GAZİANTEP UNIVERSITY GRADUATE
SCHOOL OF NATURAL &APPLIED SCIENCES

AN INVESTIGATION ABOUT THE PERFORMANCE OF CIRCULAR KNITTED FABRICS MANUFACTURED WITH POLYPROPYLENE CONTINUOUS FILAMENT YARNS

M.Sc. THESIS
IN
TEXTILE ENGINEERING

BY
TÜLİN KAYA
AUGUST 2006

An Investigation about the Performance of Circular Knitted Fabrics Manufactured with Polypropylene Continuous Filament Yarns

M.Sc. Thesis

in

Textile Engineering

University of Gaziantep

Supervisor

Inst. Dr. Fatma USKANER

by

Tülin KAYA

August 2006

T.C.

GAZIANTEP UNIVERSITY

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

TEXTILE ENGINEERING DEPARTMENT

Name of the thesis: An Investigation about the Performance of Circular Knitted Fabrics Manufactured with Polypropylene Continuous Filament Yarns.

Name of the student: Tülin KAYA

Exam Date: 15.08.2006

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Sadettin ÖZYAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science of Philosophy.

Assist. Prof. Dr. Mehmet TOPALBEKİROĞLU
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science of Philosophy.

Inst. Dr. Fatma USKANER
Supervisor

Examining Committee Members

Prof. Dr. Sedat BAYSEÇ ....

Prof. Dr. Osman BABAARSLAN ....

Assist. Prof. Dr. Nihat ÇELİK ....

Assist. Prof. Dr. Mehmet TOPALBEKİROĞLU ....

Inst. Dr. Fatma USKANER ....

ABSTRACT

AN INVESTIGATION ABOUT THE PERFORMANCE OF CIRCULAR KNITTED FABRICS MANUFACTURED WITH POLYPROPYLENE CONTINUOUS FILAMENT YARNS

KAYA, Tülin

M.Sc. in Textile Eng.

Supervisor: Inst. Dr. Fatma USKANER

August, 2006, 144 pages

Weft knitted fabrics are characterized by a flexible structure accompanied by a soft handle and drapes. They are mostly used in athletic wear and underwear. It is considered to combine the comfortability of the knitted fabric with the advantages of Polypropylene (PP) filament yarn. Therefore, an experimental work is performed to investigate the performance of polypropylene knitted fabrics manufactured by circular knitting technology.

In this experimental work, the performance tests (bursting strength, dimensional stability, pilling, snagging and skewness) were evaluated on knits from Polypropylene (PP) continuous filament yarns. The same performance tests on knits from cotton (CO), viscose (CV), acrylic (PAN) and polyester (PES) fibers were made to compare results of PP knits. Four different knitting types (s.jersey, ribana, lacoste and interlock) were used for investigation. In order to understand the statistical significance of the test results ANOVA was performed.

Our findings indicated that knits from PP continuous filament yarns have highest performance in bursting strength in tested samples. The hierarchies of knitting structure from strongest to weakest are interlock, s.jersey-ribana and lacoste. According to the Pearson correlation bursting strengths of samples are directly related with yarn strength and tightness factor. In this study, dimensional changes of samples are determined. Pilling results are given as photographs. Snagging grade of knits from PP continuous filament yarns is superior than same conditioned knits from PES continuous filament yarns. Test results show that for knits from PP multifilaments, skewness and unstable dimension problems occur because of knitting machines and distinct structures of knitting types.

Key Words: PP filament yarns, knitted structures, bursting strength, tightness factor, dimensional stability, skewness, snagging.

ÖZET

POLİPROPİLEN SÜREKLİ FİLAMENT İPLİKLERLE ÜRETİLEN YUVARLAK ÖRGÜ KUMAŞLARIN PERFORMANSI ÜZERİNE BİR ARAŞTIRMA

KAYA, Tülin

Yüksek Lisans Tezi, Tekstil Müh. Bölümü

Tez Yöneticisi: Öğr. Gör. Dr. Fatma USKANER

Ağustos, 2006, 144 sayfa

Örgü kumaşlar, esnek yapıları ile birlikte yumuşak tuşesi ve dökümlüğü ile karakterize edilirler. Bu yapılar en çok spor giysisi ve iç giyimde kullanılırlar. Örgü kumaşların rahatlığının polipropilen (PP) sürekli filament ipliklerin avantajları ile birleştirilmesi düşünülmüştür. Bu nedenle, yuvarlak örgü teknolojisi ile üretilen polipropilen örgü kumaşların performansını incelemek üzere deneysel bir çalışma gerçekleştirilmiştir.

Bu deneysel çalışmada, PP sürekli filament ile üretilmiş örgü kumaşların performans (patlama mukavemeti, boyutsal stabilite, bocuklaşma, ilmek çekmesi, verevlik ve dönme) testleri yapılmıştır. PP örgü sonuçlarını karşılaştırmak için aynı performans testleri pamuk (CO), viskon (CV), akrilik (PAN) ve poliester (PES) liflerinden üretilmiş örgü kumaşlar için de yapılmıştır. Çalışmada dört farklı örgü tipi (süprem, ribana, lakost ve interlok) kullanılmıştır. Test sonuçlarının istatistiksel önem derecesinin belirlenmesi için ANOVA uygulanmıştır.

Çalışma bulgularımız, PP sürekli filament ipliklerden yapılan örgü kumaşların, ölçülen numuneler içinde, patlama mukavemeti açısından en yüksek performansı sergileyen elyaf olduğunu göstermiştir. Örgü yapıları bakımından en mukavimden en zayıfa doğru sıralama; interlok, süprem-ribana ve lakostdur. Pearson korelasyon metoduna göre örneklerin patlama mukavemeti, iplik mukavemeti ve sıklık faktörü ile doğrudan bağlantılıdır. Bu çalışmada örneklerin boyutsal değişimleri tayin edilmiştir. Boncuklaşma dereceleri fotoğraflar olarak verilmiştir. PP sürekli filament ile örülmüş kumaşların ilmek çekme direnci aynı şartlarda örülmüş PES kumaşlardan daha iyidir. Deney sonuçları PP sürekli filamentlerden örülmüş yapılarda verevlik ve boyutsal değişimin örgü makinesi ve örgü yapısı kaynaklı olduğu kanısına varılmıştır.

Anahtar Kelimeler: PP sürekli filament iplikler, örgü türleri, patlama mukavemeti, sıkılık faktörü, boyutsal stabilite, verevlik, ilmek çekmesi.

ACKNOWLEDGMENTS

Love and praise be to God for enabling me to complete my thesis.

I would like to express my deepest gratitude to Prof. Dr. Osman BABAARSLAN for his invaluable advice and help for collection of references.

I would like to thank my supervisor Inst. Dr. Fatma USKANER for her continuous patience, invaluable advice and guidance in the preparation of this thesis. This work would not have been possible without her experience, knowledge and support.

I am gratefully to my boss Bilal KARA and my manager Aydın ABALI, Nusret YILDIRIM, Mustafa GÜLOĞLU, Refik TÜRKER from Knitting Department and Fadime KÖK from Quality Department of SELÇUK İPLİK SAN ve TİC A.Ş. for spending time with me to prepare my fabric samples for this study. I would like to thank to ÖZÇELIK TEXTILE MACH. A.Ş. for supporting to collect some PP and PES continuous filament yarn samples and USAM Textile Laboratory for testing of samples. Also, many thanks to my dearest friends Esin SARIOĞLU, Kübra KAYNAK, Huriser BALCI and H.İbrahim ÇELIK for their grand support, patient and sympathy during my thesis.

I wish to thank my friends, Emine SALCAN, Zehra CANTÜRK, Ayşe ÇELIK, Meltem ÖZDEMIR and UĞUR EREN for their words of encouragement.

Last, but not at least, I would like to express my sincere gratitude towards my parents Rukiye – Mehmet KAYA, my brothers & sisters for their patience, confidence and support for my higher education. I would like to thank my nieces & nephews for their invaluable support.

Without all of you, this degree would not be possible.

TABLE OF CONTENS

LIST OF FIGURES

LIST OF TABLES

ABREVIATIONS

1x1 rib	Ribana
BCF	Bulked continuous filaments
BRSTSTR	Bursting strength
CO	Cotton
CV	Viscose
D. T. Lacoste	Double tuck lacoste
EATP	European Association for Textile Polyolefin's
g/den - gpd	Gram per denier
HOY	Highly oriented yarn
HT viscose	High tenacity viscose
HVI	High volume instrument
L Loop	Left side of a loop
LFA	Absorbed yarn length per 100 courses
LL	Left-Left knitted structures
LOI	Limiting oxygen index
LOY	Low oriented yarn
MFI, MFR	Melt flow index, Melt flow ratio
MOY	Moderately oriented yarn
NPI, E	Needles per inch
PA	Polyamide
PAN	Polyacrylonitrile (Acrylic)
PES-PET	Polyester
POY	Pre-oriented yarn
PP	Polypropylene
Pus	Diameter of circular knitting machine
OE Rotor	Open End Rotor Spinning System
S.jersey	Single jersey
R Loop	Right side of a loop
RKM	Yarn strength as a function of km
RL	Right-Left knitted structures
RR	Right-Right knitted structures
Tg	Glass transition temperature

CHAPTER 1: INTRODUCTION

1.1 Introduction

Polypropylene (PP) was first produced in 1957 in Italy by Natta. When it meets the commercial uses, it was introduced as "a new cheaper and useful for every apparel" fiber. In 1970-75 it was used in commercial areas. Today, PP has been competitor of other man made fibers. And it does not as cheap as in the past.

PP fibers belong to the youngest generation of chemical fibers. The position of PP has become stronger compared to the other mostly used man made fibers. According to EATP (European Association for Textile Polyolefins) the share of PP fiber is 42,1 % in total man made fibers while the Nylon (PA) is 12,9% and acrylic (PAN) is 13,8%. The total consumption of PP in Europe is 2453 ktons. Staple fibers have place of 25,4% and multi filaments have 21,2% [1]. Total consumption of PP in the world estimated that 5000 ktons.

Polypropylene has many specifications that differentiate it from other natural or synthetic fibers;

- Environmentally safe
- Moisture transfer
- Quick drying
- Low specific gravity
- Thermal conductivity
- Chemically resistance to sweat, salt and chlorine
- Static resistance
- Odor resistance
- Colorfastness

- Abrasion resistance

These specifications given above permit polypropylene continuous filament yarn has wide textile applications. The main fields of application of PP fiber are apparel (active wear and sportswear, socks, thermal underwear, lining fabrics), automotive (interior fabrics), home furnishing (carpets, upholstery and wall coverings furniture and bedding contractions) and industrial (carpets, disposable, durable nonwovens, geotextiles) etc[2].

It is known that, polypropylene continuous filament yarn does not create any allergic reactions and it is very friendly to the skin. It is noted by the high color stability, low thermal conductivity and low specific weight. It is resistant to acids and alkalies as well as to oxidizing and reducing agents. It can not affected by microorganism and mould resistance. The fiber practically does not absorb any moisture; however it transports moisture very well, so the skin remains dry. For these reasons PP is very suitable for active wears, sports wears, socks, underwear and many other weft knitted fabrics.

The circular knitted fabrics are characterized by a flexible structure accompanied by a soft handle and drapes. This flexible structure is the result of the shape and mobility of the loops of yarn within the fabric structure. Such flexible structure also permits crease removal, easier launder and soil removal. Some areas of their application include socks, stockings, underwear, pullovers, jackets, blouses, suits, baby clothes, curtains, upholstery materials, artificial fur.

Some researchers have investigated the PP fibers in knitting [3-12]. According to their researches fabrics made from PP fibers are used for not only household textiles but also used for garments, sportswear and protective clothing. PP has relevant properties as density, capillary for moisture transport, biological resistance, chemical resistance, heat conductivity, tensile strength, thermal resistance, elasticity, hygroscopicity and water absorption capacity.

Finishing of knit fabrics containing PP yarns are washing and softening, centrifuging and water removal, wet stretching and draping or cutting, tension – free drying and calendaring or stabilizing [11].

An investigation combining the advantages of PP filament yarn with flexible circular knitted structures will give better insight to the use of PP fiber in knitting technological area. The aim of this thesis is to investigate the performance of knitted polypropylene fabrics manufactured by using weft knitting technology. Bursting strength, dimensional stability, pilling, snagging and skewness properties of knitted PP are examined. The produced four different knitted structures of PP fabrics are (s.jersey, ribana lacoste and interlock) compared with same type of knits from OE Rotor CO, Combed CO, Carded CO, Carded CV, OE Rotor PAN and PES continuous filament yarns.

In chapter two, literature survey of PP in knitting and performance tests are given. The production parameters of PP, their properties, advantages- disadvantages and other related literature are described. In the second part of this chapter other textile fibers which were used in this thesis are defined. In the third part of chapter two, knitting structures were reviewed. Properties of RL (s.jersey, lacoste) and RR (ribana, interlock) structures were discussed.

In chapter three; the samples that were used in this thesis are described. S.jersey, lacoste, ribana and interlock structures for OE Rotor CO, Combed CO, Carded CO, OE Rotor PAN and two different Delta shaped PP, Round shaped PP and Delta shaped PES samples are tested for determining the better sides of PP fibers. Totally 35 different knitted fabrics were tested for this experimental work. Bursting strength, dimensional stability, snagging, skewness and pilling testing methods are also given in chapter three.

In chapter four, results of the tests are given and discussed. According to the results of bursting strength, dimensional changes, pilling resistance, skewness values and snagging resistance of knits from PP continuous filament yarns were examined and discussed. Besides knits from PP continuous filament yarns, other types of fibers (CO, CV, PAN, and PES) and technologies (OE Rotor, Ring - Carded, Ring - Combed, Melt Spinning), the effect of tightness factor and washing process were also discussed in chapter four. The properties of knitting structures were compared each other. Graphical analyses of results were given. ANOVA statistical method was used for analyzing the test results.

Lastly in chapter five, conclusion drawn from experimental results and recommendations for further works are given.

CHAPTER 2: LITERATURE SURVEY

2.1 Polypropylene (PP) Fibers in Knitting

In the textile industry polypropylene fibers applications are very wide range because of relevant fiber properties such as density, capillarity for moisture transport, biological resistance, chemical resistance, heat conductivity, tensile strength, thermal resistance, elasticity, hygroscopicity, and water absorption capacity. In this section of literature survey, PP fibers in knitting are fall in the focus.

Chuang [5] studied about an elastic polypropylene wet suit fabric is made of fine count polypropylene fibers with fine denier counts. The elastic polypropylene wet suit fabric has a texture designed on the basis of elastic features and is kitted with a high speed circular knitting machine and then treated in a finishing process.

Gross [6] studied about the growth of textiles used in medical applications and its implications like as the mesh products which are slings to transport and to handle burn patients; hospital partitions such as cubicle curtains; cellular mesh blankets and blood filtration meshes of polypropylene.

Wan [8] and [20] reported that products with low shrinkage and good colorfastness properties led to a rapid development in knitting technology. Functional fabrics that offer moisture management, ultraviolet resistant, antimicrobial, soil release and wrinkle resistant properties can be achieved by using PP fibers.

Piller and Vicek [9] studied about polypropylene fibers have a pentalobal cross section that improves the water resistance and appearance properties of knit fabrics or carpets. The fibers are available in a fineness of 3.84 dtex and feature a tear strength of 3.39 cN/dtex, an elongation percentage of 53.2 % and a staple length of 60 millimeters. In their study, they used Mayer 18 E gauge circular knitting machines knit water resistant athletic apparel fabrics using 25 tex yarns made from PP fibers. Also they used, Terrot interlock circular knitting machines knit double sided tuck fabrics made from 100 % PP fibers. Other products include a knit fabric with an integrated hygienic layer, a plain knit fabric with maximum perspiration removal, and fabrics with high thermal insulation capacity.

Lam et al[10] examined an investigation into the tensile properties of weft knit thermoplastic textile composites. They take interlock knits manufactured from PES filament yarns reinforced with PP yarns.

Nielsen and Endrusick [12] examine that the role of knit structure in underwear on thermoregulatory responses. They used underwear manufactured from 100% PP fibres in five different knit structures. In their study, they measured the oxygen uptake, heart rate, skin temperature at the skin and in the ambient air, onset of sweating, evaporation rate, non evaporated sweat accumulated in the clothing and total evaporative loss of mass. Skin wetness was calculated. In their report of April 1989 [32], they monitored the dew point temperature at three skin sites. Onset of sweating was evaluated from dew point sensor records. They examine that the differences in knit structure of the underwear in clothing systems resulted in significant differences in mean skin temperature, local and average skin wetness, non-evaporated and evaporated sweat during the course of the intermittent exercise test and core temperature.

2.2. Knitted Fabric Properties

Knitted fabric properties in literature can be summarized as below:

a) **Bursting strength:** The tensile strength of knitted fabrics cannot accurately be measured by taking a strip and pulling on it because the fabric distorts considerably, as can be easily verified. These fabrics are therefore subjected to a 'bursting test' which avoids this effect.

Brushed knitted fabrics and resinated fabrics tend to have lower bursting strengths than the original fabric. For such fabrics it is necessary to indicate the minimum permissible level of bursting strength.

Knitted pocket linings are subject to much stress in use and provision is made for this by ensuring the fabric quality is about 400 kPa [52].

Candan et al. [79] stated that the knits from ring spun yarn posses more bursting strength than that of open end spun yarn.

Ertugrul and Nuray [80] reported that fabric weight, yarn breaking strength and elongation are major parameters that affect the bursting strength of knitted fabric.

Shahbaz et al. [81] stated that fabric strength reveal that the effect of machines and blending ratio is highly significant.

Kavuşturan et al. [82] stated that knitting structure significantly affected the bursting strength.

b) **Dimensional Stability:** Fabric shrinkage is a serious problem for knitwear, originating from dimensional changes in the fabric, particularly stitches. Shrinkage is a result of the combined effect of numerous factors such as relaxation, finishing, dyeing and effects of machinery. The significance of this problem has been investigated by several researchers who focused mainly on the geometry and dimensional relations of knitted structures [72].

The effect of relaxation steps on loop shape variation can be inferred from the ratio of courses/cm to wales/cm, which is defined as the loop shape factor. The variation is different for each knitting structure.

The knitting action started by a needle taking yarn form a supply package and forming a loop by pulling yarn down, the loop already on the needle slides over the new yarn and becomes part of knitted structure. The needle rises to receive new yarn to being a new cycle and has to leave yarn temporarily around the needle shank which is held firmly in place by applying a force to the fabric already being knitted (take down tension). The value of the take down tension depends on machine type and fabric structure, it is estimated in the range 15 to 25 grams per needle. At the point of loop formation a very high rapid stress is developed in the yarn. It has a value equivalent to load of 20 to 300 gram over a period of 0.005 sec. No permanent extension in the yarn is caused by this high stress over a short period. It is observed that not only the fabric has been extended along the vertical (wales) direction by take down tension, but extended in the width by "stretch board" which is used to extend the fabric along the courses. Knitted structures tend to change their dimensions as the take down tension and other forces are removed. This fact is very apparent if measurements to courses and wales per inch are made while fabric is on the knitting machine at time intervals after leaving the machine [73].

Onal [72] studied about effect of fabric characteristics and laundering to shrinkage of weft knitted fabrics. In his study, he decided that knit type and fabric tightness greatly influence fabric shrinkage. While length shrinkage is more than width shrinkage for pique fabric, the tendency is reversed for plain and fleecy knits. There is a reverse proportion between fabric tightness and direction of the fabric dimensional changes. Yarn type and fiber percentage significantly affected knitted fabric dimensional stability.

Some researchers like Gravas et al [68] and Ertugrul & Ucar [74] studied about the prediction of the shrinkage of the knitted fabrics. Most of the problems encountered in the knitting industry are concerned with variations in dimensions which directly affects the fabric weight.

Filament yarns produce stronger and smoother fabrics. The serviceability and durability of a fabric are also not necessarily determined by the length of the staple alone because fibers and blends differ in their ability to dimensional stability.

Kugler et al. [75] studied about the determination of shrinkage behaviour of synthetic filament yarns by tensile tests. In their approach they studied on PA and PES. They showed that with the help of the tensile strength determinations alternatively dimensional chances can also be obtained if the information content of the force-elongation curves and their derivatives is utilized.

c) **Pilling:** The pilling of textile fabrics is very complex property because it is affected by many factors such as type of fiber or blends, fiber dimensions, yarn and fabric constructions and fabric finishing treatments.

Pilling is a characteristic of fabrics made from spun yarns. Fabrics containing fibers such as acrylic, nylon, or polyester have a tendency to pill. Abrasion from normal wear and cleaning causes the fibers to unravel and the loose ends ball up on the fabric surface. Natural fibers like cotton, linen, or wool may also pill at times, but the balls of fibers are usually removed during laundering.

When short staple fibers are used in the formation of yarns, the degree of twist is another important factor. Tightly twisted yarns composed of short staple fibers are considered more secure than loosely twisted yarns composed of short staple fibers. Usually the higher twist of the individual fibers, more securely they are too bound and are less likely they are to pill.

Candan and Onal [83] examine that the 100 %CO samples knitted from ring spun yarns tend to have lower pilling rates than those constructed from the 100% CO OE Rotor spun yarns. This may be due to the ring spun yarns are hairier than the OE Rotor spun yarns. Knit from blend yarns tend to have a greater tendency to pill than knits from 100 % CO OE Rotor yarns. Lacoste structure has the highest resistance to pilling while single jersey fabrics have the lowest pilling rates.

Besides all this properties, it is very important to understand the mechanical response of fabrics under deformation since their aesthetic properties and performance are directly related to their mechanical properties such as tensile, bending and shear. Uçar [84] studied about mechanical behavior of knitted fabrics under bending and shear deformation. In his study, he stated that an increase in tightness factor leads to an increase in bending and shear parameters. An increase in the tightness factor results in an increase in inner friction and compression. Another general trend is that the improvements in relaxation with wash and dry treatment. This relaxation leads to an increase in bending and shear parameters. This may be due to the fact that the wash and dry treatment increases the fabric density.

d) **Snagging:** Knitted fabrics composed of textured continuous filament yarn is particularly liable to snag in use. Snagging means that catching of a thread on a point or rough surface, so that a short length is pulled out, forming an unsightly loop on the surface, while the adjacent part of the thread is pulled tight and shows as a shiny line in the fabric. Fabric snagging is a serious problem for outerwear [52].

The susceptibility of the fabric to snagging depends on the yarn type, knitted structure and fabric finish treatment.

There are five hierarchical grading from 1 to 5 to establish degree of snagging on knitted structure. Ratings greater than grade three are normally required unless a higher minimum grade of four is required to meet special needs as for some trousers fabrics [52].

e) **Skewness:** A fabric condition resulting when filling yarns or knitted courses are angularly displaced from a line perpendicular to the edge or side of the fabric [76].

Conrad et al [77] studied about the effect of laundering on the distortion of %100 CO knitted fabric. They stated that there was a significant difference between the s.jersey, ribana and lacoste structures. S.jersey showed the highest percentage of (8,1) skewness due to unbalanced nature of the structure. They noticed that the drying conditions have also important affect on skewness.

Çeken et al. [78] investigated the spirality on s.jersey fabrics and its effects on garments. They use three different loop lengths as OE Rotor and ring spun yarn. They used three relaxation situations as rinsing, dry and wet treatment. In their approach, they measure the spirality angle and its effect on the garment. They stated that fabrics made from ring yarn had more spirality tendency than the fabrics produce from OE Rotor yarn. Loop length is significantly affected on spirality.

Meriç and Demirhan [97] studied about the dimensional changes and skewness values of garments. They stated that 0,5 % and no more skew occurred in the blends of synthetic fibers.

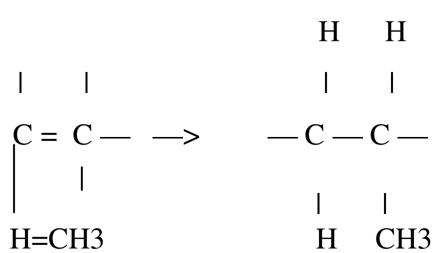
Nielson and Endrusick [85] studied the influence of underwear knit structures on physical activities and clothing structure on various sensations related to temperature and moisture. They reported that skin wetness contributes to sensation of dampness that is related to the amount of accumulated sweat in clothing.

Yeung et al. [86] examined about mathematical simulation of the perception of fabric thermal and moisture sensations. They stated that the perception of thermal and moisture sensations during the skin-fabric contact is predictable on the basis of the number of mechanisms; fiber moisture absorption and coupled heat and moisture transfer in fabrics.

Matic and Leigh [87] studied about mechanical properties of micro fiber blended knitted fabrics. In their concept, they used the microfibers and their blends with natural fibers to produce knit fabrics performance, dimensional stability and improved aesthetic characteristics.

2.3 Polypropylene

Polypropylene (PP) was first produced in Italy in 1957. USA production began in 1962. Polypropylene is made from a raw material, propylene, which is a byproduct from the cracking process in the petroleum industry. The famous way of manufacturing polypropylene is polymerization in the presence of Ziegler-Natta catalyst like titanium tetrachloride (TiCl4) in the petrochemical industry [13, 14].



Propylene Polypropylene

Figure 2.1. Ziegler –Natta polymerization [14]

Polypropylene fiber is manufactured fiber in which the fiber – forming substance is long-chain synthetic polymer composed of at least 85% of propylene (by weight) [15]. Isotactic PP is only used for fiber production [13,15]. Polypropylene is one of the members of the olefin fiber family. The other famous one is polyethylene. Since 1950s (introduction of polypropylene into the textile industry) the list of successful products and markets for polypropylene fiber has increased exponentially.

Polypropylene is one of the most successful commodity synthetic polymers, with world production capacity reaching 5 million tones a year including continuous and staple yarn. In volume terms, polypropylene fiber takes the fourth place after polyester, polyamide and acrylic fibers. PP is widely used in many applications because of its low density (0.905 g/cm^3), high crystallinity as well as its high stiffness and hardness [16].

Polypropylene fiber is a long chain of synthetic polymer composed of stereoregular isotactic polymer. Polypropylene fiber/filament possesses all the outstanding properties associated with the polypropylene polymer. It has high tensile strength, wrinkle resistance and abrasion resistance. Due to its unique feature of lowest moisture absorption amongst other textile fibers it offers desired comfort for undergarments use and is used for hosiery and knit wears.

Polypropylene yarn is the highest performance fiber compared to other synthetic and natural fibers. This raw material consists exclusively of carbon and hydrogen and is considered environmentally friendly.

PA, PES, PP and aramid are the fibers with the highest tensile strength and with the excellent abrasion resistance. Thus the most popular performance fibers currently used for durability in knitted performance fabrics are PES, PA, PP or their blends.

2.3.1 Yarn Production of PP

Polypropylene (PP) is becoming increasingly prominent within the family of polymer materials for fiber spinning. The results of the polymer and process developments over the past years have placed PP in an extremely competitive position compared to other man-made fibers. The high rate of growth of PP fibers is not only due to economic reasons, but also due to fiber properties; such as easy processability, excellent melt dyeability, good insulating rating, no moisture absorption and excellent wicking effect. If we are looking to the market for PP fiber products, four main different product groups can be identified:

1) Multifilaments;
2) Staple fibers;
3) Film tapes and fibrillated yarns;
4) Spunbonded fabrics

Multifilament yarns are produced according to the desired properties as;

- pre-oriented yarns (POY),
- fully drawn yarns (FDY)
- bulked continuous filaments (BCF)

2.3.2 Melt Spinning of PP

Polypropylene filament and fiber are manufactured from polypropylene chips by melt spinning process.

A schematic view of a melt spinning process is given in Figure 2.2. Polymer, in the form of pellets or granules, is fed into an extruder, where it is melted and pumped via a positive displacement pump to the melt spin pack. The spin pack consists of filters and channels that supply molten polymer to holes of spinneret. The molten filaments that exit the spinneret enter a cooling zone which cools and solidifies the filaments. In addition to being cooled and solidified, the molten filaments exiting the spinneret are simultaneously drawn down to a smaller cross--sectional area by the application of a drawdown force. This force is applied by action of a godet which controls the final linear velocity, or take-up velocity, of the spinning filaments. The take-up process is largely dependent upon the end use of the polymer filaments. In the case of yarn production, the multifilament yarn is usually wound onto a bobbin or sent directly to a drawing and/or texturing process [18,17,30].

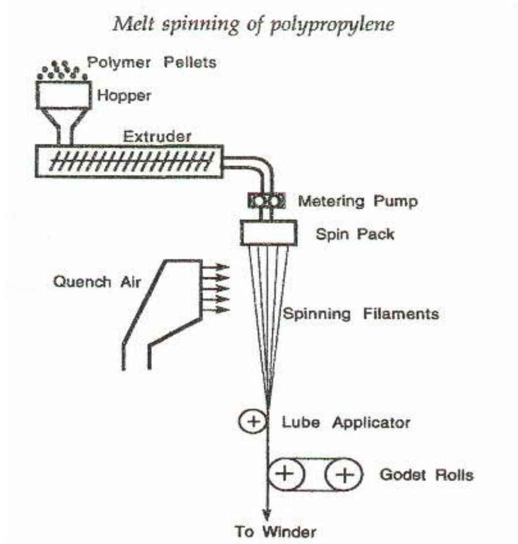


Figure 2.2 Schematic of the Melt Spinning Process.

The following conceptions are important parameters for melt spinning process and final product;

- take-up velocity[18,19],
- length of the spinline [18,19],
- cooling conditions along the spinline [18,19,30],
- extrusion temperature [18],
- mass throughput per spinneret orifice [18],
- size and shape of the spinneret holes [18,20].

