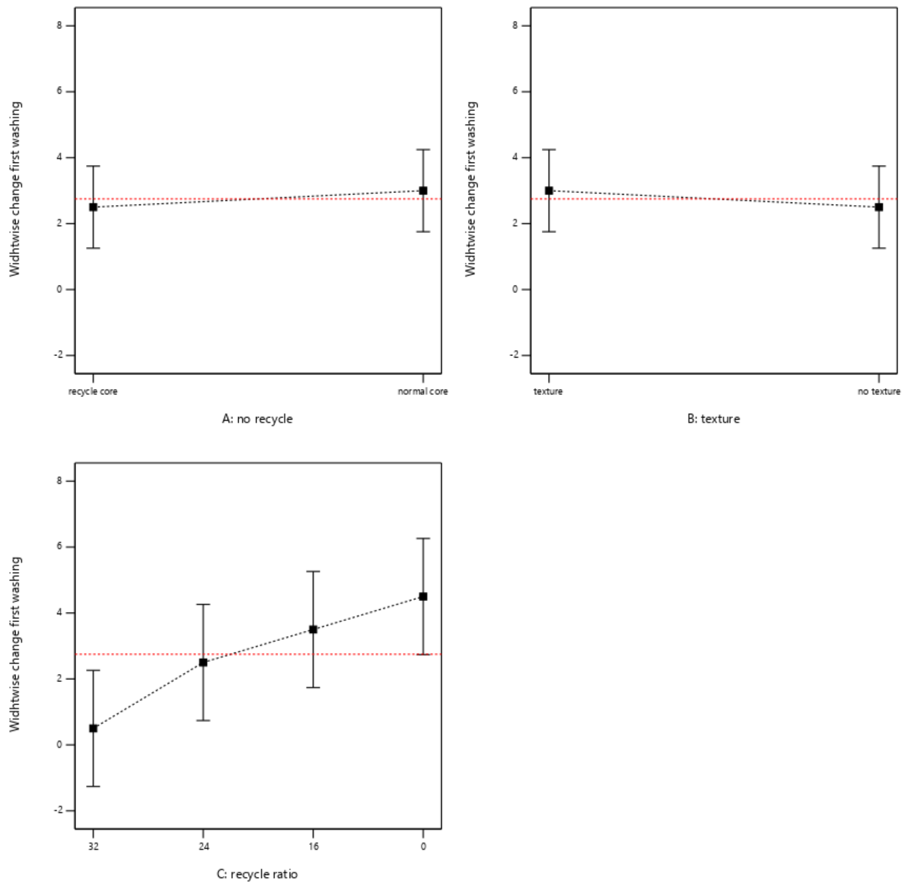
App. 9 Multiple graphical view visual of neps.



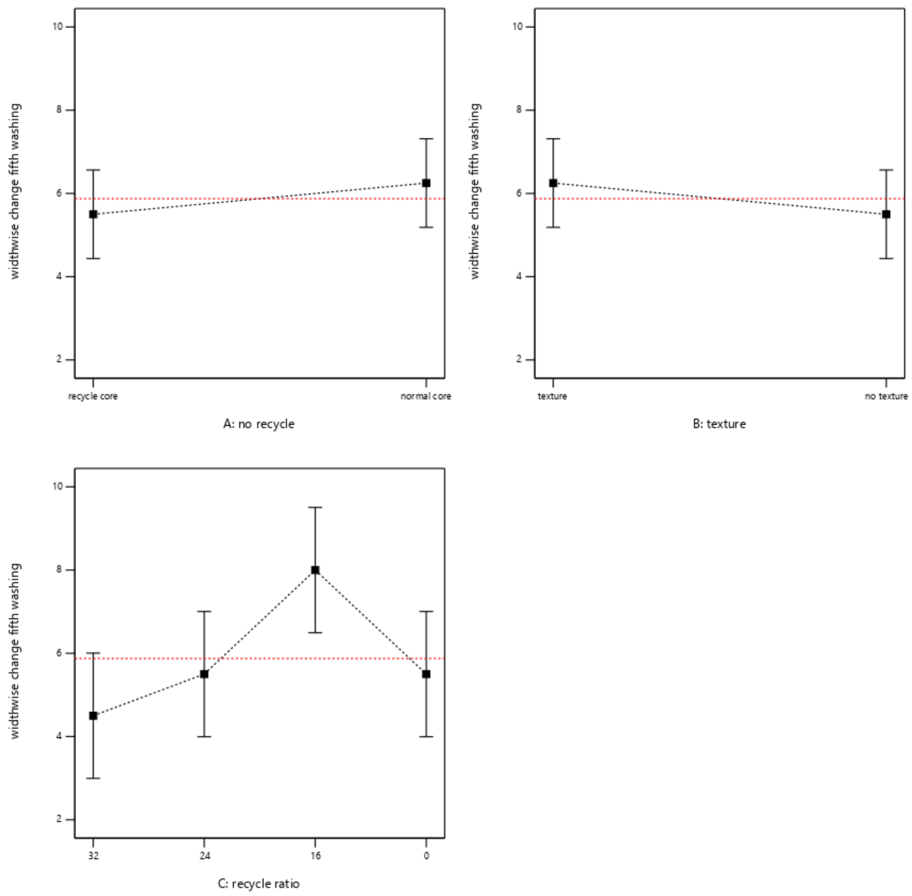
App. 10 Multiple graphical view visual of abrasion-hole detect.