2.3.4 Fiber Structure

In contrast to linear polyamides and polyesters, PP may be processed to form fibers over a wide range of molecular weight (M). The molecular weights are approximately between 80000 and 300000 g/mol which correspond to melt flow index (MFI) approximately from 30-35g/10min to 5.0-6.0g/10min [15].

PP resins are generally categorized according to their melt flow rates (MFR) [?] (melt flow index – MFI) [21], which is the amount of material that passes through a standard die whole for ten minutes. Polymers with higher molecular weight have lower MFR and higher viscosity (under a given temperature). Commercial polypropylene has a wide range of MFR from 0.25 to 800. PP melts exhibit non--Newtonian viscosity, normal stress in shear flow, excessive entrance and exit pressure drop, die swell, melt fracture and draw resonance. PP melts are more visco-elastic than PET and nylon melts.

The melt flow indexes suitable for PP fibre production are;

10-18 for high tenacity yarn

18-35 for normal tenacity, flat yarn

35-40 for POY

2.3.5. Cross – Sections of PP

Fiber cross sections for use in textiles and composites are becoming more and more complex. Cross-sectional shape affects filament properties and therefore the yarn and fabric characteristics.

Today, round fiber cross section is the most common shape manufactured by synthetic fiber producers. Other shapes are beginning to emerge for variety of reasons; performance, comfort, pilling properties, bulkiness, tactility, processing, etc. [22].

Polypropylene filament are generally produced in 5 mainly cross-sections;

a) Round,
b) Delta,
c) Hollow
d) Trilobal and Multilobal
e) Combined type

2.3.5.1 Round Type

This type is the most common production type. The vast majority of fibers are extruded through circular spinneret holes and hence the fibre cross sections are circular. Figure 2.3 illustrates the round shape.

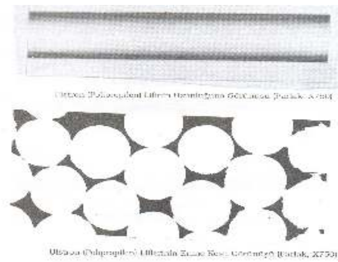


Figure 2.3. Round Cross-Section of PP [23]

2.3.5.2 Delta

The reflective surfaces can also give the fiber a sparkling appearance. The delta shaped filaments may be used to produce fibres with a modified handle compared to normal circular fibres. A more silk like handle could be expected in fine count filaments. Figure 2.4 illustrates the delta shape.

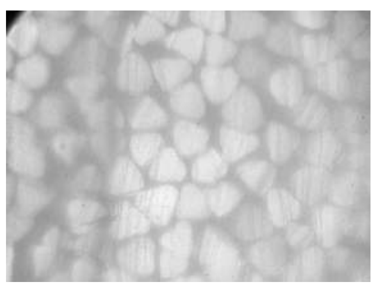


Figure 2.4. Delta Cross-Section of PP

2.3.5.3 Hollow

Hollow shapes whether circular or triangular are used to produce fibres with greater bulk for a given mass and hence good thermal insulation in wadding.

Hollow cross section polypropylene yarn, has at least one hollow void enclosed within the fiber and running the entire length of the fiber. Reference 8 uses PP hollow fiber in their knitting products. PP hollow fiber having 20% hollow percentage and specific gravity of 0,73 g/cm^3 are generally used for thermal wear, underwear and swimwear[20]. Figure 2.5 illustrates the hollow shape.

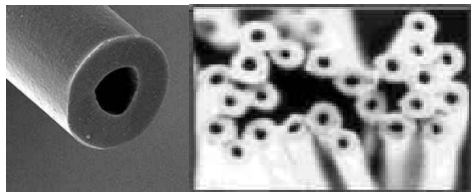


Figure 2.5 Hollow Cross-Section of PP [20]

2.3.5.4 Trilobal and Multilobal

This highly modified cross section was created for moisture transport, using capillary wicking in its many grooves. It is the most effective moisture transport fiber commercially available.

The variants of Y shaped spinnerets that can be used to produce trilobal filaments. These can be used in yarns for knitwear to give a glittery appearance but more often in carpets for their soil hiding ability and their greater stiffness and hence resilience as compared to normal cylindrical filaments. Figure 2.6 illustrates the multilobal shape.

Figure 2.6. Multilobal Cross-Section of PP [20]

2.3.5.5 Combined Type

Cross section combined with hollow section and multilobal section can be seen in the Figure 2.7[20]. This type of filaments has excellent properties such as moisture transfer, quick dry, heat retention, anti-bacterial, odor removal, optical whitening, UV-cut, etc [20]. Figure 2.7 illustrates the combined type of cross section.

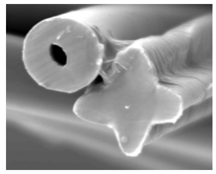


Figure 2.7. Combined Cross-Section of PP [20]

2.3.6 Properties of PP

Polypropylene has many specifications that differentiate it from other natural or synthetic fibers:

- Environmentally safe
- Moisture transfer
- Quick Drying
- Lightweight - low specific gravity
- Thermal conductivity
- Chemically resistant to sweat, salt, and chlorine
- Static-resistant
- Odor-resistant
- Colorfastness
- Abrasion-resistant
- Able to give good bulk and cover
- Thermally bondable
- Stain and soil resistant
- Sunlight resistant
- Bacteria, mold resistant
- Very comfortable [2]

2.3.6.1 Physical Properties

The general physical properties of PP fibers are shown in Table 2.1. Polypropylene fibers are produced in a variety of types with different tenacities designed to suit varying market requirements. Fibers for general textile uses have tenacities in the range of 4.5-6.0 g/den. High tenacity yarns up to 9.0 g/den are produced for the use in ropes, nets and other similar applications. High performance

PP fibers have been made with high strength and high modulus. The techniques include ultra-drawing, solid-state extrusion and crystal surface growth. The filaments with tenacities over 13.0 g/den can be made.

Table 2.1 Physical properties of Polypropylene [13,17]

Moisture Regain	<0.1%
Refractive Index	1.49
Thermal Conductivity	0.15 W/m°C
Coefficient of linear thermal expansion	$4.0x10^{-5}$/F
Heat of fusion	2.1 kJxkg
Specific heat	0.46 cal/g°C
Density of Melt at 180°c	0.769 g/cm³
Heat of Combustion	19,400 Btu/lb
Oxygen index	17.4
Decomposition temperature range	328-410°C

Mechanical properties of PP filaments are affected from the degree of orientation achieved by drawing. For PP fibers, the degree of stretch increases, tensile strength increases and vise versa. This situation is illustrated in Figure 2.8. Commercial PP mono filaments have an elongation-at-break in the range of 12-25%. Multifilaments and staple fibers are in the range of 20-30% and 20-35%, respectively.

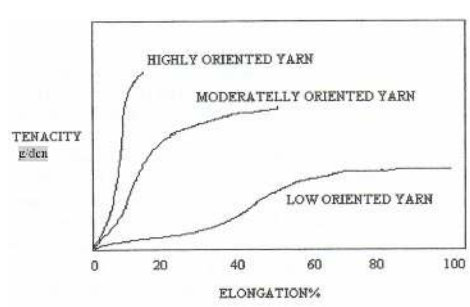


Figure 2.8.Relationship between Mechanical Property and Stretching of PP Fibers

The stress – strain characteristics of other textile fibers can be seen in Figure

2.9 [25].

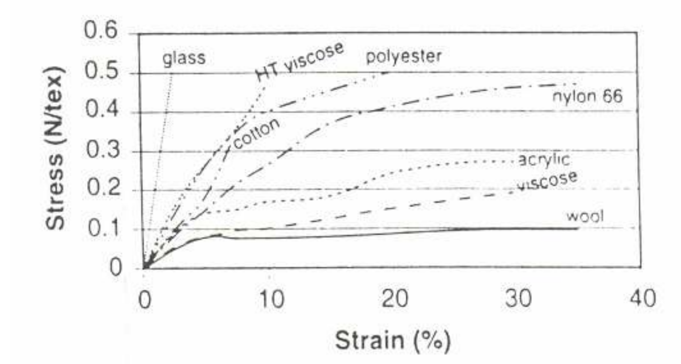


Figure 2.9. Stress-Strain Characteristics of Textile Fibres [25]

PP yarns are generally used in modified form such as texturized yarn or various cross-sectional shapes. According to Jambrich and Hodul [26], some basic properties (such as permeability, water vapor permeability, thermal resistance) of integrated PP/CO textiles increases as compared with CO properties.

2.3.6.1.1 Moisture Regain

PP is the least absorbent of the textile fibers. Moisture moves in the vapor stage to the outside of the knits from PP yarns. Also, knits from PP yarns never hold any moisture. An added benefit is the breathability of PP. The moisture moves away from the skin in the vapor stage, before it has condensed on the skin [20,27]. Condensation on the skin gives rise to a feeling of clamminess. Figure 2.10 illustrates low moisture absorption of PP which helps the quick transport of moisture.

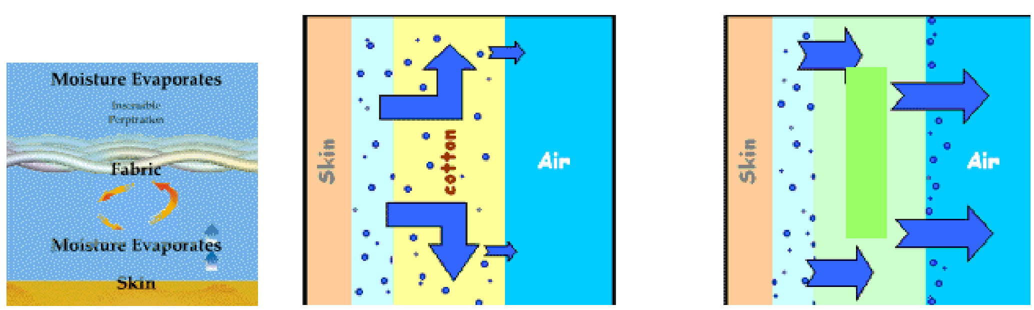


Figure 2.10. Moisture Evaporation [20]

Drying time of PP is minimal because of low moisture regain property.

Nielsen and Endrusick [28] studied about alternate work/rest had a significant influence on all temperature and humidity sensation of the body of the skin – clothing interface and of the environment. In their research they used underwear manufactured from %100 PP fibres in five different knit structures. Prototype clothing samples are produced from these knitted structures and tested. Knit structures of the underwear influenced sensations of humidity significantly but not sensation of temperature. The various sensation of temperature correlated best with core temperature whereas the sensation of humidity correlated with skin wetness.

2.3.6.1.2 Density

PP is widely used in many applications because of its low density (0.905g/cm^3), high crystallinity as well as its high stiffness and hardness [16]. In Table 2.2 specific gravity values of some textile fibers can be seen.

Table 2.2. Specific gravity values of some textile fibers [29]

Fiber type	Specific gravity (g/cm^3)
Cotton	1,54
Viscose	1,52
Nylon 6	1,14
Nylon 6,6	1,14
Polyester	1,38
Aramid	1,44
Glass	2,54
Polypropylene	0,91

PP is the lightest of all apparel fibers and is lighter than water. It is 30% lighter than polyester, and 20% lighter than nylon. Regardless of the activity, weight saving means energy saving and as a result improve performance. You get more bulk and warmth for less weight [20].

2.3.6.1.3 Thermal Conductivity

PP possesses the lowest thermal conductivity (0.15 W/mºC) of all natural or man made fibers. This means that more heat is retained for a longer length of time. In this respect, it is the warmest fiber of all. The thermal conductivity of common textile fibers is shown in Table 2.3 [31].

Table 2.3. Thermal Conductivity of textile fibers (comparison to air)

Material	Thermal Conductivity
Air	1.0
PP	6.0
Wool	6.4
Acetate	8.6
Viscose	11
Cotton	17.0

2.3.6.2 Thermal Properties

Polypropylene fibers have a softening point in the region of 150°C and a melting point at 160-170°C. At temperatures of 70°C, PP fibers retain their excellent flexibility. At higher temperature (but below 120°C) PP fibers nearly remain their normal mechanical properties [13]. PP is brittle below -15°C and this temperature is known as glass transition temperature.

2.3.6.3 Other Properties

2.3.6.3.1 Odor Resistant

Bacteria, mold and mildew can not grow on PP, and will not damage the fiber. A garment that is washed regularly in hot or warm water with detergent will not retain body odors. Machine wash warm or hot, and hang dry or low tumble dry is suitable for users.

2.3.6.3.2 Abrasion Resistant

PP is a durable fiber, and will withstand a lot of wear and tear. This will help preserve those pressure points where clothing tends to wear.

2.3.6.3.3 Color Fastness

PP is precolored during the melt spinning process so the color in the fiber is part of the fiber itself. PP will hold color longer than other fibers. Color durability is so high as no pale occurs during outdoor activities, washing or wear and tear on garment.

2.3.6.3.4 Dyeability

Baumann [33] investigated fiber modifications to make polypropylene dyeable. Its research includes copolymerization to provide dyestuffs along the macro molecular chain and blend with dyeable polymers. He has reviewed the attempts by several researchers to improve polypropylene dyeability.

Fan et al [34] studied about dyeability of PP. They applied to nanoparticles to PP resin. Moreover, since nanoparticles can be dispersed into the polymer melts like pigments, nanocomposite PP can be spun using current polymerization and extrusion equipment.

2.3.6.3.5 Chemically Resistant

In general, PP fiber has excellent chemical resistance to acids and alkalis, high abrasion resistance and resistance to insects and pests. PP fiber is also easy to process and inexpensive compared to other synthetic fibers.

2.3.6.3.6 Fire Protection

PP is a combustible material. It ignites spontaneously at about 360 ºC and can be ignited at around 345 ºC. It burns with a faint luminous flame that melts and produces droplets that have the potential to spread the fire [35]. Limiting oxygen index of PP is 18%. Reducing the flammability is still an essential primary fire safety consideration [25].

Zhang and Shields [24] studied about fire hazard with polypropylene. In their study they provided proof that PP is an inherently flammable material and therefore flame retardant treatment of the polymer is an essential consideration in relation to fire safety.

2.3.6.3.7 Bacteria, Mold Resistant

Polypropylene is a safe, non-toxic agent. It is able to bring new levels of hygiene and freshness to both commercial and domestic environments by eliminating bacteria and fighting those fungal processes which create unpleasant odors. Additionally; by combating dust mites, it assists in preventing allergy problems, respiratory tract disorders and asthma. It is also reduce the spread of infection by preventing the growth of bacteria such as Salmonella, Bacillus and Staphylococcus [36,37].

Finishing treatments of polypropylene are given on the stage of melt spinning so it can not affected by laundering [37]. In Figure 2.11 microorganism colonies on any textile surface can be seen.

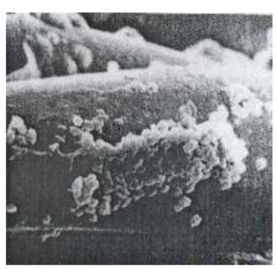


Figure 2.11. Microorganism colonies on a textile surface

2.3.7 Advantages & Disadvantages of PP Fibers

Polypropylene has been the most favorite textile fiber in the last 20 years. Its main advantages are; lowest thermal conductivity, lowest density, abrasion resistance, chemical resistance, low surface tension, mold and stain resistance, stain and soil resistance, convenience for skin and cost effective production.

Despite the PP's advantages it has got some drawbacks [13,31].

a) Low melting temperature which prevents it from being ironed like cotton, wool, nylon etc.,
b) Hard to be dyed after manufacturing, except after substantial treatment and modification,
c) High crystallinity and poor thermal conductivity leads to limited texturizability. [Drawn polypropylene requires a contact time of 2 seconds in the heater compared to PET (POY) which requires only 0.4 seconds]
d) Poor UV and thermal stability which requires addition of expensive UV stabilizers and antioxidants to overcome this problem,
e) Poor resilience compared to PET and Nylon,
f) Creeping due to its low Tg(-15 to -20°C),
g) Poor adhesion to glues and latex,
h) Flammable which melts and burns like wax.

2.3.8 PP Market in Europe & Turkey

The information given below is a unique analysis of the situation and the evolution of polyolefin fibres and textiles in Europe, issued by EATP – the European Association for Textile Polyolefins. The analysis is extended to Europe, covering 25 Member States of Europe, Norway, Iceland, Switzerland and Turkey. Special attention is given to Turkey because of its exceptional performance in polyolefin textiles. The study maintains the traditional split between Western Europe, Central Europe and Turkey, illustrating the different trends in these three areas [1].

Polyolefin textiles are by far the leading materials for textiles in Europe; more than 42 % of all man-made materials used for textiles. Total European polyolefin consumption in fibres and textiles exceeds 2.5 million tonnes. The growth rates in the three areas of Europe were very different, in Western Europe a modest 1.1 %, in Central Europe 5.5 % and in Turkey 8.6 %. The total growth on average is 2.6 % in PP textile applications.

The highest growth rate (7 %) is seen in spunbonding and meltblown applications with 504000 tonnes consumed. PP consumption as multifilament is 521 ktonnes 21,2 % and staple fibres 622 ktonnes 25,4% [1].

Overall, the carpet industry continues to grow and has reached a volume of 636 ktonnes, and is by far the largest end-use for PP fibres and textiles. Central Europe (the 10 new EU members) and Turkey consume together 608 ktonnes PP for textiles and fibres.

EATP, European Association for Textile Polyolefins, is the representative body for companies producing polymers, fibres and textiles made from polypropylene and polyethylene. The main products of the industry are floor coverings (carpets, rugs, carpet backing), bulk containers and sacks for transporting a huge variety of products, a vast range of technical fabrics for industrial use (filters, geotextiles, agrotextiles etc) and fibres used in nonwoven industry. European output of polyolefin textiles exceeds €3 billion per year [1].

In Turkey, especially in Gaziantep, PP production is significantly becoming widespread. [38]. In Table 2.4 the profile of PP fiber and yarn in Turkey can be seen.

Table 2.4. The Profile of PP Fiber and Yarn in Turkey [38]

The Profile of Polyproplen Fiber And Yarn in Turkey (Tons)

	1997	1998	1999	2000	2001	2002	2003 Estimated
PP Fiber Capacity			30.000	35.000	35.000	45.000	45.000
PP Yarn Capacity			155.000	180.000	180.000	205.000	225.000
PP Fiber Production			25.000	32.000	22.000	25.000	38.000
PP Yarn Production			140.000	162.000	130.000	160.000	180.000
PP Fiber İmportation	2.000	2.000	3.000	2.000	2.200	2.200	
PP Yarn Importation	3.000	5.200	1.500	2.900	2.600	3.700	
PP Fiber Exportation	10	80	60	250	180	130	
PP Yarn Exportation	1.600	7.000	1.500	7.500	12.000	14.000	
PP Fiber Domestic Consumption	7.000	6.000	4.200	6.000	3.000	2.400	
PP Yarn Domestic Consumption	55.000	47.000	43.000	54.000	43.000	57.000	

2.4 Spun and Filament Yarn

The type of used yarn can influence the desired fabric characteristics such as fabric comfort, strength and luster. Spun yarns are composed of staple fibers held together by some binding mechanism. There are three main types for short staple spinning method; ring, OE Rotor and air-jet.

Staple fiber yarns can be produced from natural fibers as well as from chemical fibers cut to staple length. In contrast to chemical fibers which can be manufactured industrially in almost every desirable length and shape the various natural fibers are available only in specific lengths, titers and cross – sections and with certain crimp and stress-strain behaviour depending on their type and origin.

In general, fabrics produced from filaments are stronger, smoother and more serviceable (as a comparison of durable yarns made from short staple fibers). The serviceability and durability of a fabric are also not necessarily determined by the length of the staple alone because fibers and blends differ in their ability to resist tearing [39].

The construction of the fabric can also affect the durability of a fabric. One characteristic associated with knitted fabrics is that they may exhibit elongation tendencies, which may or may not be desirable. The quality of a knitted garment is mostly based on its ability to maintain its shape and minimize elongation [39].

In knits, tightly knitted constructions, produced on fine gauge knitting machines, provide the most durable knitted fabrics.

In this experimental work, spun and filament yarns are used. Cotton, viscose and acrylic are spun yarns and PES & PP are filament yarns. The general properties of these fibers in literature are given in Table 2.5.

Table 2.5. Fiber Properties [40,41]

Fiber	Code	Density g/cm^3	Moist. 65% R.H. 20°C %	Melting temp. °C	Cont. expos. temp°C	Glass tr.temp°C	LOI %	Tenacity (gpd)	acid	alkali	org solvant	Hydrolysis
Cotton	CO	1.52-1.54	7-11	decomp. (400)	80	-		2,6-4,3	-	o	+	+
Polyacrylic	PAN	1.18	1-2	330	120		18	2,5-5,0	+	-	+	
Polyester	PET	1.38	0.2-0.5	250-265	150	80	20-22	4,5-5,5	+	-	o	-
Polypropylene	PP	0.91	0.04	160-175	90	-15	18	4-5	+	+	+	
Viscose	CV	1.52	11-14	decomp. (175-205)		-		2,0	-	o	+	+

+ = good - = fair o = poor

According to excellent and durable properties of PP continuous filament yarns, an idea of research on PP continuous filament yarns was occurred. In literature generally, thermal properties of PP fibers are emphasized. Therefore, properties of PP continuous filament yarns may be combined properties of circular knitting. For this experimental work, from this page literature of circular knitting was reviewed.

2.5 Knitting

The concept of the making of fabric on more than one needle by interlooping a thread or several parallel threads is known as knitting [42].

The art of hand knitting has been practiced since thousands of years. How this art was learnt by ancient human is still a mystery and so is the country and time of its origin. The present knitting industry is based on the invention of William Lee, who succeeded in the mechanization of the interlooping of yarns four hundred years ago [43,44].

In the 19th century power was applied to the knitting machines and simultaneously circular knitting machines appeared on the scene. A marked development in this technology has taken place over the last fifty years. Developments in the 20th century increased the production speeds of the machines and offered wide pattern of knitted fabrics. Now computer controlled knitting machines have come on the scene, which are highly versatile. Knitted garments have now become every day dress.

2.5.1 Knittability

Knitting process depends on knittability of a yarn. Knapton [45] described knitting performance as knittability. Knittability is defined as the case with which the yarn can be knitted into a fabric at a given loop length. Lawson [46] mentioned that "probably knittability is the most surprising property which we don't measure directly". Pietikainen [47] suggested that knittability should be divided into three groups. The first group would include factors affecting the running of the yarn from the package to the feeder, the way in which the yarn is guided, the elements guiding the yarn, and the yarn variables. The second group would include factors affecting knitting performance, i.e., yarn, knitting machine, and fabric properties. The third group would include yarn faults that do not affect knitting performance.

Ideally, the knitting performance of a yarn should be assessed by knitting it under carefully controlled conditions, similar to those prevailing in industry, and then counting the number of yarn breaks (holes in the fabric) that can be specifically attributed to the physical properties of the yarn. Robinson et al. [48] stated that various machine settings have important effects on the knitting performance of pure wool yarns. High fabric tightness results in a relatively large number of breaks.

Sasaki and Kuroda [49] stated that there were many factors affecting knittability, such as resistance to yarn unwinding out of a cone, yarn to yarn friction, yarn to needle friction, yarn bending moment, yarn tensile strength and elongation, yarn elasticity modulus, and yarn evenness.

Some researchers like Hu and Zhu [50] investigated the knittability of high modulus glass filament yarns.

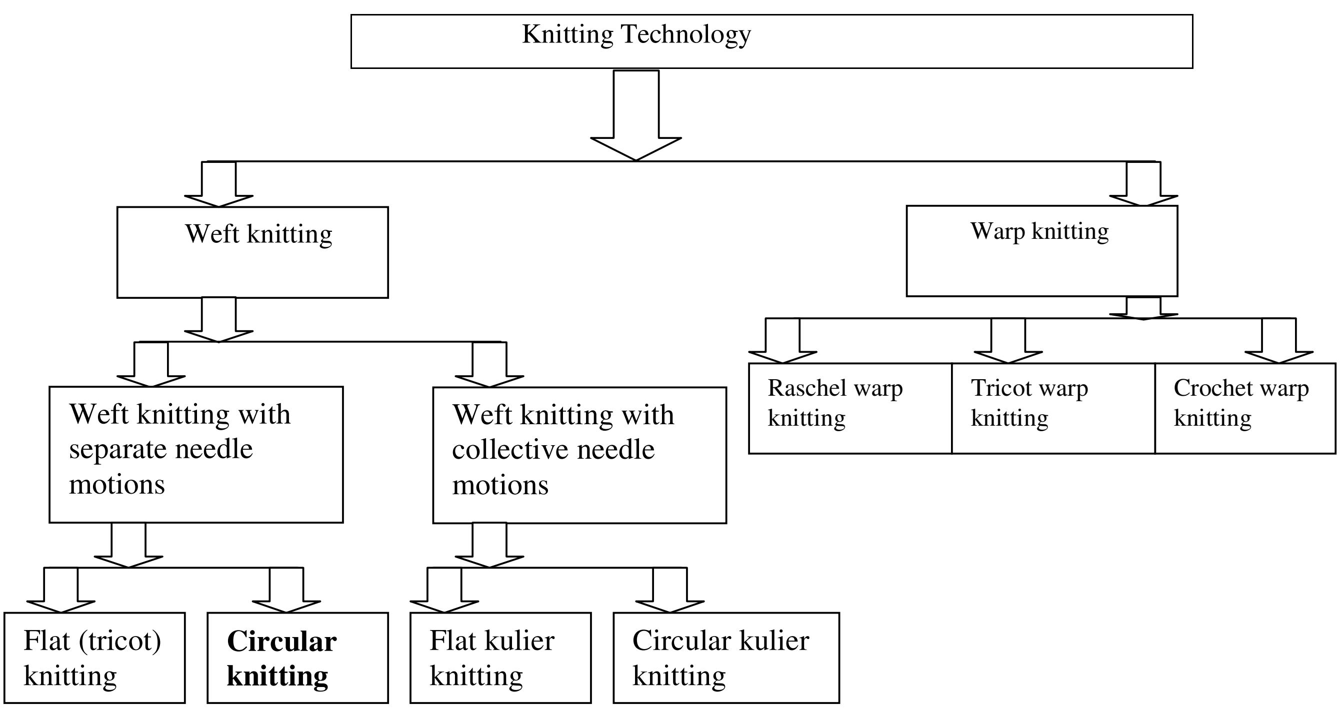
Marmaralı and Dönmez [51] studied about a model for prediction knittability of a yarn. In their study, they attempted to determine the knittability of a yarn before knitting. Thirty different yarns were knitted into 1x1 ribana structures with three different loop length values. The knitting process was observed and the number of machine stops, yarn breaks and holes were recorded. The percent correction value of prediction to knit fabric easily is very high (96,2%). A binary logistic regression analysis is used to indicate knittability depending on the yarn to needle and yarn to yarn friction values, the machine tightness factor and machine speed.

Several researchers have investigated the knittability of high modulus yarns or filaments. According to their investigations, the knittability of a yarn depends on its strength (both tensile and bending) and frictional properties. In order to knit a high modulus yarn efficiently, good yarn input tension control required. At the same time, the take down tension, stitch cam setting, machine speed and yarn lubrication conditions also influence knittability. Besides this, fabric geometry and physical properties and their relationships with cam settings are important parameters [50].

2.5.3 Knitting Technology

The production of fabric with knitting technology is one of the fabric production technologies in the textile industry. It has different properties as compared to those of the other production technologies. The interlacing of yarns is very different. Fabric is produced by formation of loops with the yarns. In Table 2.6. general knitting technologies are classified[42].

Table 2.6 General Classification of Knitting Technology [42]



2.5.3.1 Warp Knitting

Warp knitting is produced from a set of warp yarns, normally using at least one yarn per wale, knitted parallel to each other down the length of the fabric. These yarns are fed downwards to the knitting zone and all the loops in one course are knitted simultaneously. If each yarn were continuously knitted in the same wale, a series of unconnected chains of loops would be produced. To make a fabric it is, therefore, necessary for the chains of loops in the wale direction to be interconnected. This is done by moving the threads sideways at intervals to be knitted on adjacent wales. Warp knitted fabrics do not ladder and cannot be unraveled course by course. In Figure 2.12 warp knitted structure can be seen.

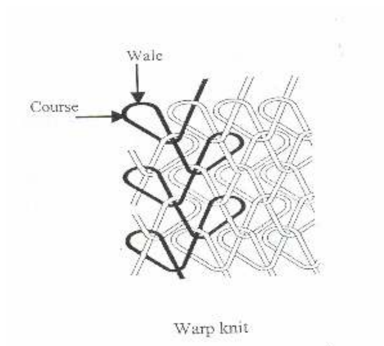


Figure 2.12 Warp Knitted Fabric

2.5.3.2 Weft Knitting

This knitting method is applicable in flat and circular knitting machines. There are many numbers of yarns as well as the number of systems. As one loop line is formed by one single yarn, the fabric that is produced is called single yarn knitted of weft knitted fabric [42]. In Figure 2.13 basic view of weft knitted fabric is illustrated.

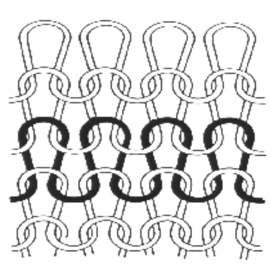


Figure 2.13. Weft Knitted Fabric

Of the two methods of knitting, weft knitting is the older. The fabrics produced by this technique are characterized by a flexible structure accompanied by a soft handle. The simplest cell of weft knitted structure is loop. It is the shape and mobility of the loops of yarn within the fabric structures that influence the extent to which the fabric conforms to the figure and drapes easily. Weft-knitted fabrics lend themselves to the comfort of daily wear, underwear and hosiery. The range also extends from light weight sheer fabrics to thick pile fabrics.

The appearance and physical properties of the material are influenced by the knitting pattern, the closeness of the structure (measured by the number of wales and courses per centimeter) the length of yarn per stitch (which determines the size of the loop), the linear density of the yarns (used in the construction) and the fiber content.

Besides the usual facility of weft knitting separate yarns with various fiber contents can also be used in weft knitting process. Consequently individual courses may consist of a yarn of different fiber content from that in adjacent courses. This is known as 'feeder blending' and enables, the appearance, texture and properties of the fabric to be modified.

Weft-knitting machines are mainly two types; flat or circular knitting machines.

2.5.3.2.1 Flat Knitting

The flat machines have all the needles arranged in straight rows. Usually there are two beds in an inverted V position to hold the needles. The yarn is fed back and forth 'across the width of the fabric and flat lengths of fabric or garment parts are produced.

2.5.3.2.1 Circular Knitting

Circular knitted fabrics are flexible fabrics because of the special linking of the loops forming it. For this reason, they conform to the contours of the body much better than woven fabrics and do not restrict the movements of the body.

Circular machines feed the yarn continuously in one direction to the needles, which are arranged in circular formation, and consequently the fabrics or garment blanks produced are usually tubular. In multifeeder system, instead of feeding only one yarn to the circular machine, and having most of the needles idle while the yarn is being knitted on its circuit, a succession of yarns are fed to the needles. This result that there are numbers of knitting zones around the periphery. In a multi-feed system, if 24 yarns are supplied there will be 24 points at which knitting occurs and 24 courses knitted simultaneously. The rate of production in this multi-feed knitting will be 24 times that of single-end knitting and the tube of fabric will be composed of spirals of yarns[52]. In Figure 2.14 yarn knitting step is shown on tubular circular knitted fabric.

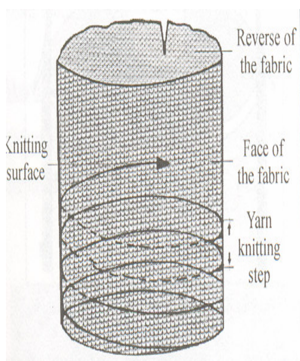


Figure 2.14. Tubular Weft Knit Fabric

2.5.4 Circular Knitting Machines

Circular knitting machines are in a cylindrical construction as can be understood by their name. The needles are inserted in the needle canals opened on the needle beds upon the cylindrical main body. In these machines, during the circular movement of the needle beds, needles are separately moved in the canals by the locker and the knitting process is realized by inserting yarns over to the needles. In order that loops are easily and comfortably produced, there are sinkers positioned in a horizontal way to the needles. First and today’s knitting machines are shown in Figure 2.15.

Figure 2.15. First and Today's Knitting Machines

2.5.5 Knitting Terms

In this section general knitting terms are explained.

a) The Loop: The basic shape into which yarn is formed in the process of knitting. All knitted fabric is made up of a succession of loops. The structure of loop and partials of a single loop (head-legs) are illustrated in Figure 2.16

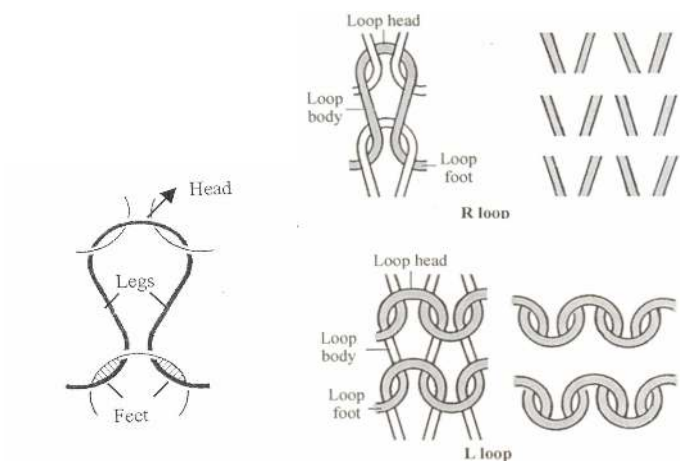


Figure 2.16. Structure of Loop

b) Formation of Loop: A needle is inserted through each one of the original loops and draws a yarn through the original loop to form a loop of the next course. This newly formed loop takes the place of the original loop on the needle, remaining there until the needle pulls the next yarn through it. This operation is repeated continuously.

c) Needle and Sinker Loops: The yarn lies in the plane of the fabric in what is called a snake curve, and the loops which are drawn through the previously formed loops by the needle are called needle loops. However, since the yarn is continuous there must be connecting loops of opposite curvature; these are called sinker loops. These loops are formed over thin plates called sinkers. Diagrammatical view of needle and sinker loops are illustrated in Figure 2.17.

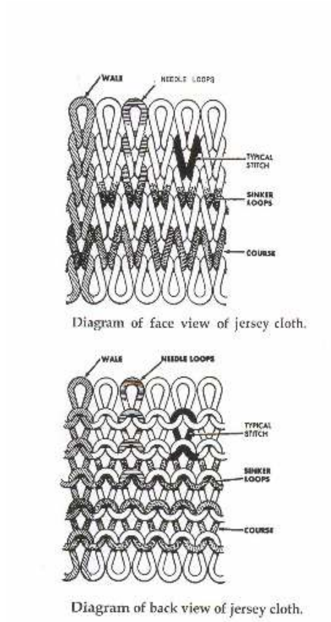


Figure 2.17. Diagram of View of S.jersey Fabric

d) Course: Loops side by side in an unit width (see Figure 2.17).

e) Length of Course: In circular knitting, a course follows a continuous helical (spiral) path in the tube of the fabric from beginning to end (see Figure 2.14). However, in practice, the length of a course is taken as one complete circuit of the fabric and successive circuits are regarded as separate courses.

f) Wale: A vertical chain of loops in the lengthwise direction of the fabric, formed by one needle, is a wale (see Figure 2.17).

g) Stitch: A stitch is the combination of loops from adjoining threads forming a fixed part of the fabric and the duplication of which forms the whole fabric. A stitch is frequently considered to consist of the shape formed by the entire length of yarn from any point on a loop to the corresponding point on a horizontally adjoining similar loop.

h) Top and Bottom of Stitch and Fabric: In a completed stitch, the needle loop is the top of the stitch and the sinker loop the bottom. The bottom of the fabric is that which is knit first and the top which is knit last.

i) Length and Width of Fabric: The width of the fabric along courses is determined primarily by the number of needles. The length of fabric is taken along the length of a wale and is unlimited except by the supply of yarn. In tubular fabrics the width is half the length of a single course, that is, the flattened width of the cloth tube.

j) Face of Fabric: That side of the cloth towards which the new needle loop is drawn through the loop already on the needle. This applies only when the cloth is still on the machine. It is quite common for patterned cloth to be reversed in use so that the back of patterned cloth becomes the face of the garment and the face of the cloth the inside of the garment since many unusual effects can be obtained in this way.

k) Counting Stitches, Courses, and Wales: Knitted cloth may be measured in one inch of width and one inch of length. Thus, when we say a knitted cloth has 20 wales and 28 courses, it means that there are 20 stitches (or loops) in one inch width and 28 stitches in one inch of length. In practice, however, the expression stitches per inch is often used as a synonym for courses per inch.

l) Cut of Cylinder, NPI, (E): The number of needles per inch in a weft knitting machine. It also refers to number of needles per inch used in the construction of a weft knitted cloth [53].

m) Gauge: A term often used confusingly. For circular needle knitting, it is an arbitrary term which expresses the thickness of the knitting needle or of the sinker [54]. It can be expressed as distance between two relative knitting needles, as illustrated in Figure 2.18.

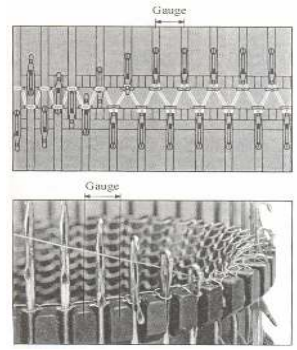


Figure 2.18. Illustration of Gauge Schematic on Machine.

n) LFA (Longueur de Fil Absorbée – Absorbed yarn length per 100 course): The yarn length which is absorbed for knitting one tour around the circumference of the needles.

o) Machine diameter (pus): This is the diameter of the needle foot formed by the cylinder needles. Figure 2.19 shows pus of a circular knitting machine.

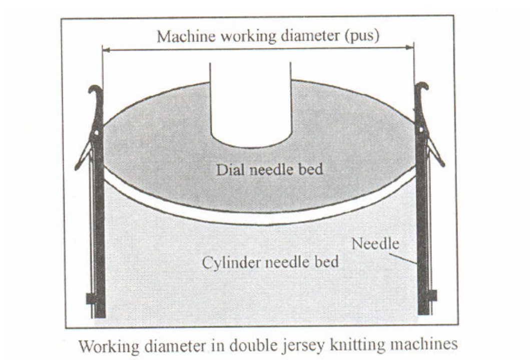


Figure 2.19 Diameter of Circular Knitted Machine

2.5.6 Loop Formation

As needles approach a yarn feeding carrier, they may be placed by pattern wheels and cams in anyone of three different positions relative to that carrier. These three positions are called:

I. Knit Position

2. Tuck Position

3. Welt Position

Figure 2.20 shows the cam system of basic s.jersey machine.

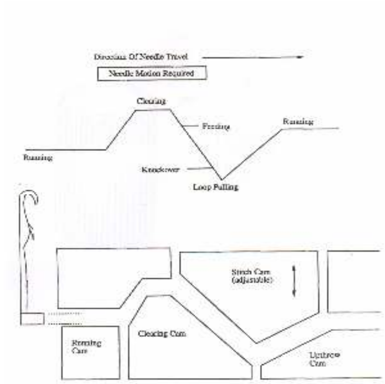


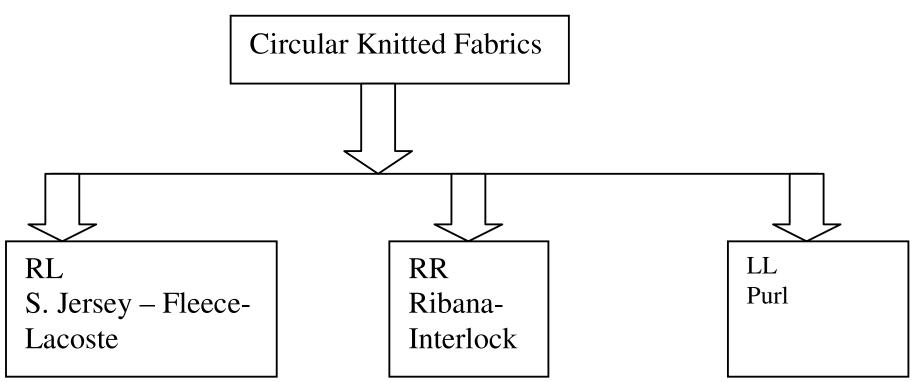
Figure 2.20 Cam System of Single Jersey Machine

2.5.7 Basic Weft Knitted Structures and Their Properties

Circular knitted fabrics are those which are produced in tubular form on circular knitting machines. Machines work in the single/multiple yarn knitting system. These machines carry the knitting elements inserted in the form of circle, producing loop courses in a helical way.

Knitting types with RL (s.jersey, lacoste, fleecy etc.), RR (ribana, interlock, cardigan etc.) and LL (purl) structures (see Table 2.7.) can all be produced in circular knitting machine. The productions of fabrics with large variations of knits and figures with the addition of electronic jacquard devices are possible with these machines.

Table 2.7. Basic Weft Knitted Structures



2.5.7.1 RL Structures

This kind of knitted structures consists of single basic loop structure. These structures have two different sides (right side and left side). Jersey fleece, velour, and terry fabrics all originate in loops protruding from the surface of the cloth. These loops are subsequently cut and brushed or sheared, with the exception of terry which is left uncut.

2.5.7.1.1 Single Jersey

In the jersey stitch, vertical components of the loops appear on the right side and horizontal components (courses) are seen on the left side. The face side of jersey usually has a softer hand than the reverse side [53].

S.jersey is the plain RL knit fabric knitted on single plate circular knitting machine. It contains only loops in the knit repeat has no tuck, miss knit [42]. However, patterned structures obtained by the introduction of float or tuck stitches.

S.jersey is a fairly elastic fabric in which face and reverse side are different in appearance and which tends to curl [52] (see Figure 2.21).

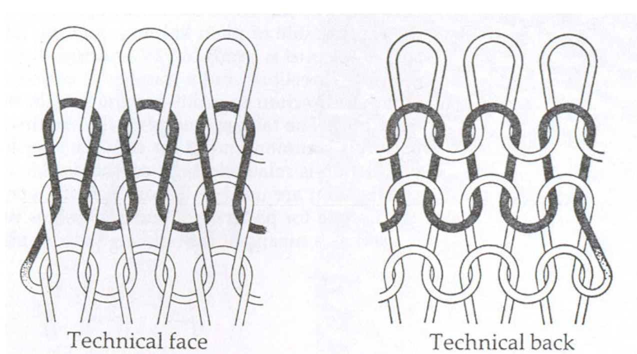


Figure 2.21. Graphical View of Single Jersey Structure

In Figure 2.22, the single jersey structure shows two courses and three wales. All loops are knitted on the front bed, therefore only the front bed needles are utilized [55].

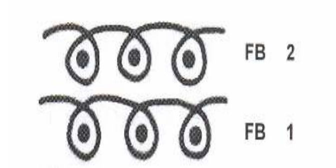


Figure 2.22. Diagrammatic View of Single Jersey

Plain structure or single jersey is the simplest weft knit structure and is formed by the inter-meshing of a number of loops from side to side and to bottom. The single jersey structure is composed solely of knit loops knitted on one bed of needles, as shown in Figure 2.23. Its production rate is very high because of stitch simplicity, and it is relatively inexpensive to produce because of machine simplicity [55].

Figure 2.23. Single Jersey One Loop Diagrammatic

Ajgaonkar [56] described s.jersey, is unbalanced because it is knitted on one set of needles. Therefore the loops tend to curl towards the front at the top and bottom ends and towards back at the sides, which makes curling difficult to control. Spirality and bias are common problems in single jersey due to its inherent structural imbalance [57]. The spirality and bias of single jersey occurs when the wales and courses lean. Lau [58] determined the effects of spirality results from yarn twist.

Jersey fabrics are commonly used in the production of hosiery, socks, t-shirts, and underwear. Hatch [59] stated that single jersey fabrics have good crosswise and lengthwise elongation, and the degree of elastic recovery varies with the fiber content and yarn structure. The fabric properties and parameters of a jersey structure are also dependent on the loop length [56].

2.5.7.1.2 Fleece (Laid in Yarn)

This is a fabric produced with two or three yarns of different counts with a knit construction different from that of single jersey. Although it is named lined fabric in technology market it is known as two yarn fabric. The ground knit is of RL structure. The coarse yarns are tied to the ground knit by the tuck movement alternately (see Figure 2.24). The appearances of the face and reverse sides of the fabric are very different (see Figure 2.25).

Coarse yarn is laid-in at the back of a plain-knitted fabric and the fabric is raised during finishing producing a fleecy appearance. Its presence tends to reduce the elasticity of the fabric. Such fabric is suitable for sweaters, tracksuits, dressing gowns, underwear, and children's wear.

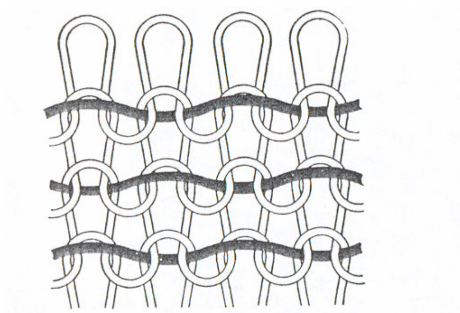


Figure 2.24. 1-1 Laid In Yarn Graphical

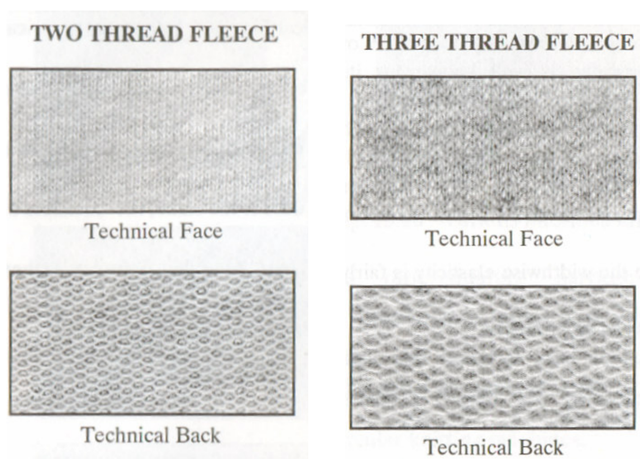


Figure 2.25. Technical Face and Back of A) Two Thread Fleece B) Three Thread Fleece

Two Thread Fleece: The ground is in the RL structure. It is produced on single jersey machines. The back side can be raised. It’s lengthwise and widthwise elasticity is low. Its dimensional stability is superior to single jersey.

Three Thread Fleece: It is a kind of fabric produced with three kinds of yarns with different properties. Two yarns produce the ground knit and the third set produces the lining. This kind of fabric is produced on special machines. There are R loops on the front face, and loops forming the lining are seen on the back. It's stability is high with almost no elasticity. It is rather thick. Three thread fleece structures usually produce in heavy weights. Pile yarns on the front and ground yarns on the back can be seen.

2.5.7.1.3 Tuck Lacoste

This stitch is produced by accumulating two or more loops on a needle and casting them off together. In plain fabric the tuck stitch extends over more than one course, pronounced raised designs develop in the structure and these can be used to produce figured shapes.

A single needle may be brought into tuck position at several feeds successively before it is placed in knit and cast-off positions and cleared. In that case, the needle will then take each fed yarn at tuck position- and hold them all until it reaches the clearing feed. The results might be termed a vertical tuck stitch that extends along a wale through several courses.

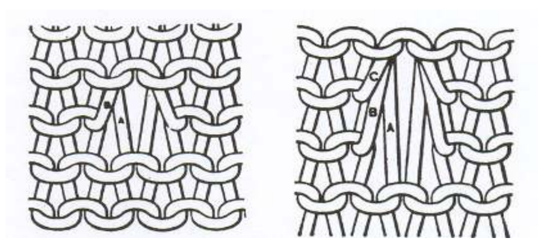


Figure 2.26.

A) Single tuck: A vertical stitch viewed from the double tuck stitch back of the fabric. "A" viewed from the back is the held loop; "B" of the fabric.
B) Double tuck: "A" is the tuck loop which held loop, "B" is not visible on the first tuck loop, and "C" face of the fabric. C is the second tuck loop.

Figure 2.26 illustrate a vertical double tuck stitch viewed from the back of the fabric. In this stitch there are two tuck loops and one held loop. The held loop is held two courses before it is cleared while the largest tuck loop "B" is held one course before it is cleared. When the tuck stitch contains more than one tuck loop, they may be numbered in the order of their formation. The longest tuck loop marked "B" would be No. I and the shortest one marked "C" would be No. 2 as shown in Figure 2.26. The longest loop of all remains the held loop. The longer each held and tuck loop remains on the needle, so the loop becomes the tighter and longer. The first reason of this is the surrounding fabric that is continually moving downward which elongates the held and tuck. Secondly, as the tuck needle is repeatedly drawn into cast-off position after it tucks, it steals yarn from the more relaxed adjacent jersey stitches.

The structure of this type of fabric is like as honeycomb. In double tuck lacoste the honeycomb effect is more visible than single tuck lacoste [60].

Pique and lacoste are different knitting structures [60].

2.5.7.2 RR Structures

RR knitted fabric is produced on two needle beds facing each other on double bed machines. They have the same appearance both at the front and back. Fabrics are heavier than RL plain knitted fabrics.

2.5.7.2.1 Ribana

The structure of the fabric is composed of normal and reverse loops successively (see Figure 2.27, 2.28). Ribana is well known for its appearance and elasticity. It is produced in double bed tubular knitting machines with cylinder and dial needles mounted in two needle beds. These needle beds are at right angles and crosswise to each other and all the needles are in operating position. If the number of loops is equal on both technical face and technical back, no rolling occurs at edges, because the loops will balance each other [42].

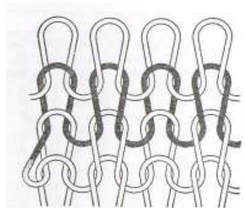


Figure 2.27. Graphical View of Ribana Structure

The 1 x 1 (English rib) is the simplest rib fabric, and alternate wales are intermeshed in opposite directions. The fabric has a similar appearance on each side and, like most ribs, does not curl. In the relaxed state it is about half the width of a similar plain knit fabric produced on the same machine. Examples of other typical constructions of ribs of different widths are 2 x 2 (Swiss rib), 2 x l (Richelieu rib), and large ribbing such as 6 x 3 (Derby rib). Rib fabrics are characterized by being bulky and very elastic widthwise, but a reduction in elasticity occurs with an increase in width of rib. A greater quantity of yarn is required in a rib fabric than in a plain fabric of similar general construction and width. Thus, rib fabrics are heavier and slightly more expensive [52].

The most important property of rib fabric is its ability to stretch. The 1 x1 rib knit structure is known for its high width-wise extensibility and recovery. The ease of bending wales in ribana results largely from high width extensibility. There is no spirality in the structure; however minimal skew is enough to easily distort the fabric. Two sets of needles are used in forming a 1x1 rib, producing a balanced fabric with identical loops on both sides.

Figure 2.28. Diagrammatic View of Ribana Structure

The two sets of needles are gaited or arranged so the cylinder bed needles are offset from the dial bed needles. This needle arrangement causes the face wales to move over and in front of the reverse wales, as shown in Figure 2.29. Smirtiff [61] stated that this rib gaiting contributes to fabric thickness, fabric width, instability and resilience.

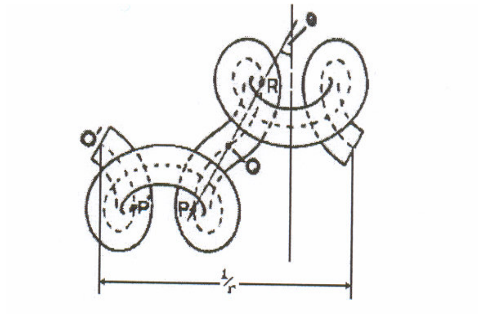


Figure 2.29. 1x1 Ribana – Perspective View

Although knitted rib structures are widely used in outerwear, their main use is in providing welts, cuffs, and collars for garments with plain-knitted bodies and sleeves. There are two properties of 1 x1 rib fabric that make it particularly suitable for these trimmings. First, fabrics of this type are free from edge curling because they are balanced, unlike the unbalanced structure of single jersey that causes edges to curl. Secondly, rib fabrics readily extend in width and show immediate recovery from extension [55].

2.5.7.2.2 Interlock

Interlock fabric is produced on two needle beds facing each other on double bed machines. This type of fabric has the same appearance both at the front and back. Figure 2.30 shows diagrammatical view of interlock.

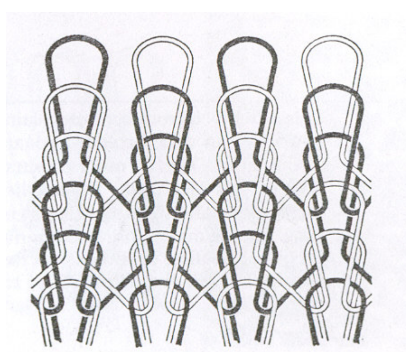


Figure 2.30. Interlock Structure

Figure 2.31. Front and Back Side of Interlock

As the knitting repeat is completed on double beds and is forming one row from two systems, the consumption of yarn is the highest. Interlock fabric has greater flexibility in the vertical direction compared to the horizontal direction. This kind of knitting has high size stability and high ability of maintaining its form. Its resistance to shrinkage is satisfactory. Heaviest knitted fabrics can be produced as compared to other single yarn knitted fabrics. When subjected to tension, the loops tend to ravel from the edge. Since the number of loops on both front and back is equal (see Figure 2.31), the fabric has a balanced structure. No rolling problem at edges exits as seen on the single bed produced fabrics. RR Interlock fabrics can only roll on the last knitted edge.

This structure consists of two 1 x 1 rib fabrics knitted together by means of two yarns which knit alternately on the face and back of the fabric. Consequently, it is reversible and has a similar smooth appearance on each side.

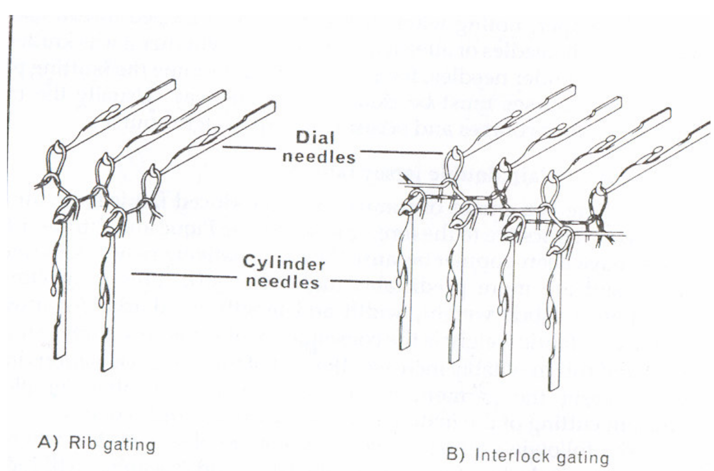


Figure 2.32. Rib and Interlock Gating

For the same stitch spacing interlock is heavier and thicker than rib knitting, but fine yarns are used in order to reduce the weight. The rate of production is slower than for rib knitting and stitch patterning is more restricted. Special machines with two sets of needles are required, of two lengths in each set. Figure 2.32 illustrates the difference between ribana gating and interlock gating.

Figure 2.33. shows the thread path diagrams of 1x1 ribana & interlock fabric structures. The continuous line round the points on Figure 2.33. indicates the path of the thread from needle point to needle point during knitting.

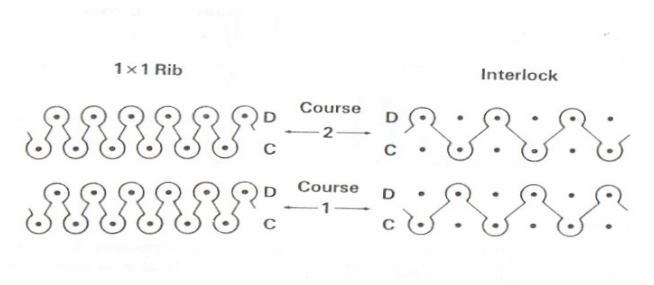


Figure 2.33. Thread Path Diagrams for Ribana and Interlock Structures

The geometry of the yarn path influences the elastic behaviour of the knitted fabrics. The change in the direction of the meshing of the stitches in neighbouring wales results in the wales of a rib knitted fabric closing up giving it better elastic properties widthwise over other structures. The combination of two rib knitted structures in the interlock structure gives very little or no room at all for the wales or courses to close up. Therefore the interlock fabric shows very poor elastic properties in both directions [62].

2.5.7.3 LL Structures

The moss stitch is represented in Figure 2.34. in two courses and two wales, where both front and back beds are utilized. The course loops are knit from front needle to back needles each time, but wale loops alternate from the front needle to back needle within each course.

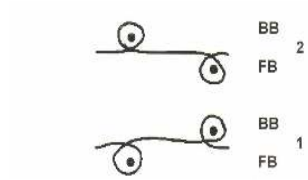


Figure 2.34. . Diagrammatic View of Moss Stitch Structure

The moss stitch is a variation of the classic 1 x1 purl represented in Figure 2.35.

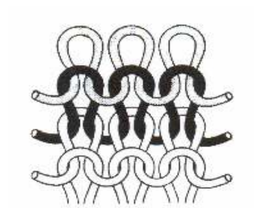


Figure 2.35. Graphical View of Purl Structure

2.5.8 Comparison of RL-RR Fabrics

Each type of knitting structure has different characteristics. A comparison of four types which is used for this study is given in Table 2.8.

Table 2.8. A comparison of single jersey, 1x1 rib, interlock, double tuck lacoste

Structure	Single Jersey	Ribana	Interlock	D.T. Lacoste
Appearance	Loops on face	Both sides identical	Both sides identical	Loops on face
Extensibility-width	Less than 1 x1 rib	High	Higher than single jersey	Similar to s. jersey
Extensibility-length	Medium	Less than single jersey	Less than single jersey	Less than single jersey
Format	Tubular or open	Tubular or open	Tubular or open	Tubular or open
Needle setup	Cylinder bed needles	Rib gaiting, cylinder and dial beds used	Int. gaiting, cylinder and dial beds used	Cylinder bed needles
Stability	Instable	Stable	Stable	Instable
Bursting strength	Less than Ribana	Less than interlock	High	Lowest one because of pores of the structure
Fabric weight with same yarn count	Lowest one	Medium	High	Medium
Thickness	Due to single needle motion less than the others	Due to double needle motion higher than s.jersey	Due to double needle motion higher than s.jersey	Due to honeycomb effect highest one
Spirality	Due to inherent structural imbalance	Not a problem because structure is balanced	Not a problem because structure is balanced	Due to inherent structural imbalance
Bias/Skew	Occurs when fabric is allowed to relax, not present when fabric is on the machine. Due to number of feeders	Occurs when fabric is allowed to relax, not present when fabric is on the machine. Due to number of feeders	Occurs when fabric is allowed to relax, not present when fabric is on the machine. Due to number of feeders	Occurs when fabric is allowed to relax, not present when fabric is on the machine. Due to number of feeders
Curl	Curling due to unbalanced structure	No curling due to balanced structure	No curling due to balanced structure	Curling due to unbalanced structure
Dimensional changes	Differential shrinkage due to bias	High and variable width shrinkage due to ease of distortion	High and variable width shrinkage due to ease of distortion	Differential shrinkage
Pilling	Medium	Less good than the interlock	Poorest	Good

There are two major problems of structural instability associated with single jersey: spirality and bias. Spirality refers to wales and bias refers to courses. Bias occurs when courses do not knit horizontally in the fabric but rather on an incline. The degree of wale spirality is associated with the level of yarn twist and has obvious influence on both the aesthetic and functional performance of knitwear [63]. Plain weft fabric or single jersey is composed of a series of courses. Each course is intermeshed with both the preceding and succeeding courses. The continuation of this repeat for every course and wale makes this an unbalanced fabric because all loops are constructed with cylinder bed needles on a circular knitting machine. Spirality is an unsuitable configuration of a plain knitted loop. It is one of the drawbacks of plain knitted structures.