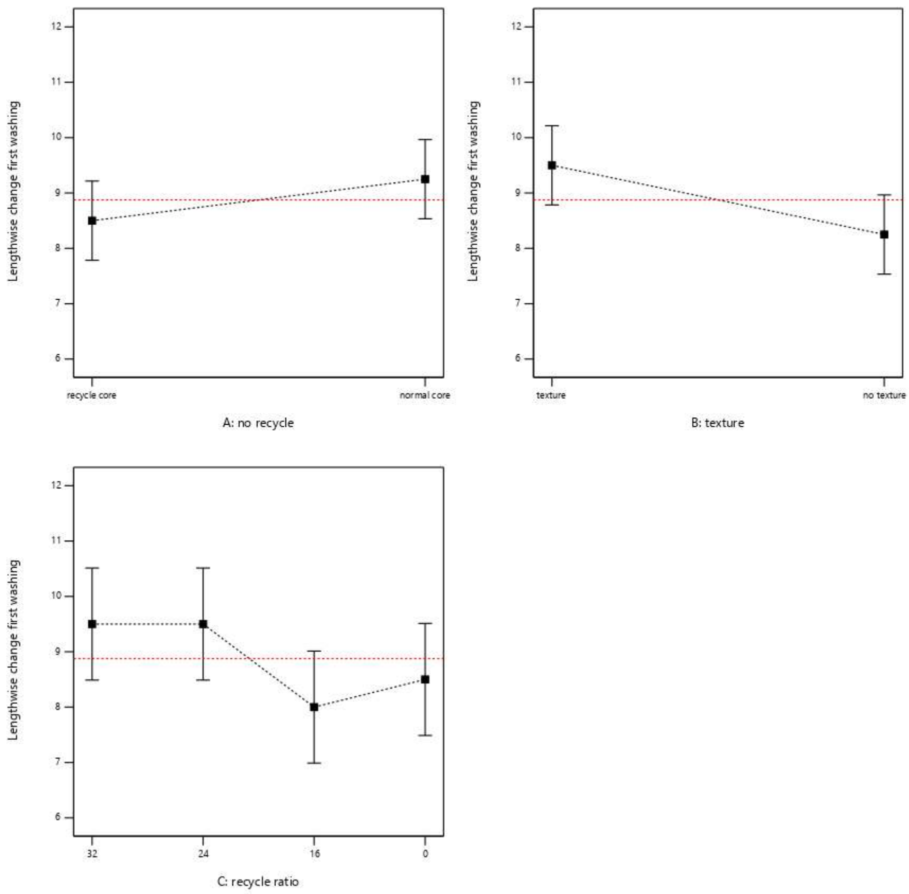
App. 11 Multiple graphical view visual of pilling.



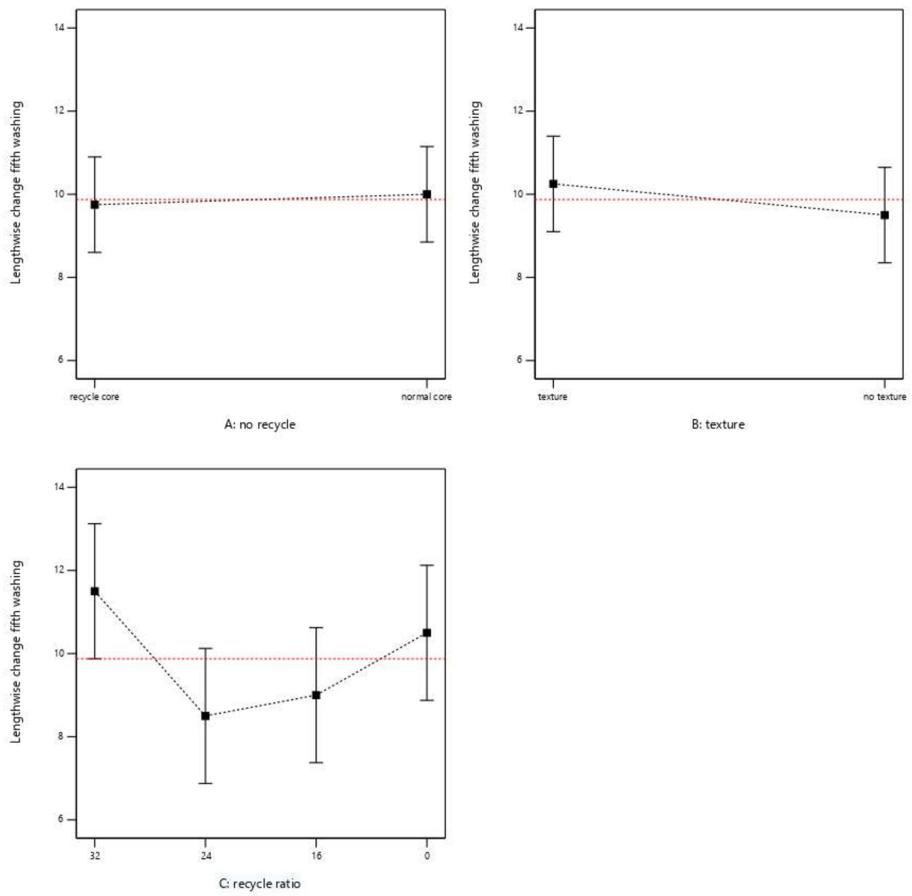
App. 12 Multiple graphical view visual of widthwise change first washing.



App. 13 Multiple graphical view visual of widthwise change fifth washing.



App. 14 Multiple graphical view visual of lengthwise change first washing.



App. 15 Multiple graphical view visual of lengthwise change fifth washing.

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Publications

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