According to Abou-Iiana et al. [64] the dimensional properties of a knitted fabric in terms of length or width parameters (courses and wales per unit length) are subject to inaccuracy because of the knit has inherent stretch at low loads and poor recovery. Thus, determining the relaxed state to measure these dimensional parameters is difficult and error rate is high.

Tou [55] described the minimum energy state as a fabric's ideal relaxed state. They found that it is different for every knit structure. Therefore, some sort of fabric deformations can be expected such as arcing, to occur when two structures are joined side-by-side. There is contention that adjoining structures will produce interactions, such as arcing, when different structures are combined.

Makinen and Meinander [65] studied about influence of physical parameters on fabric hand. Raw material, yarn structure, planar structure and finishing treatments affect the fabric hand. The density of knitted fabric depends on the gauge (needle density) of the knitting machine.

2.5.9 Loop Length and Tightness Factor Control

The fabric properties and parameters of a knitted structure are dependent on the loop length. When loop length is reduced, the fabric may appear tight and rigid. As the loop length increases, the fabric may appear looser and less rigid [56]. Loosely knitted fabrics are easily extensible and distorted; where as tightly knitted fabrics are more stable and less susceptible to distortions. Changes in loop length will cause an increase or decrease in the weight per unit area, which influences cost. Increasing the loop length will cause a decrease in the weight per unit area. This decrease in weight is due to the reduction in the number of courses per inch by lengthening the loop so that the length of yarn in a course was increased. Shortening the loop will have the opposite effect. Figure 2.36 illustrates how yarn size affects the tightness of a fabric.

Cover factor is represented by the ratio d/l, where d is yarn diameter and l is the length of yarn in a loop suggested the use of a factor to indicate the relative tightness or looseness of plain weft knitted structure [55, 66].

Tightness factor, K, can be defined as the ratio of area covered by yarn in one loop to area of one loop [87],

$$\frac{Lxd}{L^2} = \frac{1}{Lx\sqrt{N}} \qquad (2.1)$$

Yarn count, N, is related with tex. Then

$$K = \sqrt{Tex}\,/\,L \qquad (2.2)$$

where Tex is the yarn linear density and L is loop length in centimeters. The fabric dimensions depend on the tightness of the fabric. In fabrics knitted with the same loop length, the fabric dimensions vary with the count of the yarn [67,68].

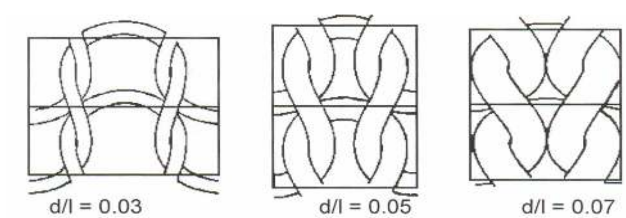


Figure 2.36 Effect of Yarn Size on Tightness

The fabric dimensions associated with these loop shapes are represented by the rectangles that are unit cells of fabric. Hepworth [67] used single jersey structures that showed clearly the differences in shape of both the loops and the unit cells. Figure 2.36 illustrate the different states of jamming that can occur in relaxed fabrics. The term “jamming,” occurs when courses or wales apply pressure at contact points. In Figure 2.36, it was determined that for d/l > 0.031, except for very slack fabrics and jamming is very low. In addition there is jamming between wales in tight fabrics for which d/l > 0.06. High jamming values will produce a more rigid fabric than a fabric with less jamming. Therefore, fabric distortions are expected to occur in fabrics with less jamming or a low K value [67]. When a knitted fabric is extended along its wale-wise direction, the width in the course-wise direction will be reduced. However, this reduction is limited by jamming of the loop structure in the course-wise direction [69]. d/l ratio is known as cover factor [87].

Yarns of different counts knitted to the same loop length will display different physical properties, such as handle, drape, openness, permeability, etc. A fabric knitted from course yarn will be much more tightly knitted for given loop length than would a fine yarn [55].

Gravas et al. [68] describes the tightness factor is a mean of assessing knitting performance. According to their experience, tightness factor has been experimentally proved that its values vary from 10 to 20 when the loop length is defined in cm. It has been found that the dynamic forces required to pull a wide range of yarn counts into a knitting loop are at a minimum when K is equal to 14.

Araujo et al.[69] studied about a theoretical model based on elastica theory and used for prediction of tensile properties of plain knitted fabrics. In their approach, they wanted to lead to a reduction in the need for destructive testing, especially in the case of knitted fabrics produced with high modulus yarns.

Different quality knitted fabrics from multi-feeder circular knitting machines are mainly produced by changing the stitch length. Altering the loop size (loop length) primarily requires adjustments the yarn delivery rate. The stitch cams also need to be adjusted to obtain a run-in yarn tension of 2-5 cN. Dias [70,71] stated that the measured loop length is changeable due to yarn winding tension.

2.5.10 Influence of Loop Length on Fabric Characteristics

Changes in loop length will cause an increase or decrease in the weight per unit area. Producing fabric with varying weight in this way may influence cost due to the amount of yarn consumed in fabric production and also influence fabric performance characteristics. Knit fabrics can be knitted loosely or tightly, but normally are knitted somewhere around the middle tightness depending on the end use of the product and the desired aesthetics. Each fabric has different extremes of knit tightness also dependent on the end use. In terms of distortion, greater fabric distortion is expected in looser fabric. Spirality and bias in single jersey cause fabric distortion, which is more apparent in loose knits. Wales should be completely vertical but spirality and extraneous forces can deform them.

The structure of a knitted fabric has large influence on the fabrics characteristics and can make them better or worse. Stitch density is directly related to the “loop length”. Loop length is the length of yarn contained in one complete knitted loop and it is adjusted on the knitting machine.

Loop length effects [64];

- Stitch density/fabric density,
- Fabric weight and fabric cost,
- Fabric dimensions and panel size, shaped knitwear,
- Dimensional stability, relaxation and shrinkage,
- Physical performance, pilling, burst strength

Yarn size and volume can potentially have a direct influence on the amount of fabric thickness and resilience. If equal loop lengths are used, a yarn with a larger diameter, such as a bulkier yarn, would effectively make the fabric tighter. Tight fabric influence the amount of fabric movement due to less open space in the fabric for each loop while the loop length is the same, and the diameter of the yarn is varied [55].

CHAPTER 3: EXPERIMENTAL STUDY

The purpose of this study is to investigate the performance of the Polypropylene (PP) continuous filament yarn in knitted structures. Tests were performed for two sets of samples. In the first set four knitting structures, nine different yarn types [OE Rotor Cotton (CO), Carded CO, Combed CO, Carded Viscose (CV), OE Rotor Acrylic (PAN), PP Delta 1, PP Delta 2] were used to prepare 23 knitted samples. Second set of samples are produced from four continuous filament yarns [PP Delta 1, PP Delta 2, PP Round and Polyester (PES) Delta] and at three different tightness factor (tight, medium, and loose) for s.jersey structure.

3.1 Fiber

Five different fiber types had been chosen for this study. The fibers were selected due to their individual characteristics as well as their availability.

Beside PP multi filament yarn types, CO, CV, PAN and PES were selected because of wide usage in knitting, its handle and trend recently.

CO was from Greece and its identification chart is given in Table 3.1. Properties of CO are measured by HVI Spectrum.

Table 3.1. Specification of CO

Staple (mm)	29,67
Micronaire	4,10
Strength (cN/tex)	30,23
Elongation (%)	6,70
UI	83,30
SFI	8,60
Color	31-4

CV was from India and its identification chart is given in Table 3.2.

Table 3.2. Specification of CV

Staple (mm)	32
Fiber fineness (dtex)	1,3 dtex
Color	Bright -white
Strength (cN/tex)	28.1
Elongation (%)	15

PAN was from Montefibre and its identification chart is given in Table 3.3.

Table 3.3. Specification of PAN

Staple (mm)	28
Fiber fineness (dtex)	1,3 dtex
Cross - section	Round
Color	Bright-ecrou
Strength (cN/tex)	48
Elongation (%)	33,3

PES was from Özçelik – TMY Ltd. in Syria and its identification chart is given in Table 3.4.

Table 3.4. Specification of PES

	1/70 denier PES	1/150 Denier PES
Number of filaments	72	72
Cross -section	Delta	-
Color	White	White

The cross-sectional view of PES Delta is given in figure 3.1.

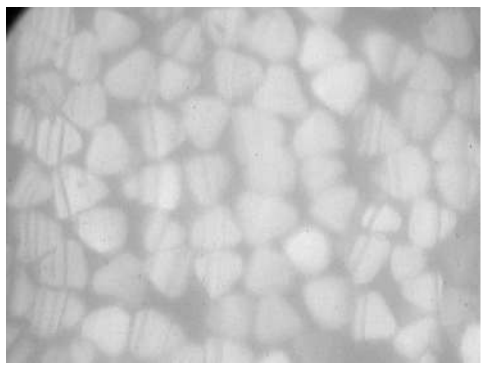


Figure 3.1. Cross-sectional View of PES Delta Continuous Filament Yarn

Three type of PP's identification chart is given in Table 3.5.

Table 3.5. Specification of PP

	1	2	3
Number of filament	72	72	72
Cross - section	Delta	Delta	Round
Color	White	Turquoise	Light Blue
MFI	24	24	25

The cross-sectional views of PP Delta 1, PP Delta 2 and PP Round used in this thesis are given in Figure 3.2, 3.3 and 3.4, respectively.

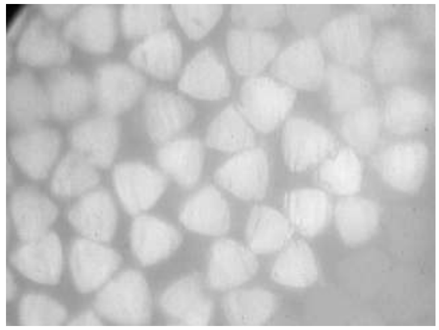


Figure 3.2. Cross-sectional View of PP Delta 1 Continuous Filament Yarn

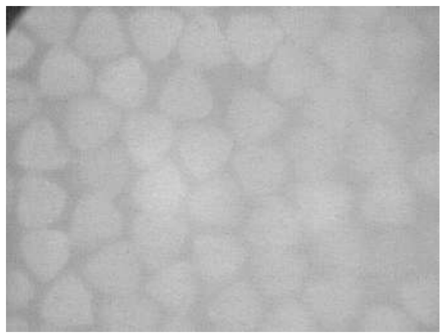


Figure 3.3. Cross-sectional View of PP Delta 2 Continuous Filament Yarn

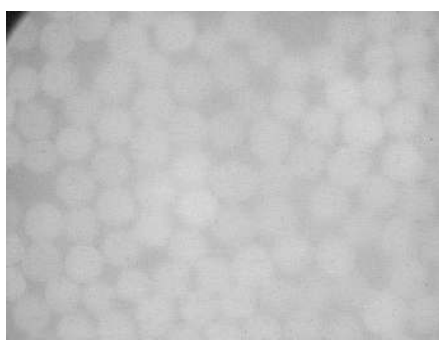


Figure 3.4. Cross-sectional View of PP Round Continuous Filament Yarn

3.2 Yarn

Three different yarn production technologies were selected for this study. OE Rotor, Ring (carded-combed), melt spinning systems were selected due to their individual characteristics. These samples were selected as well as their availability.

CO was span by OE Rotor, Ring (carded-combed) systems. CV was produced by Ring – carded method. PAN was produced by OE Rotor yarn technology. PES and

PP was produced by melt spinning system without textured. All specifications are given in the Table 3.5.

Table 3.5 Specifications of Selected Yarns

Spinning System	OE Rotor		Ring-Carded		Ring-Combed	Melt Spinning	
Fiber type	CO	PAN	CO	CV	CO	PES	PP
Count Ne	30	30	30	30	30	35	35
Count CV	1,0	1,0	1,1	1,3	0,9	0,5	0,5
αe	3,6	3,6	3,6	3,6	3,6	-	-
Number of filaments	-	-	-	-	-	72	72
Um	10,40	10,36	11,01	10,90	10,06	9,64	8,06
CVm	13,01	15,31	13,75	13,76	12,63	11,21	10,01
Thin Places (-50)	27,5	1	20	2	0	0	0
Thick Places (+50)	95	2	120	27	75	0	0
Neps (for OE Rotor +280, for Ring +200)	32,5	0	150	7	45	0	0
Strength (Rkm)	10,21	14,90	13,64	9,76	14,65	31,52	51,44
Elongation (%)	4,78	20,80	5,09	7,42	4,96	34,87	22,17

Yarn count is measured by Zellweger Uster Autosorter, yarn strength is measured by Zellweger Uster Tensorapid standards and yarn unevenness &IPI values are measured Zellweger Uster Tester 3.

3.3 Knit Structure

Four different knitting structures, (s.jersey, ribana, interlock and double tuck lacoste), were used in this study. Single jersey is basic type of circular knitting; it has a high production rate and is inexpensive than the others. Spirality was occurred while preparing the specimens. Ribana is well known for its appearance and elasticity. The most important property of rib fabric is its ability to stretch. The 1 x1 rib knit structure is known for its high width-wise extensibility and recovery. Interlock structure is the heaviest knitted fabrics as compared to other single yarn knitted fabrics. This kind of knitting has high size stability and high ability of maintaining its form. Double tuck lacoste has got good pilling properties and more porosity than the other basic structures.

3.4 Knitting Machine

Fabrics were knitted using Mayer, Terrot and Atlas circular knitting machines. The machine specifications are given in Table 3.6. Mayer and Terrot machines are available in Selçuk İplik Company Knitting Department and they are high speed commercial circular machines. Atlas machine is a type of circular machine which is made for laboratories and available in Textile Engineering Department of Gaziantep University.

Table 3.6. Machine specifications

Knitting type	S.jersey	S.jersey	Ribana	Interlock	Lacoste
Machine manufacturer	Mayer	Atlas (laboratory type)	Terrot	Mayer	Mayer
Machine type	Circular knitting machine (single plate)	Circular knitting machine (single plate)	Circular knitting machine (double plate)	Circular knitting machine (double plate)	Circular knitting machine (single plate)
Fineness (E)	28	22	16	24	28
Diameter (inch)	32”	3,5”	34”	30”	32”
Number of needle	2813	241	1921x2	2260x2	2813
Number of yarn feed system	102	1	64	96	102
Knitting Speed (rpm)	18	25	18	20	18

3.5 Loop Length

Loop length is measured by using manual method for all loops. 100 loops were counted 10 of them were measured under 10g stretched force. Smirtiff [88] stated that it is does not give extra extension to deknitted yarn by using 10g stretch force for reforming the curl on deknitted yarn. The average value of 100 loop length (LFA) is divided in 100 to obtain the individual loop length.

In this study different loop lengths are used to prepare the samples. Tight, medium and loose loop lengths were selected for PP and PES continuous filament yarn to show differences in fabric tightness. We use only one loop length for CO, CV and PAN.

3.6 Fabric Tests

All tests were performed for unwashed and washed cases. TS 5720 –EN ISO 6330 "Textiles – Domestic Washing and Drying Procedures for Textile Testing" were firstly guide the washing procedure for all tests [89].

The apparatus and materials used in the experimental studies are;

- Automatic washing machine
- Automatic tumble dryer
- 1993 AATCC standard reference detergent
- Ballast of 92x92 cm hemmed pieces of bleached cotton sheeting (wash load ballast type 1)
- Indelible ink marking pen for use with suitable rule

  Measuring devices

3.6.1 Bursting Strength Measurement

EN ISO 13938-2 "Textiles – Bursting Properties of Fabrics – Part 2: Pneumatic Method for Determination of Bursting Strength and Bursting Distension" is used in this experimental study [92]. In Figure 3.5 James Heal Truburst bursting strength test machine is shown. This standard describes a pneumatic pressure method for the determination of bursting strength and bursting distension of textile fabrics.

For the purposes of this standard the following definitions apply:

Figure 3.5. James Heal Truburst Bursting Strength Test Machine

Test area: Area of the test specimen within the circular clamping device.

Bursting Pressure: Maximum pressure applies to a test specimen clamped over an underlying diaphragm until the test specimen ruptures.

Bursting Strength: is obtained by subtracting the diaphragm pressure from the mean bursting pressure.

Bursting Distension: Expansion of a test specimen at the bursting pressure.

Height at Burst: Distance between the upper surface of the test specimen before distension and the top of the test specimen at the bursting pressure.

Time to Burst: Time taken to distend a test specimen to burst.

Principle: A test specimen is clamped over an expansive diaphragm by means of a circular clamping ring. Increasing compressed air pressure is applied to the underside of the diaphragm, causing distention of the diaphragm and the fabric. The pressure is increased smoothly until the test specimen bursts. The bursting strength and bursting distention are determined.

The apparatus shall be capable of producing an increase in air pressure to achieve a testing time to burst of (20±5)s. Height at burst up to 70 mm shall be indicated with an accuracy of ±1mm. A test area of 50 cm^2 (79,8 mm diameter) are used.

Precondition is applied to specimens for at least 4 hour by laying each specimen separately on the screen atmospheric temperature of 21±1 C° and relative humidity 65 ±2 %RH.

3.6.2 Dimensional Stability Measurements and Calculations

TS 392 – EN ISO 25077-ISO 5077 "Textiles – Determination of Dimensional Change in Washing and Drying" and TS 4073 EN ISO 3759 "Textiles preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change" are used to determine the dimensional stability of specimens [90].

Marking of Specimens: The recommended sample size is 500mmx500mm and for routine works a minimum sample size of 300mmx300mm is considered sufficient. In this study specimens were prepared as 500mmx500mm. The samples are marked with 5 set of marks in each direction a minimum 350mm apart and at least 50mm from all edges. In Figure 3.6 area of dimensional stability test is drawn.

All samples are then conditioned in the standard atmospheric conditions.

All samples were washed as explained in TS 5720 –EN ISO 6330.

Precondition and condition are applied to specimens for at least 4 hour by laying each specimen separately on the screen in atmospheric temperature of 21±1 ºC and relative humidity 65 ±2 %RH.

After conditioning, each test specimen is laid without tension on a flat smooth horizontal surface. The distance between each pair of bench marks are measured and recorded.

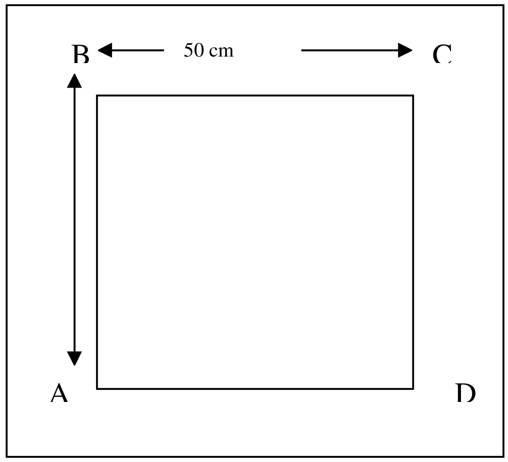


Figure 3.6. Area of Dimensional Stability Test

Calculation of dimensional stability for each direction is done according to following equations;

$$DC = \frac{(a-b)}{b} * 100 \quad (3.1)$$

Where;

DC is dimensional change

a is final dimension

b is original dimension

The decrease in the dimension can be characterized as "-" and the increase in the dimension can be characterized as "+".

3.6.3 Pilling Measurements

TS EN ISO 12945-2 "Textiles – Determination of Fabric Propensity to Surface Fuzzing and to Pilling – Part 2: Modified Martindale Method" is used to investigate the pilling resistance of specimens [93]. In Figure 3.7 Martindale abrasion and pilling tester is shown. This test method covers the determination of the resistance to the formation of pills and other related surface changes on textile fabrics using Martindale tester.

Figure 3.7 Martindale Abrasion and Pilling Tester

Precondition is applied to specimens for at least 4 hour by laying each specimen separately on the screen in atmospheric temperature of 21±1 ºC and relative humidity 65 ±2 %RH.

A pair of circular specimens from each swatch is cut in the laboratory sample with one of each pair of specimens being 38mm in diameter and other 140mm in diameter.

Principle: Pilling and other changes in the surface appearance such as fuzzing, that occur in normal wear are simulated on a laboratory testing machine. Fabrics are mounted on the Martindale Tester and the face of the test specimen is rubbed against the face of the same mounted fabric in the form of a geometric figure called lissajous movement. The degree of fabric pilling or surface appearance change produced by this action is evaluated by comparison of the test specimen with visual standards (photographs of fabrics) showing a range of pilling resistance. The observed resistance to pilling is reported.

All specimens were controlled in 125, 500, 1000 and 2000 movements. The tests are stopped at 2000 movements.

Grading: The 38 mm disc specimen is placed in the viewing cabinet (cool white fluorescent tube).

Using suitable view conditions and suitable photographic standards, pilling points on the face of each specimen is rated. The pilling result of each specimen is compared with rating standards given below. When the appearance of a test specimen falls between that of two rating standards assign the half value.

Grade 5: No pilling

Grade 4: Slight pilling

Grade 3: Moderate pilling

Grade 2: Severe pilling

Grade 1: Very severe pilling

3.6.4 Snagging Measurement

Debenhams PD14a "Resistance to Snagging of Knitted and Woven Fabric" was used for examining the snagging [91]. Figure 3.8 shows the James Heal snagging test machines.

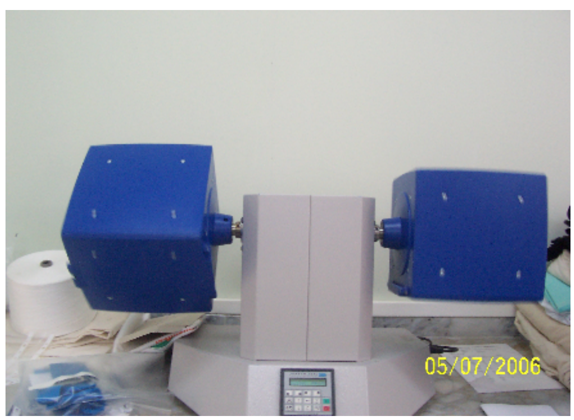


Figure 3.8 James Heal Snagging Test Machines

The templates are used to prepare 4 samples as 105mmx115mm and sewed as a tube. These tubes are mounted on the cylindrical polyurethane apparatus.

Precondition is applied to specimens for at least 4 hour by laying each specimen separately on the screen in atmospheric temperature of 21±1 ºC and relative humidity 65 ±2 %RH.

Test method: Before commencing the test, the inside of each box is cleaned with the soft brush to remove fluff and debris from the previous test. 4 mounted test samples are placed the in the same ICI box. The tubes are tumble in the box 600 revolution in 10 min.

Grading: All specimens are controlled on the Pilliscope (see Figure 3.9) . It is sited in a curtained off area. The samples are viewed from above the light source at distance 15-30 cm to prevent glare.

Figure 3.9. View of Pillioscope

For knitted fabrics;

Grade 5: No change

Grade 4: Short to medium snags in isolated areas.

Grade 3: Short to medium snag covering at least 50 % of the surface.

Grade 2: Short to medium snag covering entire specimen.

Grade 1: Medium to long snags covering entire specimen causing puckering.

Snag Length,

2 mm and below: Short

2mm-5mm : Medium

5mm and above : Long

Shiner : Tight pulled threads across the fabric

If the rating appears between two grades, the result is reported between the two grades eg.3-4.

3.6.5 Skewness Measurements and Calculation

Skewness: AATCC Test Method 179-1996 “Skewness Change in Fabric and Garment Twist Resulting from Automatic Home Laundering” is used as a guide this experimental work. This method determines change in skewness in woven and knitted fabrics or twits in garments when subject to repeated automatic laundering procedures commonly used. Washing and drying procedures use for shrinkage tests and other home laundering tests are specified for this method [76].

Marking of Specimens: On each 38x38cm fabric test specimen two 25 cm pairs of bench marks to the length of the specimen and two 25 cm marks perpendicular to the length of the specimen. A line is drawn through each of four sets of adjacent bench marks so that a square is formed as shown in Figure 3.10.

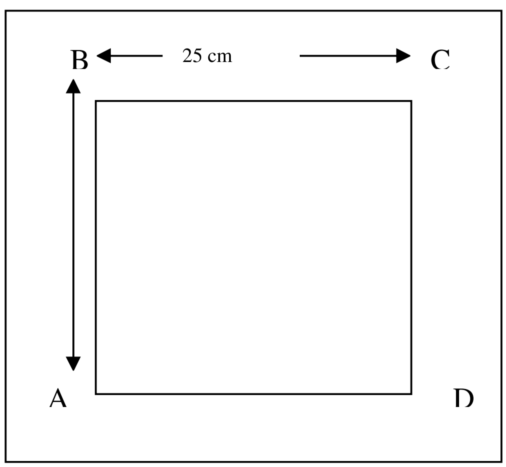


Figure 3.10. Area of Skewness Test

All samples are washes as explained in TS 5720 –EN ISO 6330.

After conditioning, each test specimen is laid without tension on a flat smooth horizontal surface. The distance between two diagonal lines are measured and recorded.

Calculation of dimensional stability for each direction is done according to following equations;

$$X = 2\frac{(AC - BD)}{(AC + BD)} * 100 \qquad (3.2)$$

X is % change in skewness

CHAPTER 4: RESULTS AND DISCUSSION

This chapter gives the performance test results obtained from knitted samples. The knitted samples were prepared from five fiber types (CO, CV, PAN, PES and PP), three spinning technology (OE Rotor, Ring and melt spinning) and four knitting structures (s.jersey, ribana, lacoste and interlock) as described in chapter 3. According to tested knitting properties this chapter is divided into five main sections; bursting strength, snagging, dimensional stability, skewness and pilling results. The effects of these properties on knitting structure, material and yarn types, washing process, tightness factor and ANOVA analysis of the results are discussed.

In order to understand the statistical importance of samples on given test methods and their effects an ANOVA was performed. Tukey multiple comparison test was used to determine the groups of fiber/yarn types, knitting structure and the effects of these groups on given properties. In addition to these, Pearson correlation analysis was done to show the relationship between bursting strength versus yarn strength and tightness factor from statistical approach. The effect of washing treatment on bursting strength is also related with Pearson correlation analysis. For this aim the statistical software package SPSS 11.5 was used to interpret the experimental data. All test results were assessed at significant levels of $P < 0,05$ and $P < 0,01$.

4.1 Bursting Strength

Bursting strength tests were performed for two sets of samples. In the first set four knitting structures, nine different yarn types (OE Rotor CO, Carded CO, Combed CO, Carded CV, OE Rotor PAN, PP Delta 1, PP Delta 2) were used to prepare 23 knitted samples. These samples were tested to obtain the effect of knitting structure, fiber & yarn type, washing process on the bursting strength. Second set of samples are produced from four continuous filament yarns (PP Delta 1, PP Delta 2, PP Round and PES Delta) for s.jersey structure. 12 samples were knitted for second set in tight, medium and loose tightnesses. The effect of tightnesses on (tight, medium, loose) the bursting strength is obtained from the results of second set. Test results indicated that knitting structure, material and yarn type, washing process and tightness factor affect the bursting strength. Knits from PP continuous filament yarns are most superior one in knitted samples and in different yarn types.

4.1.1 Effect of Knitting Structure

As illustrated in Figure 4.1 bursting strength is plotted against the knitting types for 5 different yarns.

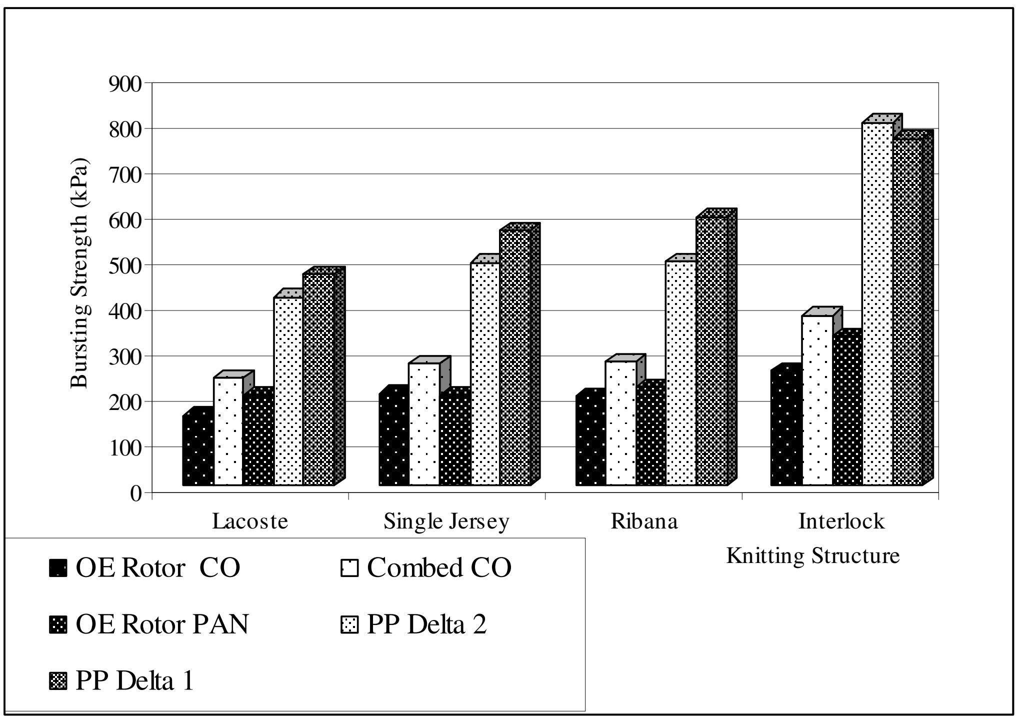


Figure 4.1. Bursting Strength of the Knitting Structures.

According to the test results shown in Figure 4.1, the strongest knitting structure is interlock and the weakest knitting structure is lacoste for all of the yarn types. According to the tensile properties of knitted fabrics are directly derived from loop configuration and yarn properties.

In interlock, because of the consumption of yarn is the highest, the knitting repeat is completed on double beds and is forming one row from two systems. This result is probably due to double and single plating structure. Heaviest knitted fabrics can be produced by interlock structure as compared to other single yarn knitted fabrics. Highest the yarn consumption and weight (stitch density) may probably cause highest bursting strength. For all type of fiber type and yarn technology; interlock is 50-37 % stronger than the lacoste, 38-15 % stronger than the ribana and 39-21 % stronger than the s.jersey structures.

Lacoste is produced by accumulating two or more loops on a needle and casting them off together. For Ne 30/1 and when the tightness factor is between 16,5-17,5 the structure of double tuck lacoste has at least 10 pores for w/cm and at least 6 pores for c/cm. Also lacoste has the lowest value of bursting strength because of porosity of knitting structure. This result is supported by Hongerall [69] who analyzed the unit cell/single loop.

Ribana and s.jersey fabrics have nearly similar effect on bursting strength. In general ribana is stronger than s.jersey for an average of 10-3%. This result may probably be the spring like structure of ribana.

ANOVA results on the effect of knitting structure are given in Appendix B1. Bursting strength data used in ANOVA analysis of knitting structures are grouped as knitting types 1, 2, 3 and 4 for knitting structures s.jersey, ribana, lacoste and interlock respectively. However, bursting strength results of PP Delta 1 and PP Delta 2 are assigned in the below.

The test results for PP Delta 1 exhibited that ($F_{(3-16)} = 78,40$, $P<0.01$) knitting structure has a significant effect on bursting strength.

The groups of samples were created by Tukey method according to the effect of knitting structure on bursting strength values. These results indicated that knitting type 3 ($\overline{X}$ =465,64) belonged the group that has the lowest value ($P < 0.05$) of bursting strength while knitting type 1 ($\overline{X}$ = 562,48), knitting type 2 ($\overline{X}$ = 589,98) fall in the group of the middle range of bursting strength value. The strongest value of this multiple comparison is knitting type 4 ($\overline{X}$ =762,06). According to Tukey multiple range test for PP Delta 1, hierarchy of knitting structure from strong to weak are interlock, ribana, s.jersey and lacoste as shown in Figure 4.1.

The test results for PP Delta 2 also exhibited that ($F_{(3-16)}$ = 282,27, $P<0.01$) knitting structure has a significant effect on bursting strength.

The groups of samples were created by Tukey method according to the effect of knitting structure on bursting strength values. These results showed that knitting type 3 ($\overline{X}$ =415,82) belonged the group that has the lowest value ($P < 0.05$) of bursting strength while knitting type 1 ($\overline{X}$ = 492,38), knitting type 2 ($\overline{X}$ = 494,56) fall in the group of the middle range of bursting strength value. The strongest value of this multiple comparison is knitting type 4 ($\overline{X}$ =800,84). According to Tukey multiple range test for PP Delta 2, hierarchy of knitting structure from strong to weak are interlock, ribana, s.jersey and lacoste as illustrated in Figure 4.1.

4.1.2 Effect of Fiber Type, Spinning Technology

Figure 4.2 shows the effect of fiber and yarn types on bursting strength for s.jersey structure.

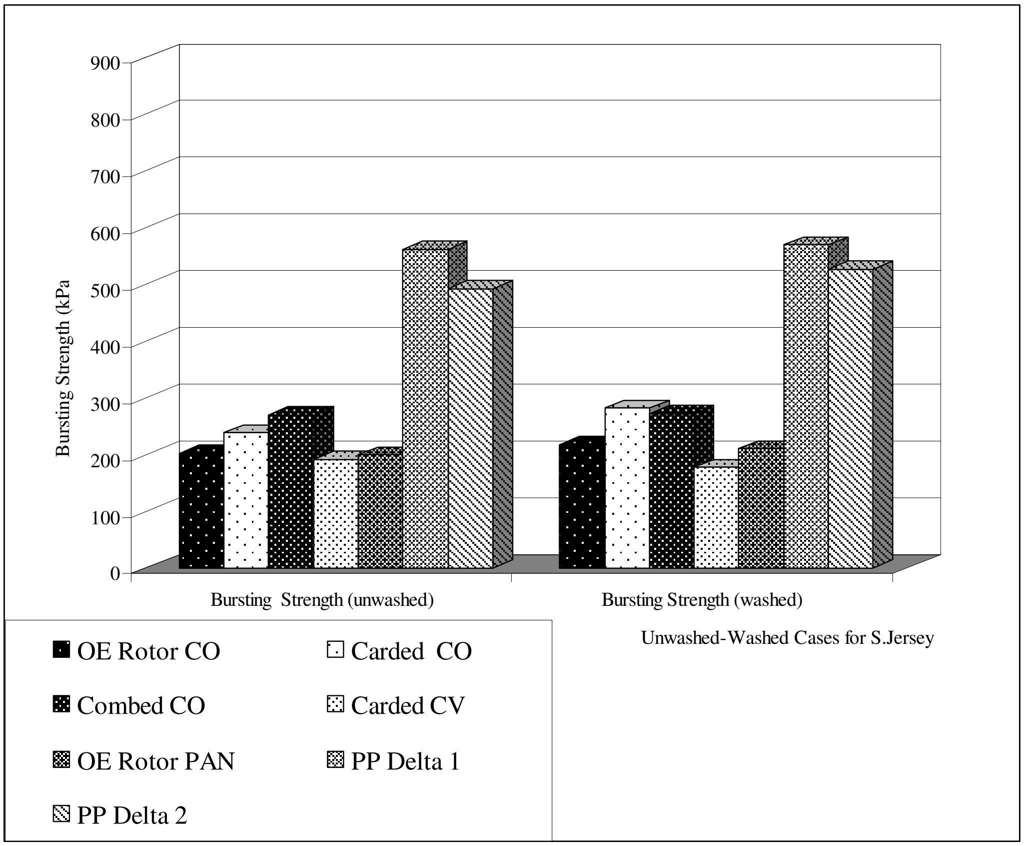


Figure 4.2. Effect of Fiber Type on Bursting Strength (S.jersey)

In Figure 4.2, four different spinning technologies and four different fiber types are illustrated. In this Figure, bursting strength values for s.jersey structures made up of seven different yarn types are plotted for unwashed and washed cases.

According to test results, bursting strength of knitted sample from PP Delta 1 for 28E s.jersey is 64% greater than the OE Rotor CO, 59 % stronger than the Carded CO, 51 % stronger than the Combed CO, and 12.5 % stronger than the PP Delta 2, 65% stronger than the OE Rotor PAN and 66% stronger than the Carded CV knits.

Test results of cotton yarns show that s.jersey structures knitted from combed cotton yarns are stronger than carded and OE Rotor CO knits (Figure 4.2). The bursting strength values of carded CV and OE Rotor PAN knits are in order of bursting strength values of OE Rotor CO. However, bursting strength values from s.jersey structures from filament yarns which are PP Delta1 and PP Delta 2 have much stronger values from those of the knits of spun yarns. Spun and filament yarns have considerable differences in performance, comfort, and aesthetics. Filament yarns are stronger than spun yarns of the same size and fiber type. The strength of spun yarns primarily comes from the ability of the fibers to adhere to each other, within the yarn twist. Filament yarns get their strength from their length [59], morphological structure. The tensile behaviour differences between s.jersey produced from PP and other spun yarns may be explained due to the tensile properties of fibers and spinning method. This idea is supported by Hatch [59] who was interested in mechanical and chemical properties of spun and filament yarns.

Therefore, knits from PP continuous filament yarns have more bursting strength value than the knits from spun yarns. This can be explained with the different production character of filament yarn structure and properties of PP fibers from that of spun yarns. It is known that PP fibers are used for reinforced structures. Even though, the advantage of strength of PP fiber is investigated by some researchers and some of them are discussed in literature survey. Similar results are also measured from other knitted structures (ribana, lacoste and interlock) and they are plotted in Figures 4.3, 4.4 and 4.5, respectively.

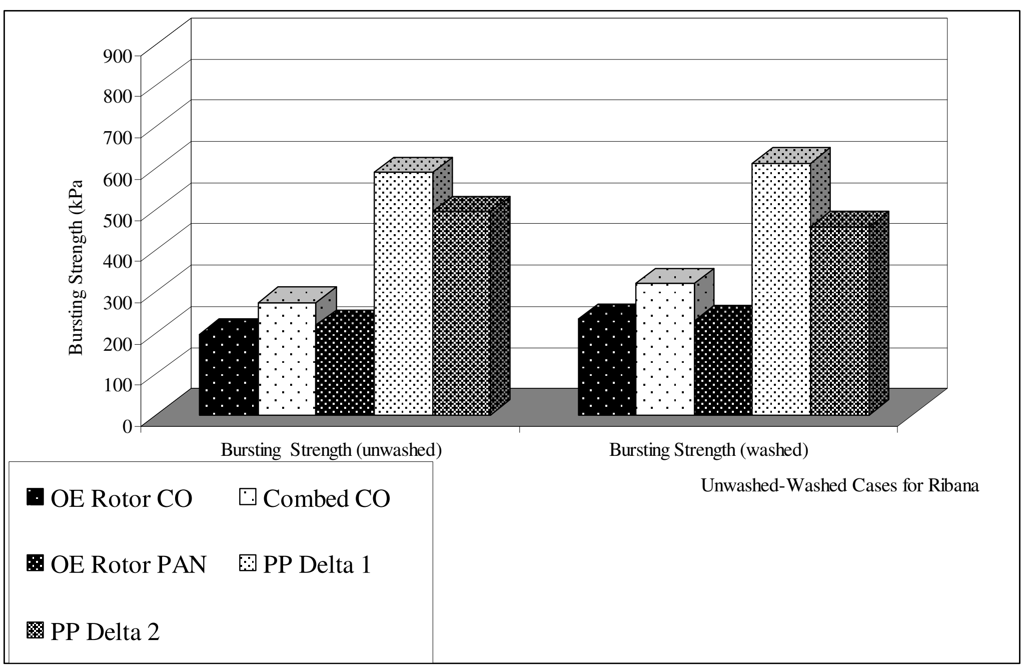


Figure 4.3. Effect of Fiber Type on Bursting Strength (Ribana)

Three different spinning technologies (OE Rotor, Ring and Melt Spinning) and three different fiber types (CO, PAN and PP) are shown in Figure 4.3. Five different samples were used to obtain the results.

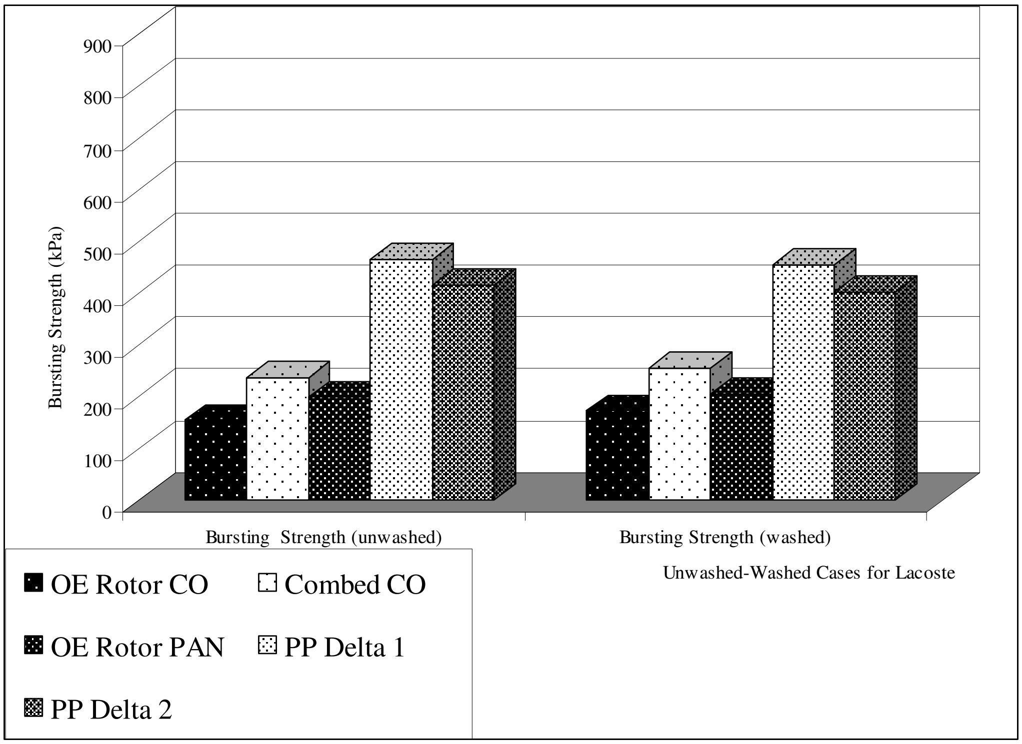


Figure 4.4 Effect of fiber type on bursting strength (lacoste)

Three different spinning technologies (OE Rotor, Ring and Melt Spinning) and three different fiber types (CO, PAN and PP) are shown in Figure 4.4. Five different samples were used to obtain the results.

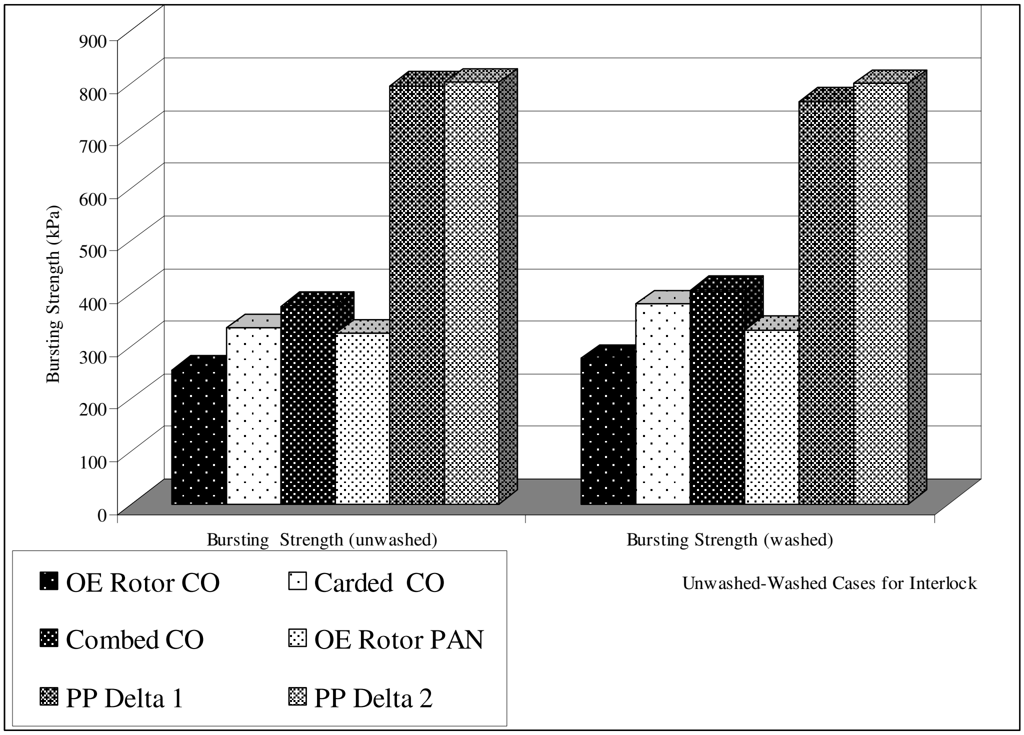


Figure 4.5 Effect of Fiber Type on Bursting Strength (Interlock)

Three different spinning technologies (OE rotor, Ring and Melt Spinning) and three different fiber types (CO, PAN and PP) are shown in Figure 4.5. Six different samples were tested and mean bursting strength values are used for plotting the graphs in Figure 4.5.

According to the test results, PP Delta 1 is stronger than PP Delta 2. This phenomenon can be explained probably the drawn process on the godets. Drawing affects the crystallinity of filaments from 50-60%[17].

Different fiber types and spinning technologies have different properties. The bursting strength of knitted fabrics compared with ANOVA. According to ANOVA, the effect of fiber type on bursting strength is found to be significant ($P<0.01$). ANOVA results on effect of fiber type are given in Appendix B2.

Bursting strength data used in ANOVA analysis of fiber types are grouped by Tukey multiple comparison test. The results for s.jersey structures are grouped as 1,2,3,4,5,6 and 7 for yarn types OE Rotor CO, Carded CO, Combed CO, Carded CV, OE Rotor PAN, PP Delta1 and PP Delta 2 respectively. The test results of fiber types in s.jersey structure ($F_{(6-28)}$ = 271,00, P<0.01) have a significant effect on bursting strength.

Tukey test designed five groups of samples according to the effect of fiber type on bursting strength values. Group 1 are consisted of fiber type 4 ($\overline{X}$ =191,7), fiber type 5 ($\overline{X}$ =199,22) and fiber type 1 ($\overline{X}$ =202,82), that have the lowest values ($P < 0.05$) of bursting strength while fiber type 6 ($\overline{X}$ =562,48) has highest bursting strength value. According to Tukey multiple range test for s.jersey, 7 different fiber types were analyzed. The results indicated that the strongest fiber was PP Delta 1 than PP Delta 2, combed CO, carded CO, OE Rotor CO, OE Rotor PAN, and carded CV.

The Pearson correlation analysis given in Appendix B5 shows that there is an important, positive and significant relationship between yarn strength and bursting strength values (r=0.966, P<0.01). Bursting strength data of s.jersey knits are plotted against yarn strength for all yarn types and shown in Figure 4.6. It is seen that high yarn strength causes high bursting strength of knitted structure. The calculated r^2 value for correlation, given in Figure 4.6, is determined as 0,933.

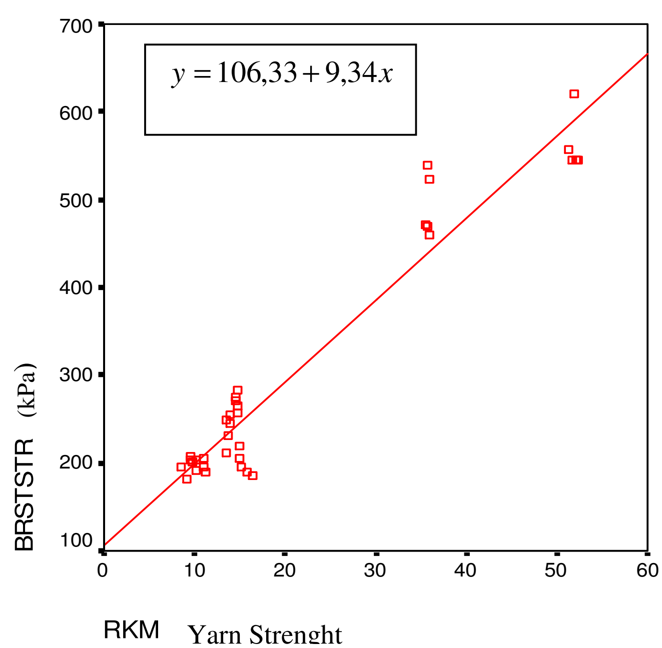


Figure 4.6. Effect of Yarn Strength on Bursting Strength

According to the Pearson correlation, test results shows that there is significant correlation between yarn strength and bursting strength (Appendix B5). All results were also supported by the researchers, Shahbaz et al. [81], Ertugrul and Nuray [80], Candan et al. [79] and Ömeroğlu [96]. Shahbaz et al. [81] revealed that fabric strength largely depends upon the yarn strength. Ertugrul and Nuray [80] reported that the fabric weight, yarn strength and yarn elongation are the major parameters that affect the bursting strength of knitted fabrics.

According to Tukey multiple range test for s.jersey, the mean bursting strength value of OE Rotor CO, carded CO and combed CO are $\overline{X}$ =202,82, $\overline{X}$ =238,58 and $\overline{X}$ =270,22, respectively ($P < 0.05$). This result is well supported by Candan et al. [79]. They stated that the knits from ring spun technology have more bursting strength value than that of knits from OE Rotor spun technology. Ömeroğlu [96] reported the bursting strength value of s.jersey structure manufactured with combed CO is 230,8 kPa. This value is less than that of combed CO samples of this research.

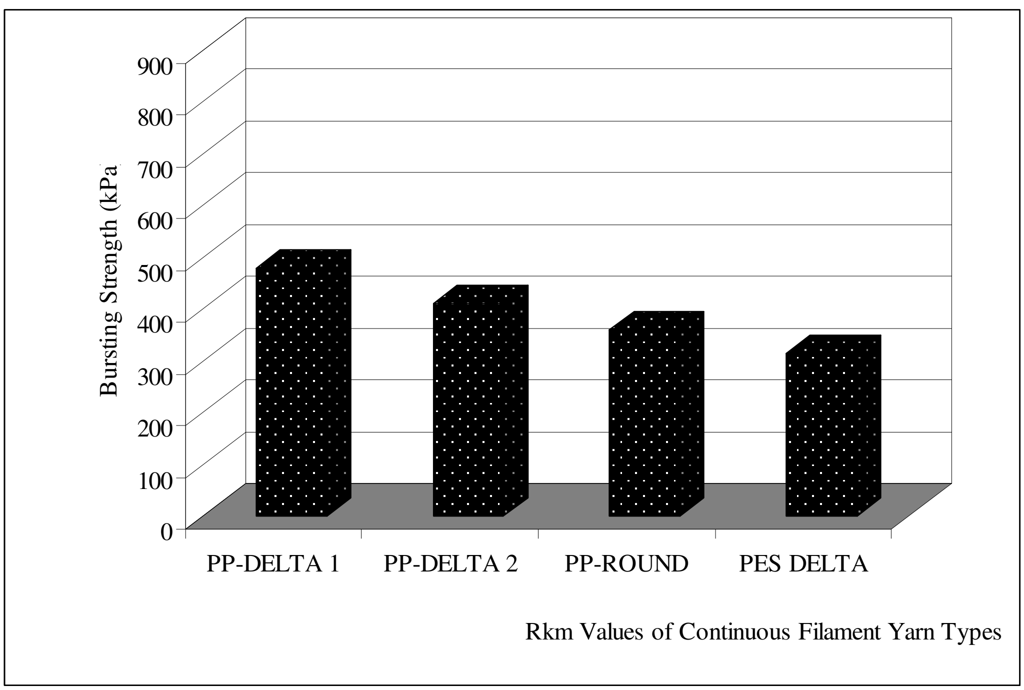


Figure 4.7. Bursting Strength of Continuous Filament Yarns (S.Jersey on 22E machine)

In Figure 4.7, the bursting strength values of s.jersey fabrics from 22E knitting machine is plotted for filament yarns PP Delta 1, PP Delta 2, PP Round and PES Delta. It is seen from Figure 4.7 that PP Delta 1 is stronger than PP Delta 2, PP Round and PES Delta. The yarn strength value of PP Delta 1 is 51.44 Rkm while bursting strength value is 477,9 kPa.

ANOVA results about the effect of continuous filament yarns are given in Appendix B3. Bursting strength data used in ANOVA analysis of s.jersey structures manufactured on 22E machine for the same tightness factor ($\overline{X}$ =13,6) are grouped as 8, 9, 10 and 11 for PP Delta1, PP Delta 2, PP Round and PES Delta respectively The test results of continuous filament yarns used in s.jersey structure produced with same tightness factor ($F_{(3\text{-}16)}$ = 55,08, $P<0.01$) have a significant effect on bursting strength.

Tukey test created groups of samples according to the effect of continuous filaments yarn type on bursting strength values. These results showed that PP Delta 1 ($\overline{X}$ = 477,9) belong the group that has the highest value ($P < 0.05$) of bursting strength while the PP Delta 2 ($\overline{X}$ = 410,56) and PP Round ($\overline{X}$ = 359,44) belong the second and third group respectively. The group fourth is PES Delta ($\overline{X}$ = 312,96) and has the lowest bursting strength value. According to Tukey multiple range test for s.jersey manufactured in 22E knitting machine, hierarchy of bursting strength of continuous filament yarns from strong to weak are PP Delta1, PP Delta 2, PP Round, PES Delta like as illustrated in Figure 4.7 .

4.1.3 Effect of Washing Treatment

The influence of washing conditions on bursting strength of knitted samples can be seen from Figures 4.8, 4.9, 4.10 and 4.11 for knitting structures s.jersey, ribana, lacoste and interlock respectively.

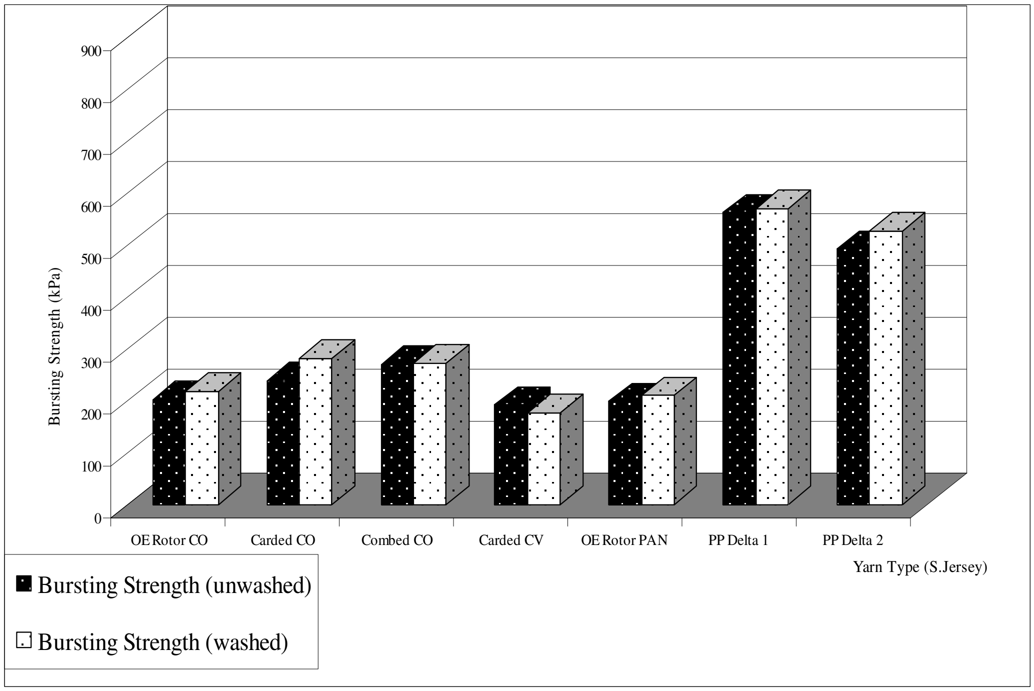


Figure 4.8. Washing Effect on Bursting Strength (S. Jersey)

According to the test results shown in Figure 4.8 there is an increase in bursting strength with washing process except carded CV. The decrease in bursting strength of carded CV with washing process can probably be due to the low wet modulus of viscose.

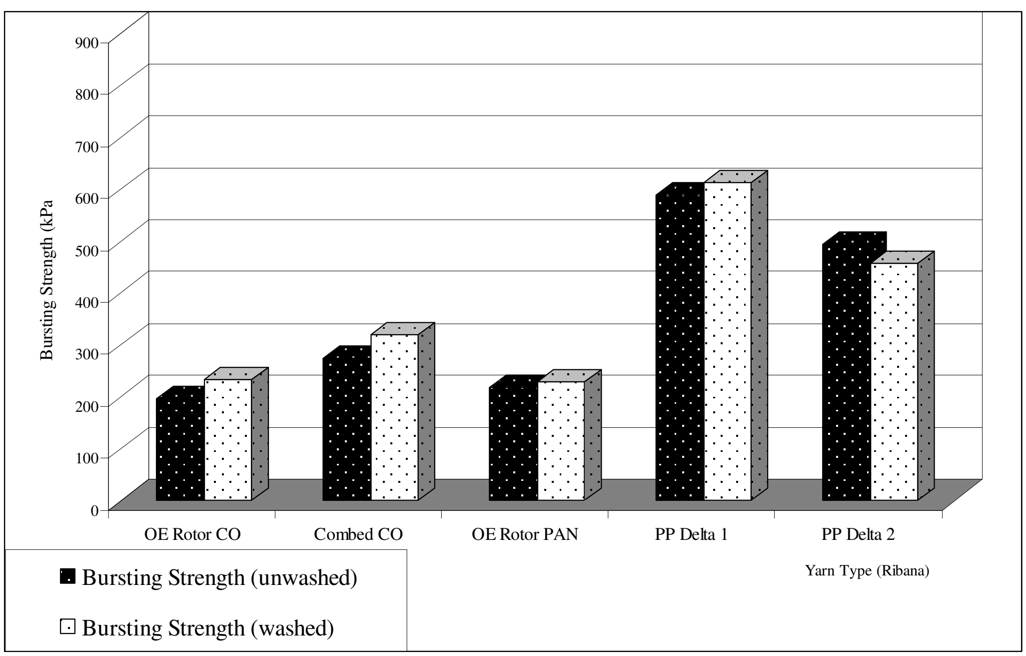


Figure 4.9. Washing Effect on Bursting Strength (Ribana)

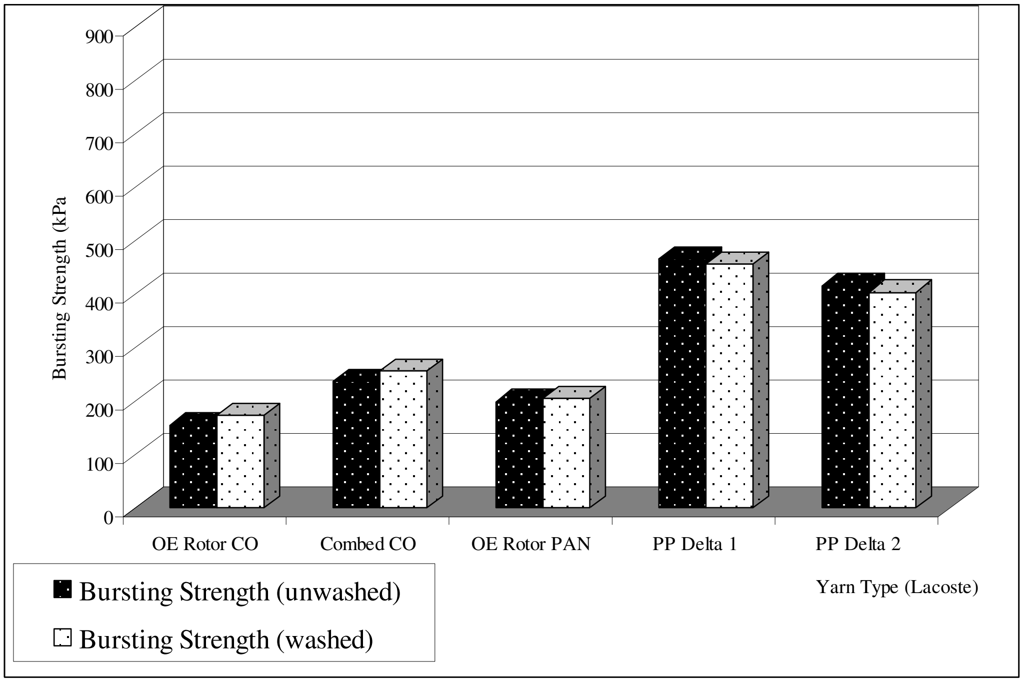


Figure 4.10. Washing Effect on Bursting Strength (Lacoste)

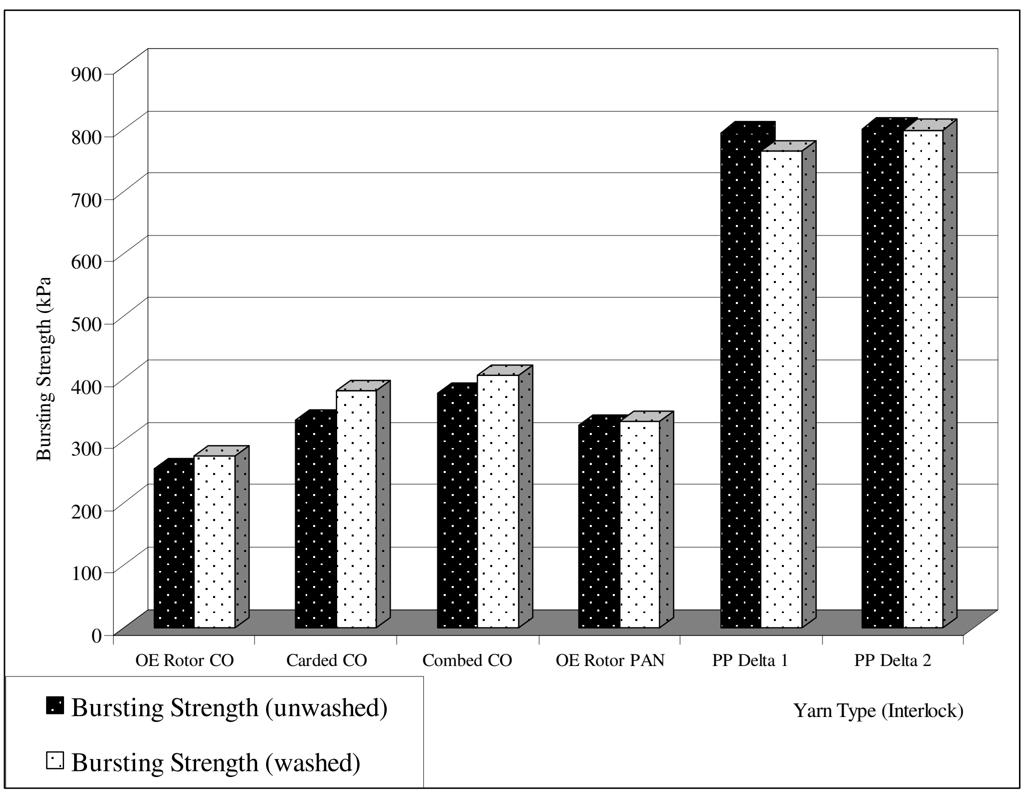


Figure 4.11. Washing Effect on Bursting Strength (Interlock)

The Pearson correlation analysis showed that there is an important, positive and significant relationship between bursting strength values of unwashed and washed samples (r =0.987, P<0.01) (Appendix B6). Bursting strength data of washed samples are plotted against unwashed samples shown in Figure 4.12. There is linear correlation between them with a calculated r^2 value is 0.974 (Figure 4.12). This means the washing treatment increases the bursting strength.

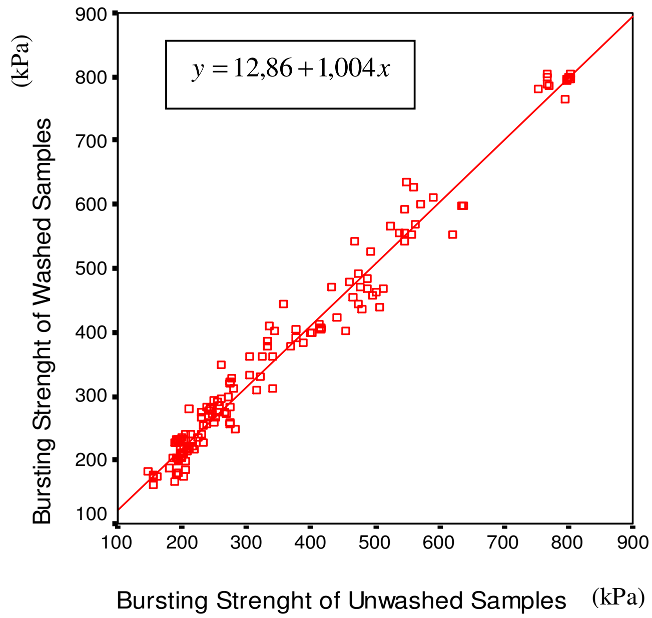


Figure 4.12. Correlation between Unwashed and Washed Samples

For all knitted structures, bursting strength values of samples changed in a variety range after washing process. A positive change of bursting strength values indicates an increase in bursting strength after washing. A negative value represents a decrease in bursting strength after washing. For s.jersey structures, the changes after washing are 7,07%, 15,45 %, 0,93 %, -8,01%, 5,17%, 1,3% and 6,6% belong to the yarn types of OE Rotor CO, Carded CO, Combed CO, Carded CV, OE Rotor PAN, PP Delta 1 and PP Delta 2, respectively. For ribana structures, the changes after washing are 16,06%, 14,22 %, 5,35%, 3,56% and -8,19 % belong to the yarn types of OE Rotor CO, Combed CO, OE Rotor PAN, PP Delta 1 and PP Delta 2, respectively. For lacoste structures, the changes after washing are 10,6%, 7,2 %, 3,3%, -2,07% and -3,06 % belong to the yarn types of OE Rotor CO, Combed CO, OE Rotor PAN, PP Delta 1 and PP Delta 2, respectively. For interlock structures, the changes after washing are 7,6%, 12,09 %, 7,13 %, 1,7%, 3,83% and -0,25% belong to the yarn types of OE Rotor CO, Carded CO, Combed CO, OE Rotor PAN, PP Delta 1 and PP Delta 2, respectively. However in ribana, the increase is more than the other knitting structures. This can be probably explained by the loop shape factor or increase in the stitch density.

It is clearly seen that the bursting strength value of ribana of PP Delta 2 decreased by washing. This result can be thought as a special case. The tightness factor of PP Delta 2 for ribana structure is 14,54. Normally the tightness factor of ribana is a range of 15,30-17. As a result of this tightness factor, dimensional stability of ribana manufactured from PP Delta2 is enlarged while the others shrink. This can also be probably reason why the bursting strength of PP Delta 2 is stronger than PP Delta 1 in ribana structure.

From results of the comparison of unwashed and washed values, it is clearly seen that the bursting strength value of PP continuous filament yarn do not change significantly after washing. For lacoste the bursting strength values are decreases after washing. This can probably be the porosity structure of lacoste or non-texturized structure of PP continuous filament yarns. For the structures other than lacoste manufactured from PP continuous filament yarns, change of bursting strength values are not significant and not similar. However the decreases may probably be occurred from the operator of this test. The increases of the bursting strength values may probably be the dynamics of knitting machine. As given in the chapter 2, dimensional stability is affected by the take down tension. After washing process the stress on the fabric is relaxed. Normally washing process not only affects the relaxation of the fabric but also affect the relaxation of the yarn stress. However, filament yarn stress within yarn structure is less than the spun yarns. These two reasons may probably be an explanation of less changes of bursting strength of knitting structures manufactured from PP continuous filament yarns. This opinion is supported by Tuarijonaviciene et al. [94] who had reported that yarns were relaxed after washing procedure.

An increase in the bursting strength value is also supported by Conrad et al [77]. They observed that the changes occurring after laundering were largely due to alterations in the loop shape rather than the loop length dimensional changes.

However this opinion belongs to finished fabrics. For raw fabric, it is assumed that natural fibers are shrinking when the first wet operation goes on. Regenerated fibers are shrinking less than natural fibers and synthetic fibers are nearly never shrinking. They indicated bursting strength after washing increased because of changes in loop shape. Ucar [84] observed that with wash and dry relaxation of fabric progresses, compactness of structure (loop number per area) increases. This leads to an increase in inner friction and compression.

4.1.4 Effect of Tightness Factor

There is a general trend that an increase in the tightness factor leads to an increase in bursting strength. As discussed in chapter 2, cover factor (d/l) affect the tightness of the fabrics. The effect of the tightness factor can probably be explain as follows; when loop lengths are at the lower values the jamming value increases due to the higher tightness of knitted structures.

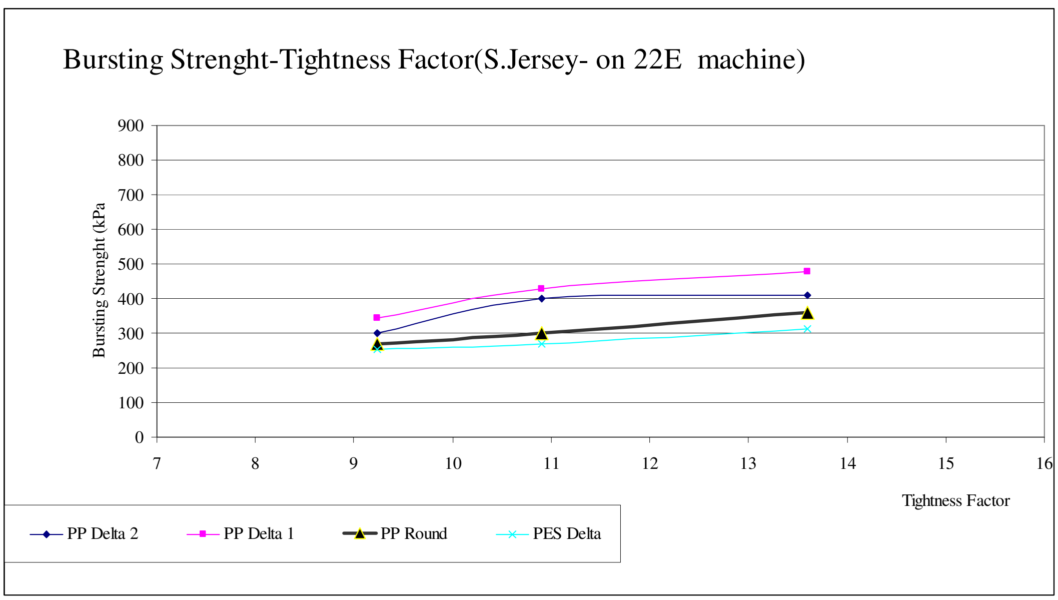


Figure 4.13. Effect of Tightness Factor as a Comparison of Raw Material on Bursting Strength (S.Jersey)

Figure 4.13 shows the effect of tightness factor on bursting strength for PP Delta 1, PP Delta 2, PP Round and PES Delta. From Figure 4.13 it is clearly seen that there is a correlation between tightness factor and bursting strength. Also the

Pearson correlation analysis used to determine the correlation between these two parameters. Figure 4.14 shows scatter plotted diagrams of this correlation for PP Delta 1 in 22E s.jersey structure. Pearson correlation results (Appendix B7) show that there is positive and significant relationship between tightness factor and bursting strength values (r =0.856, P<0.01). The calculated r^2 value is 0.732. This means when the tightness factor increases, the bursting strength increases.

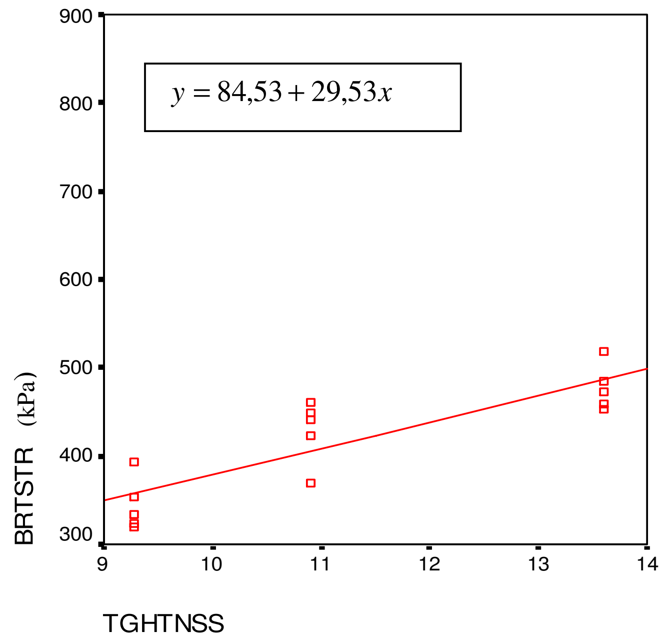


Figure 4.14. Correlation between Tightness Factor and Bursting Strength

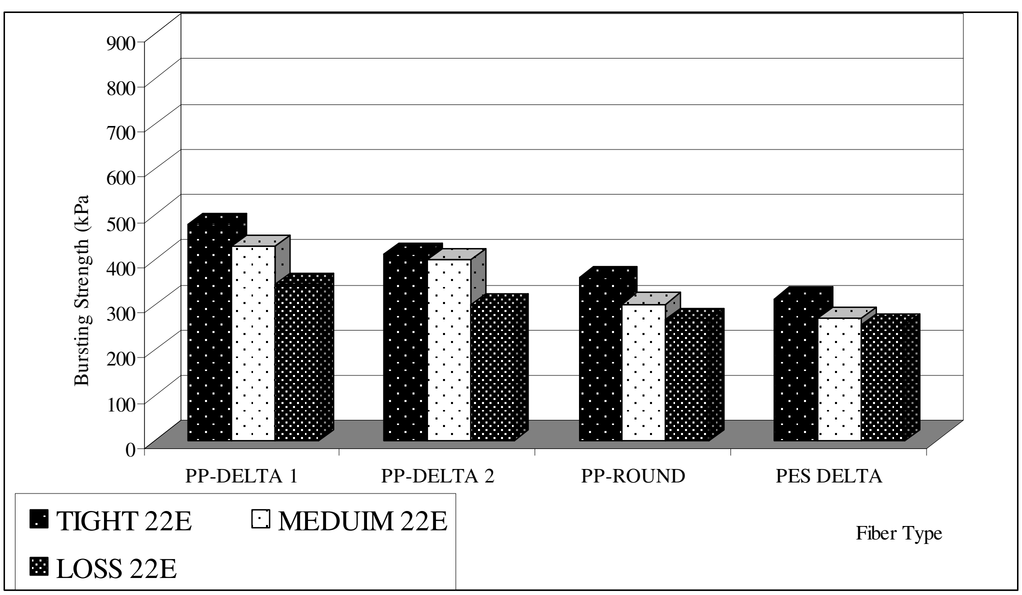


Figure 4.15. Effect of Tightness Factor on Bursting Strength (S.Jersey)

For S.jersey manufactured in 22E knitting machine; the effect of tightness factor on bursting strength is found to be significant ($P<0.01$) according to ANOVA.

ANOVA results about the effect of tightness factor are given in Appendix B4. Bursting strength data used in ANOVA analysis of s.jersey structures are grouped as tightnesses 1, 2 and 3 for tight, medium and loose structure respectively. According to the results of bursting strength for PP Delta 1 ($F_{(2\text{-}12)} = 23{,}27$, $P<0.01$) tightness has a significant effect on bursting strength.

Tukey test created groups of samples according to the effect of tightness factor on bursting strength values. These results showed that the samples have tight loop length ($\overline{X} = 477{,}9$) and medium loop length ($\overline{X} = 428{,}24$) consisted the group that has the highest value ($P < 0.05$) of bursting strength while the sample has loose loop length ($\overline{X} = 344{,}82$) consisted the group that cause the lowest value of bursting strength. According to Tukey multiple range tests for filament type PP Delta 1 for s.jersey manufactured in 22E knitting machine, hierarchy of bursting strength from strong to weak are tight, medium and loose like as illustrated in Figure 4.15. Figure 4.15 also shows that the effect of tightness factor on bursting strength knits from PP Delta 2, PP Round and PES Delta. Same trend with knits from PP Delta 1 can be observed on this Figure for other continuous filament knits.

It is clearly seen in Figure 4.5. that the bursting strength value of PP Delta 2 in interlock is higher than the PP Delta 1. This result can be thought as a special case. Despite the tightness of interlock manufactured with PP Delta 1 is 13,73, the tightness factor of interlock produced with PP Delta 2 is 17,45. This is the why the bursting strength of PP Delta 2 is stronger than PP Delta 1 in interlock.

4.2 Dimensional Stability

The results obtained from dimensional stability tests would significantly be different for four fabric structures due to distinct nature of each structure. A positive dimensional stability test result indicates an increase in length extension. A negative value represents a decrease and hence shrinkage.

The first set of samples which described in section 4.1 are tested for dimensional stability.

4.2.1 Effect of Knitting Structure

Figure 4.16 and 4.17 illustrate the test results of dimensional stability of knitting structures for widthwise and lengthwise, respectively.

As discussed in the section 4.1.3 dimensional changes are different from fiber to fiber and spinning technology to spinning technology. From Figure 4.16 it is clear that the dimensional stability for s.jersey structure in widthwise direction is very high, except knits from PP continuous filament yarns. The highest value for widthwise direction of s.jersey may due to the single plated and unbalanced structure of the s.jersey. For the four different knitting structures dimensional changes of s.jersey knits widthwise and lengthwise are different. This is not very surprised because various stitch formation (knit, tuck and miss) create individual knit structures, causing relevant fabric structures to have different dimensional behaviour.

Despite s.jersey, dimensional stability values of ribana structure for widthwise are very high for all type of samples (Figure 4.16). This may probably be the spring like structure of ribana. The positive value of PP Delta 2 is discussed in the section 4.1.3.

As shown in Figure 4.16 dimensional stability of lacoste has minimum value for CO knit fabrics in widthwise direction. This result is supported by Conrad et.al [77] who observed that the plain s.jersey and lacoste fabrics displayed lower changes in width direction. Despite the dimensional behaviour of CO lacoste fabric, PP continuous filament yarns have opposite tendency for widthwise dimensional changes. This problem is probably due to the filament yarn texturized effect. However, filament yarns used in this thesis are not texturized so there is not a frictional force to connect loops each other. Lacoste structure is consisted of tuck loops, filament yarns can easily slipped over. However, there is no miss, tuck or float loop in s.jersey, ribana and interlock. This is the reason why the effect of texturizing does not seen in the other knitting types.

The same effect observed from s.jersey can also be seen from interlock. Interlock is known as double jersey and it has a balanced structure. Tendency to dimensional changes for interlock is highest for natural fibers and lowest for synthetic filament fibers.

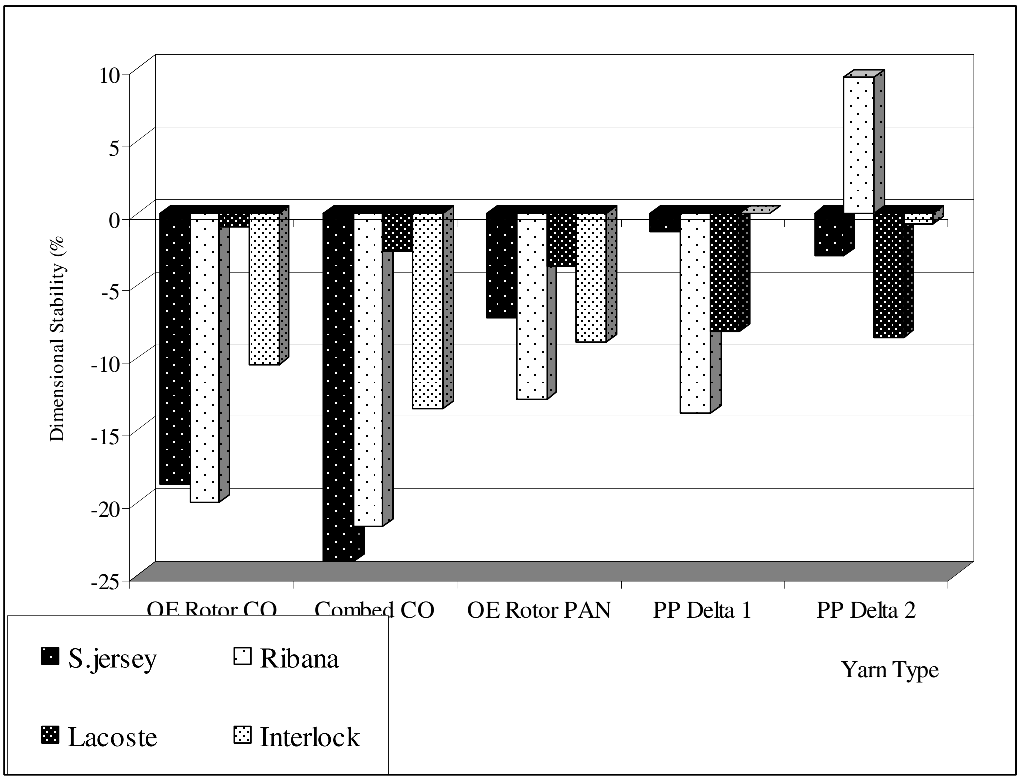


Figure 4.16. Dimensional Stability of four Knitted Structure (for widthwise)

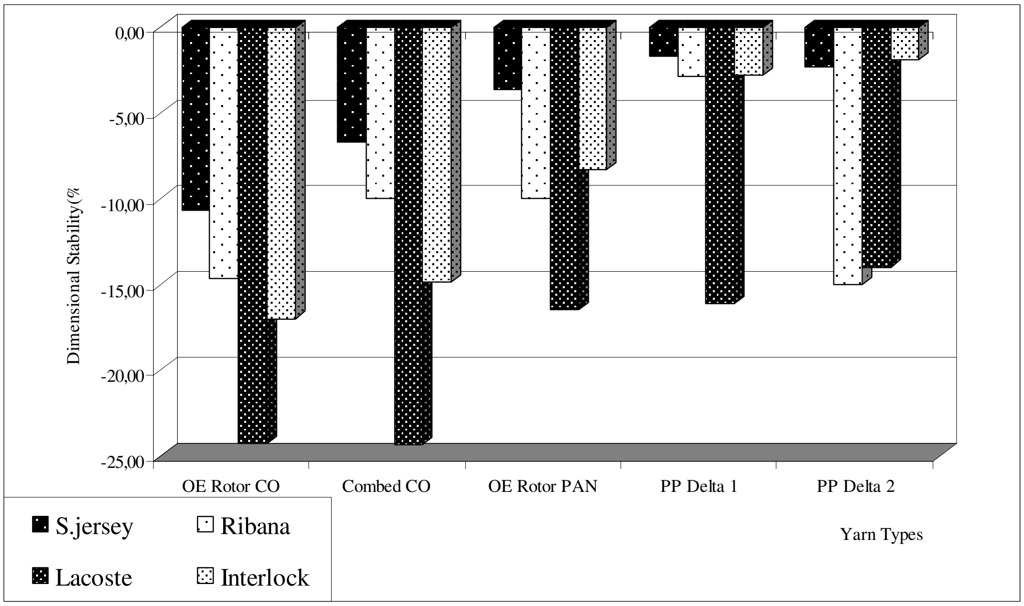


Figure 4.17. Dimensional Stability of four Knitted Structure (for lengthwise)

Lengthwise dimensional stability value is affected by the take-down tension. According to Abou-IIana [73]; the value of take-down tension depends on machine type and fabric structure. As it is seen in Figure 4.17, the lengthwise directional changes are not only depends on the fabric types but also have been extended along the vertical direction by take down tension.

Even with the same knit type (shown in Figure 4.18, 4.19, 4.20 and 4.21) dimensional stability change for both yarn type and fiber type. Fiber distribution and physical properties of spinning technology affect the amount of fabric dimensional stability.

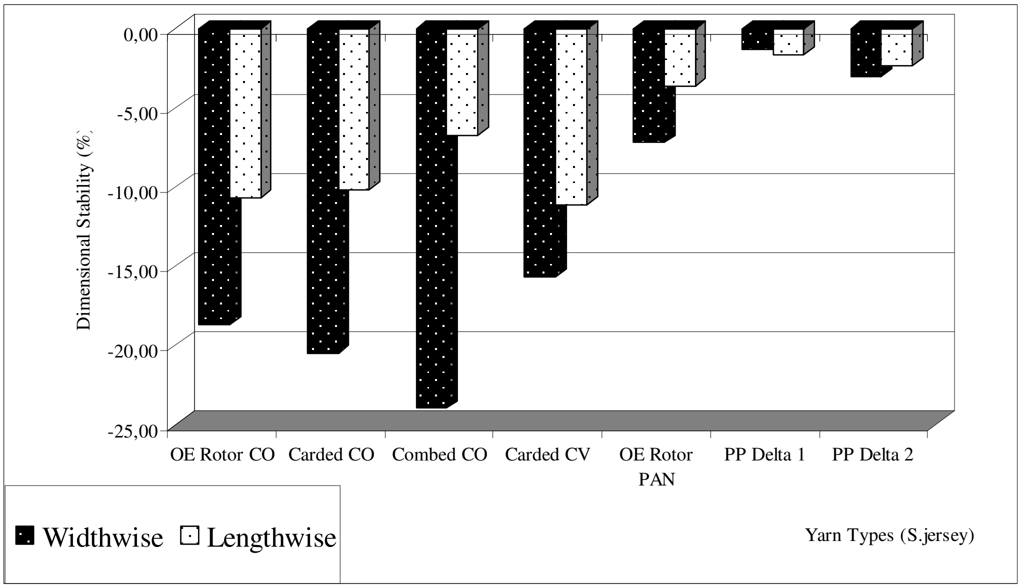


Figure 4.18. Dimensional Stability of Yarn Types (S.jersey)

As illustrated in Figure 4.18 S.jersey has a special behaviour for lengthwise direction. This may probably be due to the non elastic structure of s.jersey in the lengthwise direction.

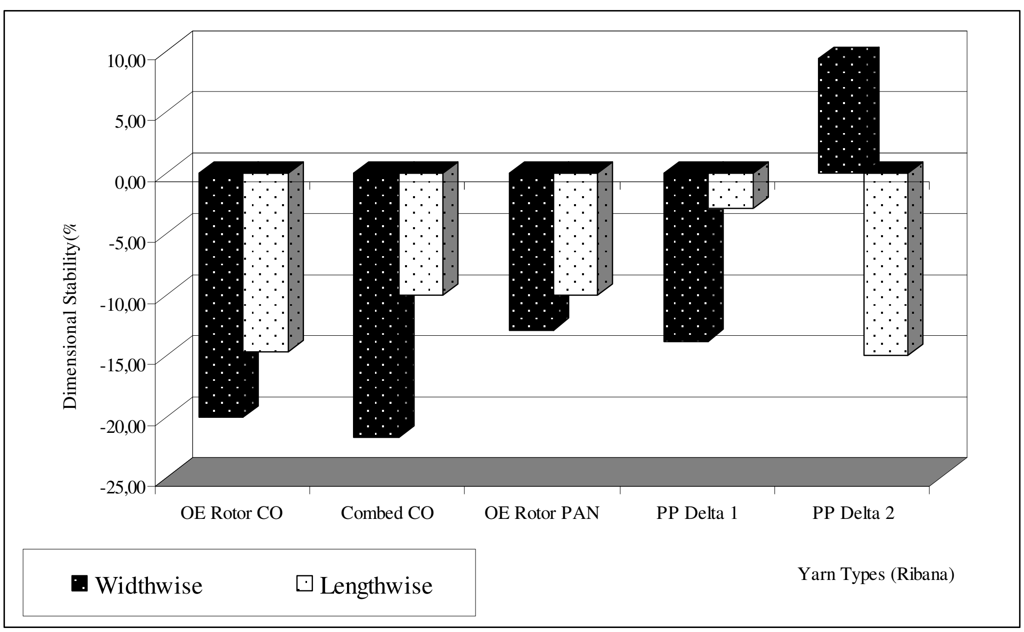


Figure 4.19. Dimensional Stability of Yarn Types (Ribana)

According to the test results shown in the Figure 4.19, ribana structures have similar trend in OE Rotor CO and OE Rotor PAN in widthwise and lengthwise directions. On the other hand, the ratios of widthwise/lengthwise dimensional changes for OE Rotor CO and OE Rotor PAN are nearly same while it is different for combed CO.

High widthwise changes may be probably due to the spring like structure of ribana. It is shrunk when it is in the relaxation treatment.

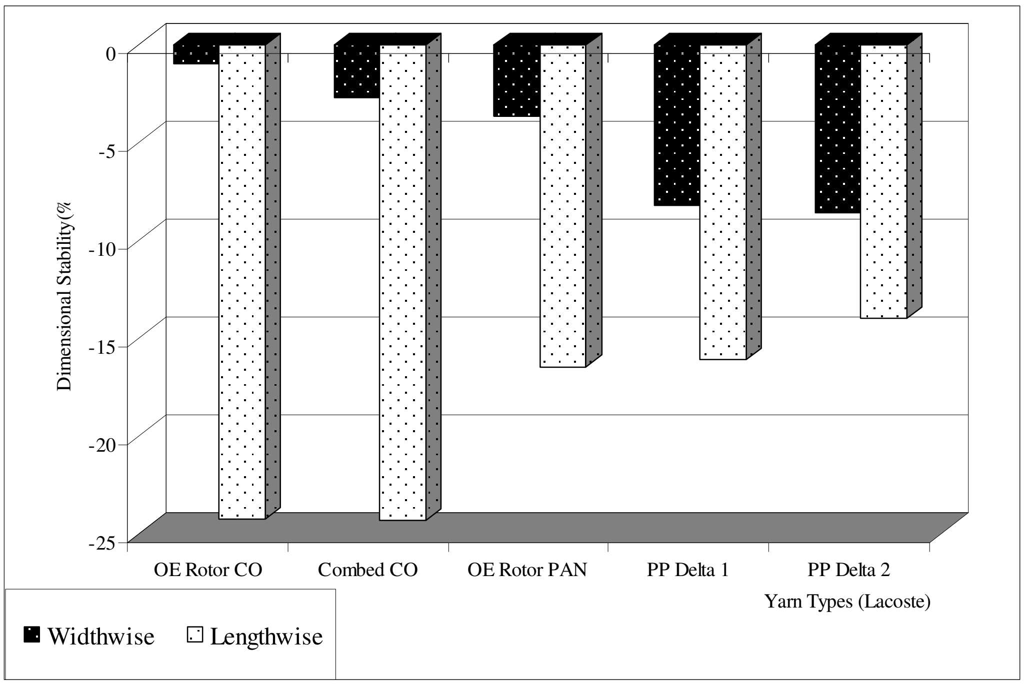


Figure 4.20 Dimensional Stability of Yarn Types (Lacoste)

According to the test results shown in the Figures 4.18 and 4.20; dimensional stability values in widthwise direction for s.jersey structure decrease from combed CO, OE Rotor CO, OE Rotor PAN, PP Delta 1, and PP Delta2. On the other hand, dimensional stability values for lacoste in widthwise direction increase from OE Rotor CO, combed CO, OE Rotor PAN, PP Delta 1 and PP Delta2. Our results agree with Onal [72] for both knitting structures. The existence of double tuck stitches in pique knit is believed to be responsible in this reverse relation. The shorter loop length of the tuck stitch possibly decreases the amount of width dimensional stability.

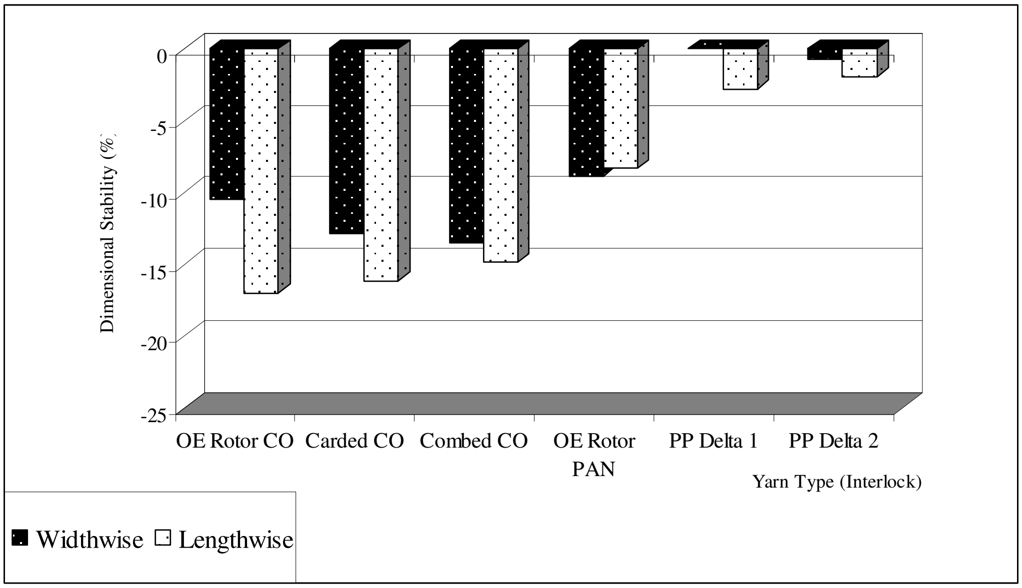


Figure 4.21 Dimensional Stability of Yarn Types (Interlock)

Due to the test results of dimensional stability, in interlock structure widthwise dimensional stability is lower than the lengthwise direction. This may be due to the balanced structure of this kind of knitting type. Lengthwise changes may be due to the take down tension of the knitting machine.

4.2.2 Effect of Fiber Type and Spinning Technology

The dimensional stability differences not only depend on the knit type but also the fiber type and spinning technology.

For s.jersey structure, it can easily be seen that OE Rotor spinning technology is better than the carded CO and combed CO, respectively. As shown in Figure 4.18, for the widthwise direction carded CV is better than the OE Rotor CO. Dimensional stability of PP continuous filament yarns is the best one. Filament technology may probably be causing the results.

Since, OE Rotor spinning technology processes have better extensibility; evenness and bulk, knitted fabrics of OE Rotor yarns are expected to be more dimensionally stable than the ring spun yarns. This phenomenon is supported by test results of Onal [72] who is revealed OE Rotor fabrics shrink somewhat less widthwise than ring spun samples of s.jersey and lacoste. From the Figures 4.18 and 4.20 the dimensional change behaviour of s.jersey and lacoste structures were reversed for lengthwise for OE Rotor CO and combed CO. Same relation is expected between ring spun and melt spinning method. Dimensional stability of knits from PP continuous filament yarns is lower than the knits from spun yarns. Therefore this causes easy finishing processes for knits from PP knits in dying house. The shrinkage potential (stitch density) of fully relaxed continuous filament PP knits is lower than the OE Rotor CO, Combed CO, OE Rotor PAN. Hallman et al [75] attempt to determine the shrinkage behaviour of the filament yarns. They reported that the shrinkage behaviour describes stress relaxation in the crystalline regions of the fiber material. The amount of shrinkage is essentially determined by the molecular weight, the amorphous orientation factor and degree of crystallinity [75].

The dimensional stability results of s.jersey structures indicated that the knits from OE Rotor PAN are 41% better than knits from OE Rotor CO. This is supported by Coruh [66]. She investigated the effect of PES, PAN and CO on dimensional stability and she was found the above value as 37% better than OE Rotor CO.

4.3 Pilling

23 knitted samples were used in pilling tests and sample lists are given in Table A1. These samples were tested to obtain the effect of knitting structure, fiber & yarn type, washing process on the pilling resistance.

It was well known that filament yarns do not have pilling tendency. However, in this study, pilling tests were performed. Figure 4.22 shows the photographic view of a sock, which is produced for R&D center of Özçelik A.Ş., used and washed nearly every weak during 1,5 years. According to these practice from real life, under high forces and more tumbling time, pilling behaviour of continuous filament yarns can be occurred. The prediction of pilling performance is therefore an enormous task. It requires an in-depth knowledge of PP. In this study, only 2000 revolution was used as implementation in the industrial uses.

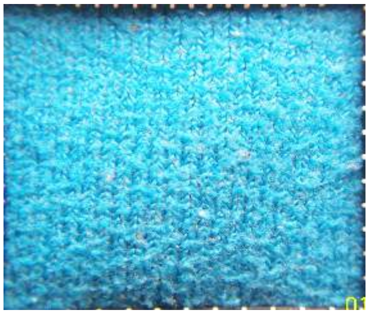


Figure 4.22 Photographic View of used PP S.Jersey Knitted Fabric

The pilling results for 125, 250, 500, 1000 and 2000 revolution for unwashed & washed samples are listed in Table 4.1.

Table 4.1 Pilling Resistance Test Results

Test Methods		Pilling Martindale (Unwashed Cases)				Pilling Martindale (washed Cases)			
Type of Fabric		Test Results				Test Results			
		125	500	1000	2000	125	500	1000	2000
OE Rotor CO	S.Jersey	4-5	4	4	4	4	4	3-4	3-4
	Ribana	4	4	3-4	3-4	4-5	4	4	4
	Lacoste	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
	Interlock	3	3	2-3	2	3-4	3	2-3	2
Carded CO	S.Jersey	4	3-4	3	3	3-4	3	2-3	2-3
	Interlock	3	2-3	2-3	2-3	3-4	3	3	2-3
Combed CO	S.Jersey	3-4	4	3-4	2-3	3-4	3-4	3-4	3
	Ribana	4	3-4	3	3	4	3-4	3-4	3
	Lacoste	4-5	4-5	4-5	4	4-5	4-5	4-5	4-5
	Interlock	3-4	3	3	2-3	3-4	3	2-3	2
PP Delta 1	S.Jersey	5	5	5	5	5	5	5	5
	Ribana	5	5	5	5	5	5	5	5
	Lacoste	5	5	5	5	5	5	5	5
	Interlock	5	5	5	5	5	5	5	5
PP Delta 2	S.Jersey	5	5	5	5	5	5	5	5
	Ribana	5	5	5	5	5	5	5	5
	Lacoste	5	5	5	5	5	5	5	5
	Interlock	5	5	5	5	5	5	5	5
OE Rotor PAN	S.Jersey	4-5	4-5	4-5	4	4-5	4-5	4-5	4-5
	Ribana	4-5	4-5	4-5	4	4-5	4	4	4
	Lacoste	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
	Interlock	4-5	4-5	4-5	4-5	4-5	4	4	4
Carded CV	S.Jersey	3	2-3	2	2	3	2	2	2

5.3.1 Effect of Knitting Structure

The pilling resistances of knitted samples for unwashed & washed cases at 2000 revolution for different fiber & yarn types(OE Rotor CO, Carded CO, Combed CO, Carded CV, OE Rotor PAN, PP Delta 1, PP Delta 2) in single jersey, ribana, lacoste and interlock structures are plotted in Figure 4.23, 4.24, 4.25 and 4.26, respectively.

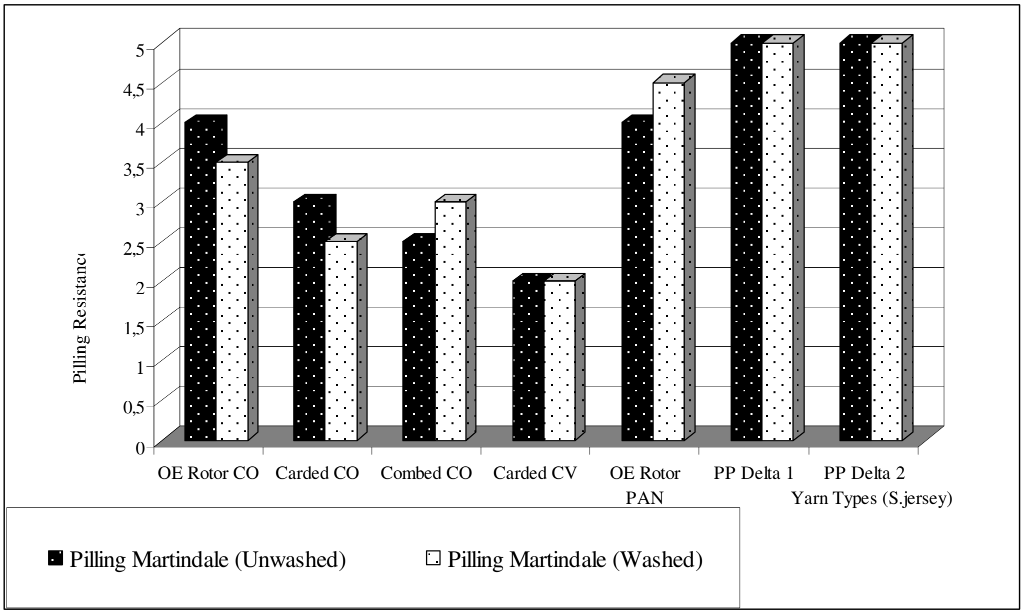


Figure 4.23 Pilling Grade of Yarn Types (2000 revolution-S.jersey)

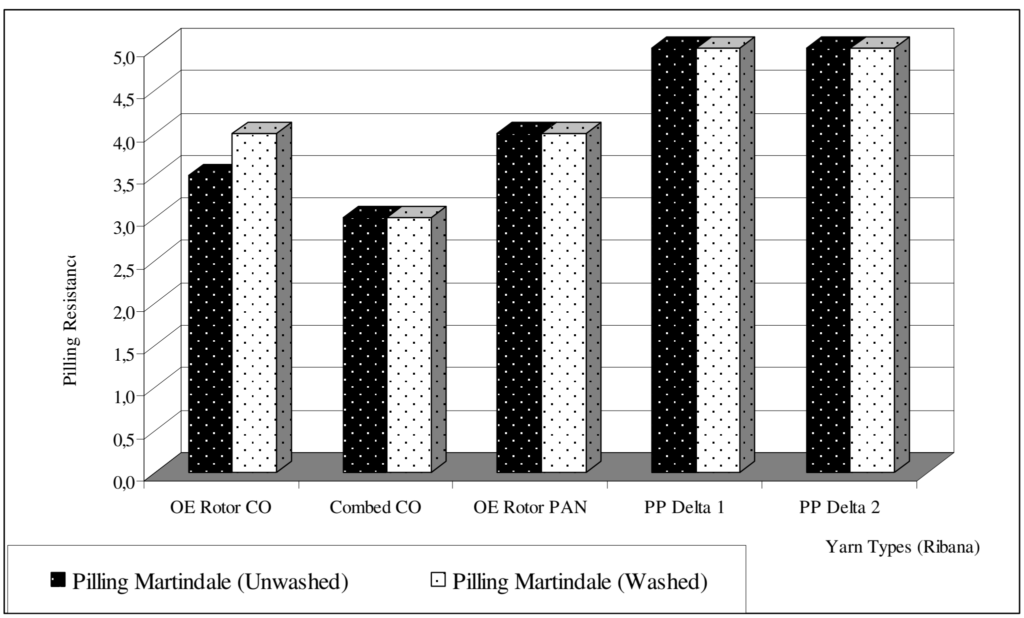


Figure 4.24 Pilling Grade of Yarn Types (2000 revolution-Ribana)

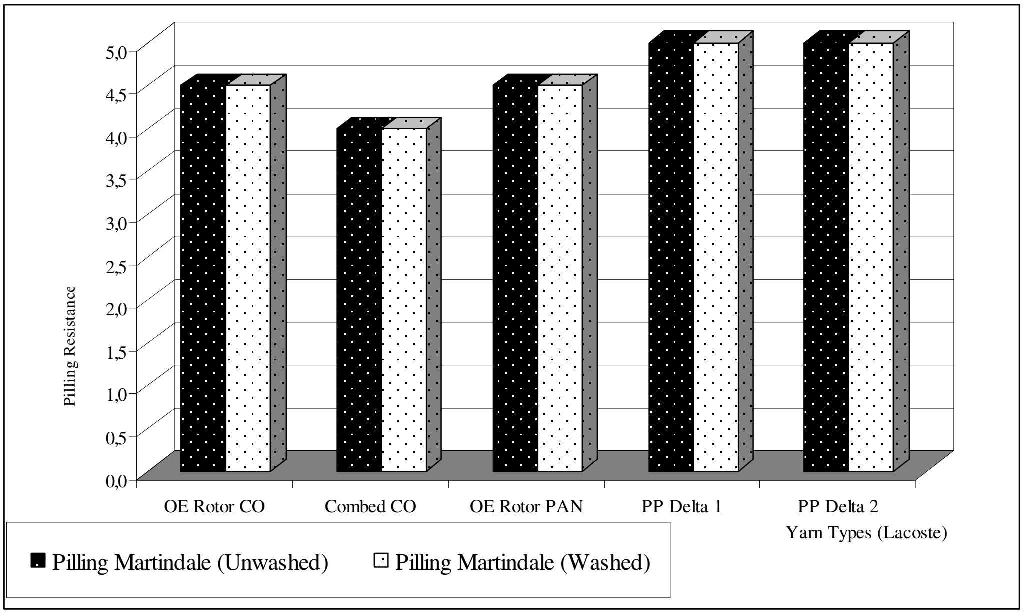


Figure 4.25 Pilling Grade of Yarn Types (2000 revolution-Lacoste)

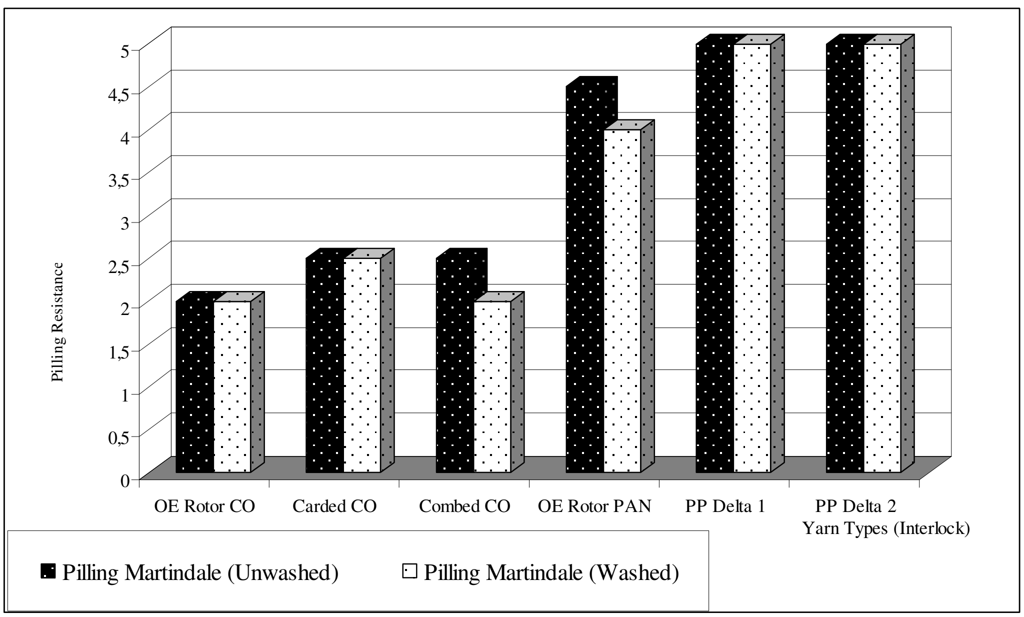


Figure 4.26 Pilling Grade of Yarn Types (2000 revolution-Interlock)

The pilling resistance results mentioned above cases are photographed and given in Appendix A1 that the lacoste structure has highest resistance to pilling. As it is seen from photographs of samples 1.3, 3.3, 5.3, 6.3 and 7.3 the subjective results of pilling grade for lacoste is highest. The possible explanation for this may be that for the lacoste structure, tumbling time (even for 2000 revolutions) is not long enough for completion of the pill formation of this structure. Second probability is unsmoothness surface of the lacoste structure because of the float loops.

As it is seen on the photographs of samples 1.4, 2.4, 3.4, 5.4, 6.4 and 7.4 in Appendix A1 and Figure 4.26, unlike the lacoste structure, interlock structure has the lowest resistance to pilling. The reason of lowest grade of pilling of interlock structure is the smoothness of the knitted surface and frictional surface of the knitting structures. These results are supported by Onal and Candan [83] who mentioned the pilling resistance of lacoste and s.jersey.

As illustrated in the Appendix A1. pilling tendency of s.jersey structure is (sample 5.1) similar as ribana for OE Rotor PAN. For OE Rotor CO (sample 1.1), s.jersey has high pilling resistance than ribana structures (sample 1.2). The reversed mechanical pilling behaviour is reported for combed CO as seen in photographs of samples 3.1 and 3.2 in Appendix A1. The values between 3 and 3/4 are not so much difference. The reversed behaviour for OE Rotor CO may probably be a coincidence because according to the literature survey, s.jersey has lower pilling resistance than ribana as agreed with this study.

4.3.2 Effect of Fiber Type and Spinning Technology

As illustrated in photographs in Appendix A1, the pilling grade of s.jersey CO is for OE Rotor (sample 1.1), carded (sample 2.1) and combed (sample 3.1) are 4, 3 and 2-3 respectively. This may be because the ring spun yarns are hairier than OE Rotor spun yarns, which may allow easy exposure of raised fiber ends to abrading forces. Second probability is spinning and also effect of twisting structure.

From the photographs of samples 6.1, 6.2, 6.3, 6.4, 7.1, 7.2, 7.3 and 7.4 illustrated in Appendix A1. , it can easily be seen that the knits from continuous filament yarns never pills under this conditions.

As shown in photograph of sample 4.1 in Appendix A1. carded CV has the worse value for pilling resistance. This may be due to the sensitive property of CV and perfect handle of carded spinning technology.

4.3.3 Effect of Washing Process

According to photographs of samples in Appendix A1, in washing process fiber assemblies forming was lost from the fabric surface. After washing process, the fabric surface is turns into tighter and harder pill entanglements which have various forms. The fiber damage is occurred when washing process is used. The damage varies from slight flaking to small cracks and fractures depending on the fabric and fiber & yarn types.

4.4 Snagging

Snagging tests were performed for two sets of samples. In the first set four knitting structures, two different yarn types (PP Delta 1, PP Delta 2) were used to prepare 8 knitted samples. These samples were tested to obtain the effect of knitting structure and washing process on snagging. Second set of samples are produced from four continuous filament yarns (PP Delta 1, PP Delta 2, PP Round and PES Delta) for s.jersey structure. The effect of tightness (tight, medium and loose) on snagging resistance is observed from the results of this set. Test results indicated that knitting structure, material and yarn type and tightness factor affect the snagging resistance. Knits from PP continuous filament yarns are most superior than PES knitted samples. Totally 21 knitted samples were used in snagging tests and sample lists are given in Table A2.1. Snagging resistance results mentioned above cases are photographed and given in Appendix A2. The snagging results are given in Table 4.2.

Table 4.2 Snagging Results

Test methods		Snagging (Unwashed)	Snagging (Washed)
Type of Fabric		Grade	
PP Delta 2	S.Jersey	5	5
	Ribana	4-5	4-5
	Lacoste	4	3
	Interlock	5	5
PES-1/70 Denier	S.Jersey	3	3-4
	Ribana	2-3	3
	Interlock	2	2
PP Delta 1	S.Jersey	4-5	5
	Ribana	4	5
	Lacoste	4	4
	Interlock	4	4-5
PP Delta 1	Tight (S.Jersey)	5	-
	Medium (S.Jersey)	4	-
	Loose (S.Jersey)	3-4	-
PES Delta	Tight (S.Jersey)	4	-
	Medium (S.Jersey)	2-3	-
	Loose (S.Jersey)	1-2	-
PP Delta 2	Tight (S.Jersey)	5	-
	Medium (S.Jersey)	4-5	-
	Loose (S.Jersey)	3-4	-
PP Round	Tight (S.Jersey)	4-5	-
	Medium (S.Jersey)	4	-
	Loose (S.Jersey)	3	-

4.4.1 Effect of Knitting Structure

In Figure 4.27, the effect of knitting structure is shown. For creating this graph, set one (sample 6.1, 6.2, 6.3, 6.4, 7.1, 7.2, 7.3 and 7.4) were used.

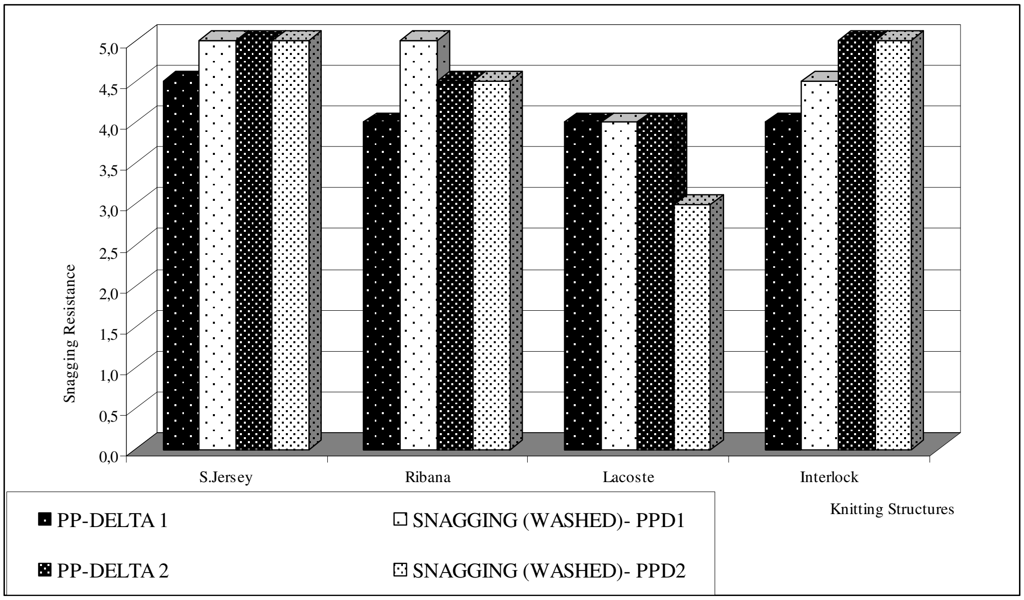


Figure 4.27. Snagging Grade of Knitting Structures (PPD1 and PPD2)

According to photographs of samples 6.3 and 7.3 in Appendix A2 and Figure 4.27, it is clearly seen that lacoste has the lower snagging resistance. This is perhaps the unsmoothness surface of the structure affected from the tuck formation. It has got lots of holes and protrusion on the surface because of the float loop shape.

Unlike lacoste, interlock and s.jersey have the highest snagging resistance. This may be due to the smooth surface of the structures. The photographic views of samples 6.1, 6.4 and 7.1, 7.4 are given in the Appendix A2.

4.4.2 Effect of Fiber Type

The photographs of samples 8.1, 8.2, 8.3, 9.1, 9.2, 9.3, 10.1, 10.2, 10.3, 11.1, 11.2 and 11.3 shown in Appendix A2 indicated that PP Delta 1 is better than the PP Delta 2, PP Round and PES Delta, respectively. For same production conditions; PP delta 1, PP Delta 2 and PP Round have slightly differences. However there is great difference between knits from PP continuous filament yarn and knits from PES Delta continuous filament yarn. The possible explanation for this may be the effect of elongation. PP continuous filament yarns have nearly same elongation values (PP Delta 1=22,17 %, PP Delta 2= 21,92%, PP Round=20,36%). PES continuous filament yarn has elongation value as 34.87%. According to this difference, in the same force, PES is more elastic so it can be easily distorted. Individual filament is leaved from the knitting structure easier than the PP continuous filament.

4.4.3 Effect of Tightness Factor

The photographs of samples 8.1, 8.2, 8.3, 9.1, 9.2, 9.3, 10.1, 10.2, 10.3, 11.1, 11.2 and 11.3 shown in Appendix A2 observed that tightness factor is affected the snagging resistance. Figure 4.28 shows the effect of tightness factor on snagging.

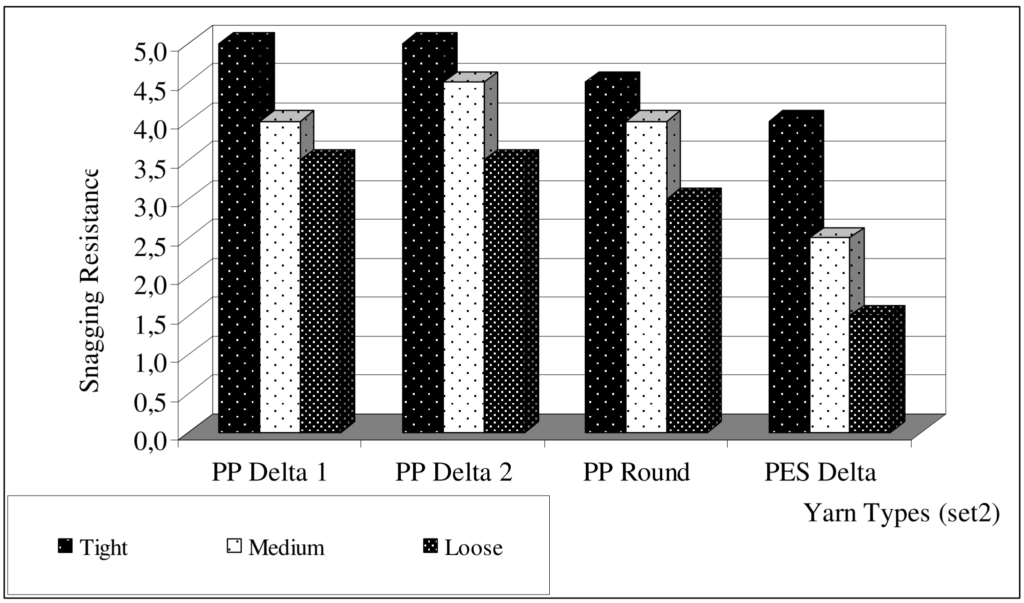


Figure 4.28. Effect of tightness Factor on Snagging

For comparison three different tightness values are chosen. From the Table 4.2 and Figure 4.28, higher the tightness value causes better the snagging resistance. This is perhaps explained as stitch density. Higher the stitch density means, tighter the structure. As stitch density increases, d/l ratio (cover factor) decreases. Also a more rigid fabric is produced.

4.5 Skewness

Skew refers to courses [55] when courses or wales are not at right angles to the fabric edges; they are referred to as being skewed. The term skew refers to distortion in both course and wale direction, but more specifically skew refers to courses and spirality refers to wales. The fabric images on the right illustrate skew in the Z direction; reverse side is skew in S direction.

Skew is introduced during the knitting process when courses do not knit horizontally, but rather on an incline. The 1x1 rib is a common structure, normally used for trim or in the body portion of garments. It is a rather unstable fabric and has tremendous widthwise extensibility.

4.5.1 Effect of Knitting Structure

The results obtained for the skewness tests after washing are illustrated in Figure 4.29.

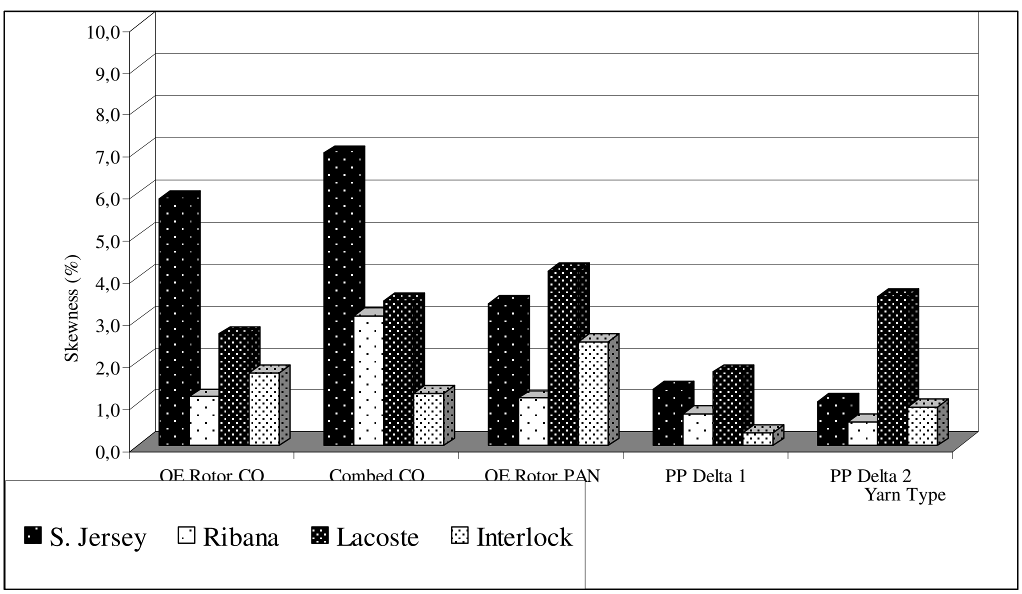


Figure 4.29 Skewness Values of Yarn Types

According to the Figure 4.29, the minimum value of skewness belongs to the interlock. This is may be due to the balance structure of interlock. Percentage value of skewness is high for s.jersey manufactured from spun yarns. The main reason for this is because the structure is highly unbalanced. RL structures are unbalanced because they are produced on single plated knitting machines.

Spirality is a particularly serious problem for knitted fabrics due to asymmetric loops. Figure 4.31, 4.32 and 4.33 shows that interlock and ribana structures have less skewness tendency.

4.5.2 Effect of Fiber Type and Spinning Technology

Figure 4.30 shows the effect of fiber and spinning type on the skewness by the means of s.jersey.

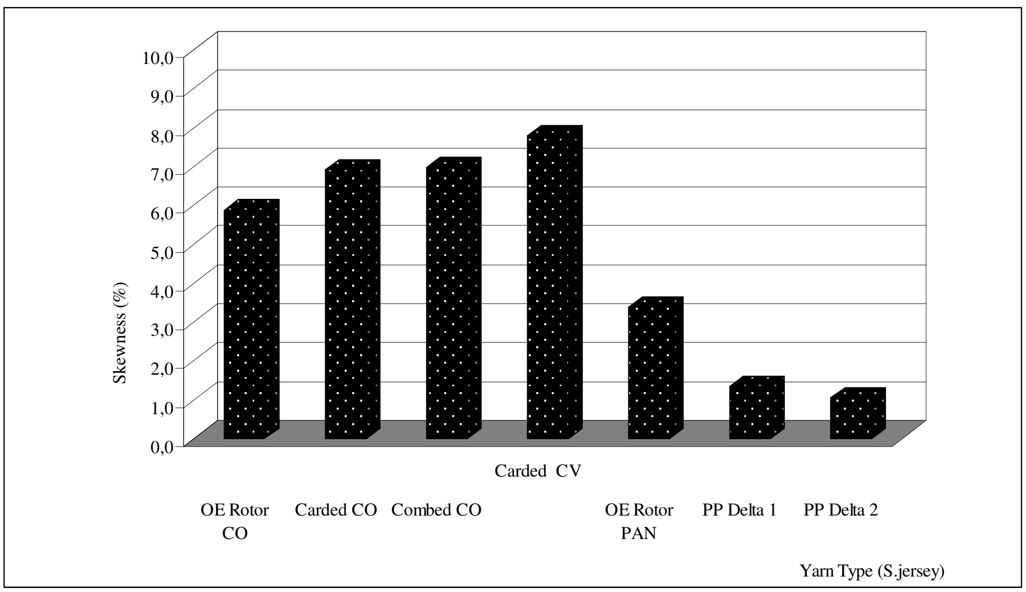


Figure 4.30 Effect of Fiber and Spinning Type on the Skewness (S.jersey)

Yarn twist factor is the most important variable influencing fabric spirality. Skewness is also influenced from yarn twist factor. Çeken et al.[78] indicated that spirality is influenced by yarn twist. According to the Figure 4.30, twist structure effect can be easily seen, the highest skewness tendency is belongs to Carded CV, Carded CO, Combed CO, OE Rotor CO, OE Rotor PAN, PP Delta 1 and PP Delta 2, respectively. The non-twist structures of continuous filament yarns have minimum skewness values.

From the Figure 4.30, knits from combed and carded CO values are slightly different but knits from OE Rotor CO so much different. Çeken et al.[78] observed that OE Rotor CO yarns are less skew than the ring spun yarns.

All of the yarn types and knitting structures have at least 0,5% of skewness. This may be due to the rotation of the knitting machine in cross-wise direction. According to the non twist structure of continuous filament yarns there has been no-skewness on the fabrics except the addition of machine skewness.

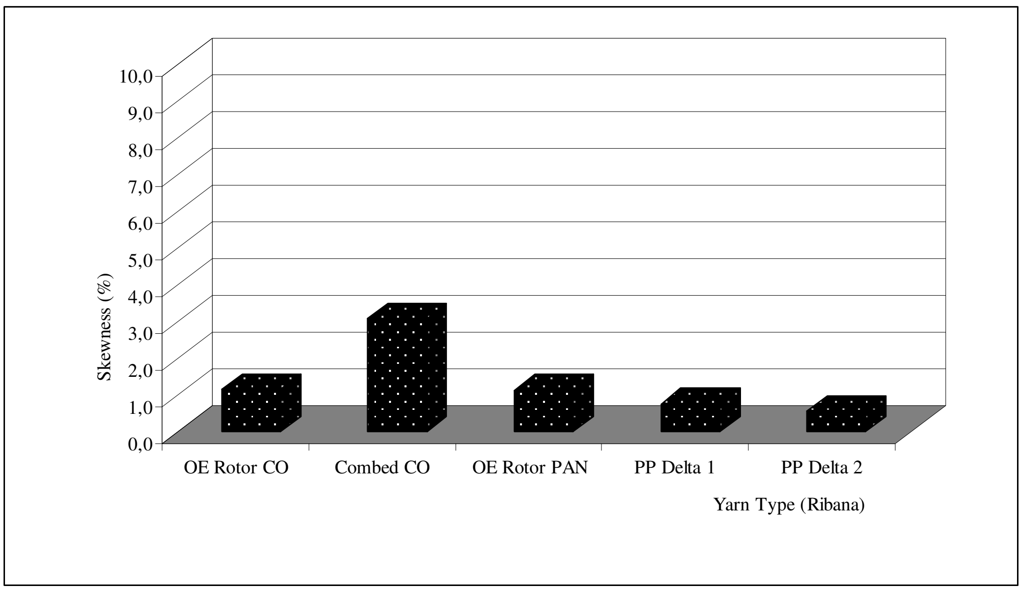


Figure 4.31. Effect of Fiber and Spinning Type on the Skewness (Ribana)

From Figure 4.31 combed CO, has the highest skewed knitting structure. It is also found that OE Rotor CO and OE Rotor PAN have nearly same character on this type of knitting structure.

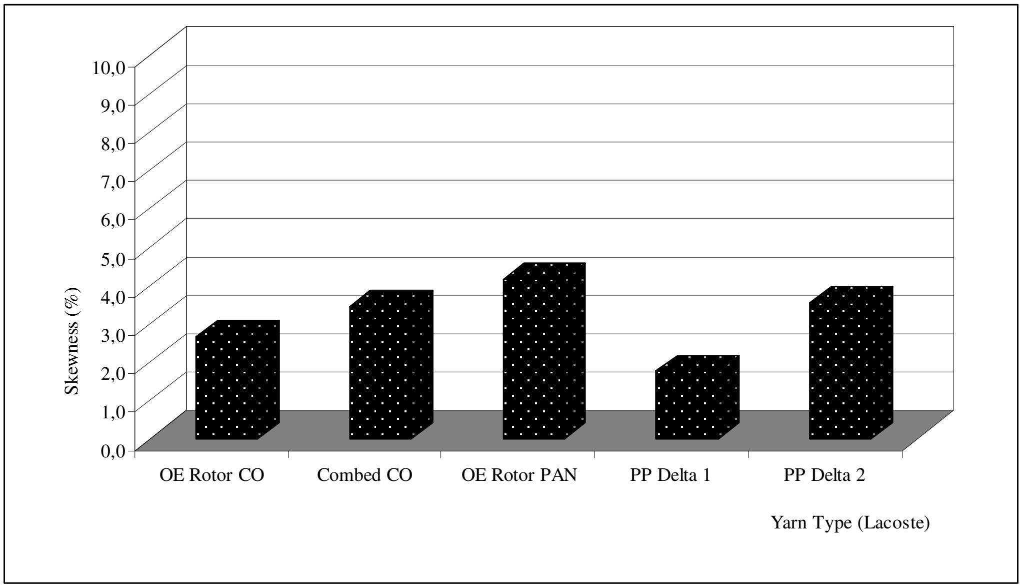


Figure 4.32 Effect of Fiber and Spinning Type on the Skewness (Lacoste)

The skewness values seen from Figure 4.32 and 4.33 OE Rotor PAN is the worst yarn type in tested samples. Our findings indicated that natural fibers have more skewness tendency while man made fibers have less skewness. The value of OE Rotor PAN as illustrated in Figure 4.32 and 4.33 may also be a coincidence.

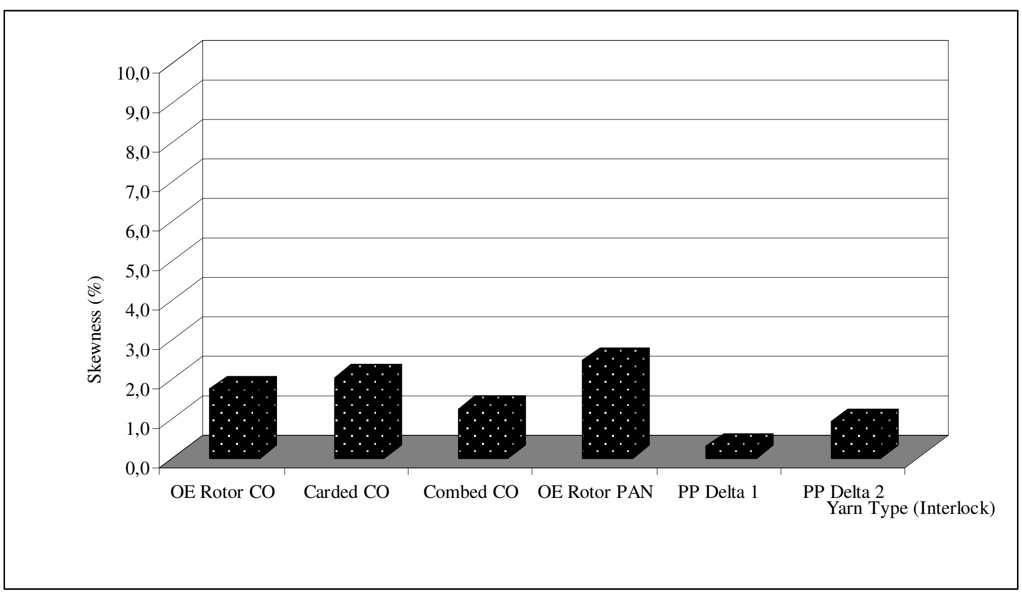


Figure 4.33 Effect of Fiber and Spinning Type on the Skewness (Interlock)

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Different knitting structure, different yarn technology and different fiber properties cause different mechanical behaviour. In this experimental work, the performance of knitted fabrics manufactured with PP continuous multifilament yarn were investigated and compared with other knit structures, other yarn types and other spinning technologies. Tested samples were knitted in four different structures and from OE Rotor CO, Combed CO, Carded CO, Carded CV, OE Rotor PAN, PES and three different PP samples. 35 different knitted samples were tested.

Bursting strength, dimensional stability, pilling, snagging and skewness tests were performed for prepared samples. The performance evolutions of PP knits was established and results were compared test results of other samples.

The conclusions that are drawn from this experimental work are given as follows;

1. In this study four basic knitting structures s.jersey, ribana, lacoste and interlock were compared. Test results indicated that bursting strength of knitted fabric is different from knitting structure to knitting structure. The highest value of bursting strength is achieved by interlock structure. The weakest structure is lacoste, because of the float loop shape. For all type of knitting structure PP has the greatest value of bursting strength. It is nearly 3 times stronger than knits from OE Rotor CO.

2. Our findings indicated that knitted fabrics manufactured from PP continuous filament yarns are stronger than the same conditioned CO, CV and PAN.

Yarn strength of PP is the highest value, too. According to the statistical analysis there is a very good correlation ($r=0.966$, $P<0.01$) between yarn tensile strength and bursting strength of fabric.

3. Washing process also affected on the value of bursting strength of knitted samples. There is a linear relation between washed and unwashed bursting strength of knitted samples ($r=0. 0.987$, $P<0.01$). The calculated r^2 value of this relation is found as 0.974. This means the washing treatment increases the bursting strength.

4. Bursting strength of the knitted structures was also measured to obtain tightness factor effect. As tightness factor increases bursting strength increases for PP Delta 1 in 22E s.jersey structure. Pearson correlation results show that there is positive and significant relationship between tightness factor and bursting strength values ($r =0.856$, $P<0.01$). The calculated r^2 value is 0.732.

5. It is apparent from the results that dimensional stability in widthwise direction of lacoste has minimum value for all CO knit fabrics. Despite the dimensional behaviour of CO lacoste fabric, PP continuous filament yarns have opposite tendency for widthwise dimensional changes. This problem is probably due to the filament yarn texturized effect.

Our findings indicated that for widthwise direction, dimensional stability of knits from OE Rotor CO is better than knits from combed CO. Same relation was observed between ring spun and melt spinning method. Dimensional stability of knits from PP continuous filament yarns is higher than dimensional stability of knits from spun yarns. Yarn twist and twist formation may probably be causing this result. Therefore lower dimensional changes causes easy finishing processes for knits from PP knits in dying house.

6. Pilling results showed that the lacoste structure has highest resistance to pilling while interlock has the worst subjective results.

It was well known that filament yarns do not have pilling tendency. The photographs support this hypothesis; however in this study, only 2000 revolution was used.

7. According to photographs of samples, it is clearly seen that snagging is affected from knitting structures. Lacoste has the lower snagging resistance while interlock and s.jersey has the highest snagging resistance. The lowest grade of lacoste perhaps due to the unsmoothness surface of the structure affected from the tuck formation.

Snagging resistance of knits from three types of PP (Delta1, Delta 2 and Round) have nearly same grade while knits from PES Delta continuous filament yarns have lower grades.

According to the test results, washing process has insignificant effect on snagging resistance.

Tightness factor affected the snagging resistance. According to the tight, medium and loose structure samples, knits with tight loop length have highest snagging grade while knits with loose loop length have lower snagging grade.

8. Single jersey is a common structure that is used extensively because it has a high production rate and is relatively inexpensive to produce, but it is easily distorted due to its simplicity and inherent spirality and skew. The ribana is the simplest and most unstable fabric, more easily distorted than s.jersey especially in the width.

Test results obtained that the minimum value of skewness belongs to the interlock. This may be due to the balance structure of interlock. Percentage value of skewness is high for s.jersey manufactured from spun yarns. The main reason for this is because the structure is highly unbalanced. RL structures are unbalanced because they are produced on single plated knitting machines.

In addition, all of the yarn types and knitting structures have at least 0,5% of skewness. This may be due to the rotation of the knitting machine in cross-wise direction. According to the non twist structure of continuous filament yarns there has been no-skewness on the fabrics except the addition of machine skewness and spirality.

In this experimental work, we focused on knits from PP continuous filament yarns. Different knitting structures obtained from staple & continuous filament yarns are examined and compared with knits from PP continuous filament yarns. Some preliminary results about knits from PP continuous filament yarns are determined from this experimental study and given above. Further study on this subject is necessary to determine complete performance characteristics. Usage of PP continuous filament yarns in knits (underwear, childwear…etc) is going to be developed due to its excellent and durable properties.

5.2. Recommendations

The work presented here was carried out on industrial and laboratory type circular knitting machines. Due to the adjustment limit of the machines, other factors such as; knittability of PP, yarn in put tension, take – down tension, degree of filament breakage, high speed limit of PP continuous filament yarns, texturizing effect of PP continuous filament yarns were not investigated.

The further study on this subject may be structured as follows;

- These tests may also be done on different knitting structures like; two thread fleece (one or two thread may also be produced from PP continuous filament yarns), three thread fleece (one or more thread may also be produced from PP continuous filament yarns), vanized jersey structures, terry cloths or special double layer knits.

- The range of yarn types for the same investigation can be extended to compare the findings with other spun and filament yarns such as PA, spun PP, spun PES

- It could be useful the use of texturized PP continuous filament yarns to compare with the non texturized PP continuous filament yarn results.

- These tests may also be done on s.jersey knitting structures with different elastane counts and ratios.

- These samples may also be examined by other testing methods like as; abrasion resistance, air permeability, thermal transmittance, moisture transmission, porosity, handle and bacteria and mold resistance.

LIST OF REFERENCES

[1] http://www.eatp.org/news_eatpreleases.asp "Polyolefin Textiles in the Greater Europan Market"

[2] http://www.fibersource.com/f-tutor/olefin.htm

[3]Kerr, P., L., (1992). "Olefin Textile Fibre Based on a New Polymer Combination" *Translation of Melliand Textilberichte* 73 p702

[4]Decraemer, L.(1998, May)."Monofilaments and Staple Fibres from Ostend Textiles – in Polyester and Polypropylene" Technical Textiles International; Vol.**7** Issue 4, p15, 2p.

[5] Chuang, C.C.,(2003,September 18),"Elastic Polypropylene Wet Suit Fabric" United States Patent Application: 20030172429,

[6]Gross, D., (2005, Fall) "Healty Markets for Knits" *KnitAmericas*, **4c** p22-41, 5p,

[7] Lo, T. Y., (2005,Aug.). "Techtextil/Avantex 2005" *Textile Asia*, Vol.**36** Issue 8, p11-33, 21p,

[8] Wan, A. (2002,Nov.) "Innovation and Efficiency" *Knitting International*; Vol.**109** Issue 1298, p18, 2p.

[9] Piller, B.(2001, June). Vlcek, M., "Knitted Fabric Innovation with Profiled Polypropylene Fibers" *Melliand International*, Vol. **7** Issue2, p122, 3p

[10] Lam, S.,W., Tao, X., M., Yu, T., X..(2002, May). "Tensile Behaviour of Thermoplastic Weft – Knit Composites" *Textile Asia*, Vol. **33** Issue 5, p28, p4

[11] Mielicka, E., Kaczamarska, H., Baczynska, M.(1997, Jan./Mar.). "Specific Properties of Polypropylene Yarns and Their Applications in the Polish Knitting Industry" *Fibres & Textiles in Eastern Europe*; Vol.**5** Issue1 (16), p58, 5p.

[12] Nielson., R., Endrusick, L.T., (1989, April) "Thermoregulatory Responses to Intermittent Exercise are Influenced by Knit Structure of Underwear." Pentagon Reports

Storming Media Ref No: A780902, pp26

http://www.stromingmedia.us/17/1700/a170022.html

[13] Özkürkçüler, Ö., Karaaslan, U.(4/2005, Temmuz – Ağustos). "Polipropilen Lif ve Özellikleri" *Tekstil Maraton* **4**, 23-25.

[14] Ulcay, Y.(1997, Mart-Nisan) "Polipropilen Üretimi" *Tekstil Maraton,* **2,**p27-31.

[15] Marcincin, A., Jambrich, M. (1999) Polypropylene: An A-Z Reference J.Karger –Kocsis (Eds.) Kluwer Publishers, Dordrecht "*Textile Polypropylene Fibers: Fundamentals*"

[16] Karacan, İ., (1999) Polypropylene: An A-Z Reference J.Karger –Kocsis (Eds.) Kluwer Publishers, Dordrecht "*Structure – Property Relationships in Polypropylene Fibers*"

[17] Uskaner, Y. A., Uskaner F., Aksoy M., (1999, Eylül) "Polipropilen İplik Çekim Ünitesi Tasarımı, İmalatı ve Performans Testleri" UMTS 1999, 9.Ulusal Makine Teorisi Sempozyumu, pp 35-45, 15-17, Gaziantep.

[18] Spruiell, J., E., Bond, E.(1999) Polypropylene: An A-Z Reference J.Karger – Kocsis (Eds.) Kluwer Publishers, Dordrecht "*Melt Spinning of Polypropylene*"

[19] Karakaş, Canbaz, H. (Eylül-2005). "Polipropilen Lifleri" *Tekstil ve Teknik*

[20] http://www.dreamfel.com/frame.html

[21] Yang., R., Mather, R., R., Fortheringham, A.,F. (2004). "The Influence of Fiber Processing Parameters on the Structural Properties of As-spun Polypropylene Fibers: a Factorial Design Approach" *Journal of Applied Polymer Science*, Vol.**93**, 568-576

[22] Bueno, M., A., Aneja, A.,P., Renner, M. (2004). "Influence of the Shape of Fiber Cross Section on Fabric Surface Characteristics" *Journal of Materials Science* **39**, 557-564

[23] Yazıcıoğlu, G.(1996) "*Tekstil Mikroskopisi*" Ege Üniv. Basımevi Bornova-İzmir.

[24] Shields., T., J., Zhang, J. (1999) Polypropylene: An A-Z Reference J.Karger – Kocsis (Eds.) Kluwer Publishers, Dordrecht "*Fire Hazard with Polypropylene*"

[25] Horrocks, A.R., and Anand S.C., (2000) "*Technical Textile Handbook"* Woodhead Publishing Ltd., CRC Press.

[26] Jambrich, M., Hodul, P.,(1999) Polypropylene: An A-Z Reference J.Karger – Kocsis (Eds.) Kluwer Publishers, Dordrecht "*Textiles Applications of Polypropylene Fibers*"

[27] http://www.fibrochem.sk/index.php?pageId=76

[28] Nielson., R., Endrusick, L.,T., (1990) "Sensation of Temperature and Humidity during Alternative Work/Rest and the Influence of Underwear Knit Structure" Pentagon Reports Storming Media Ref No: A431522, pp14 http://www.stromingmedia.us/43/4315/A431522.html

[29]Wootton, D.B., (2001) "*The Application of Textiles in Rubber*", Rapra.

[30] Uskaner, Y. A., Uskaner F., Aksoy M., (2000,Şubat) "Conditioned Air Quench System for Polypropylene Carpet Yarn Spinning Machine" ULIBTK'99, 12. Ulusal Isı Bilimi ve Tekniği Kongresi, pp 265-270, 28-29, Sakarya.

[31] http://www.swicofil.com/polypropylene.html

[32]Nielson., R., Endrusick, L.,T., (1989, April) "Thermoregulatory Responses to Intermittent Exercise are Influenced by Knit Structure of Underwear." Pentagon Reports Storming Media Ref No: A780902, pp26
http://www.stromingmedia.us/78/7809/a780902.html

[33]Baumann, H., P. (1963). "The Mechanism of Dyeing Polypropylene" American Dyestuff Reporter 79527-529

[34]Fan., Q., Ugbolue,S.,C., Wilson, R.,A., Dar, S.,Y., Yang, Y.(2002,June). "Dyeable *Polypropylene via Nanotechnology. NTC Project: C01-MD20 (formerly C01-D20) National Textile Research Briefs-Chemistry Competency*

[35] http://www.ischool.utexas.edu/cochinea/txt/m-esteva-01-polypropylene.txt

[36] Studer., H.(1999). "Poliolefin Liflerinin Antimikrobik Korunması*" Melliand Türkiye Sayısı* **1**. pp18.

[37] Ward., D., (1999) "Polypropylene Fibers with Permanent Anti-bacterial, Anti-fungal Properties" *ITB International Textile Bulletin* **1**

[38] Demir, A. (2004). "Gaziantep can be Carpet Base of the World" *T.A.D.* **2**, pp140-141

[39]Swantko, K., (Fall 2004), "Fabric Durability and UV Protection" *KnitAmericas,* 24-24.

[40] http://www.swicofil.com/companyinfo/manualphysicalproperties.html

[41]http://www.dreamfel.com/comparison.html

[42] Yakartepe, M., Yakartepe, Z.(1999). "*Textiles in General*" T.K.A.M. Textile&Clothing Research Center Istanbul

[43] http://www.geocities.com/invtex/knitwear/basics.htm

[44]http://www.knitting.umist.ac.uk/Lectures_knitting/basic_structures/Introduction_knitted_structures.htm

[45] Knapton, J., J., F., (1967) "Knitting Performance of Wool Yarns" *Textiles Researches Journal* **37**, 539,

[46]Lawson, J. (1966). Knitting Outwear, *Times* 35, **43**, 18

[47]Pietikainen, I. (1975). "The Description and Determination of Knittability in Weft Knitting" *Textile Journal Inst*. **5**, 194-195.

[48]Robinson, G., A., Dobson, D., A., Green, M., V., (1974)"*A Proposed Method of Assessing the Knittability of a Yarn*" Sawtrı Technology Republic 235, 1-13.

[49]Sasaki, T., Kuroda, K. (1975) "Evolution and Measurement of Knittability" *Journal Textile Machines Soc*. Jpn. 21(**1**), 9-16

[50] Hu, H., Zu, M.(2005, Sep.). "A Study of the Degree of Breakage of Glass Filament Yarns During the Weft Knitting Process" *AUTEX Research Journal*, Vol. **5**, No.3

[51] Dönmez, S., Marmaralı, A., (2004,Dec.). "A model for Predicting a Yarn's Knittability" *Textile Research Journal.*

[52] Taylor, M., A. (1990). "*Technology of Textile Properties an Introduction*" Third Edition Forbes Publications.

[53] Wingate, I. (1976). "*Textile Fabrics and Their Selection*" Prentice Hall Inc., Englewood Cliffs, New Jersey.

[54] Mishcon, L., Abrams, A., "*Pattern Wheel Designing for Circular Knitting Machines*" Published by Supreme Knitting Machine Co., Inc.

[55] Tou, A., N. (2005). "*An Investigation of Arcing in two Structure Weft Knit Fabrics*" M.Sc. Thesis Textile & Apparel Technology & Management North Carolina State University

[56] Ajgaonkar, D.B.,(1973,March). "Principles of Knitting V" *The Indian Textile Journal*, 159-165.

[57] Bayazıt, A.,(2000) "*Introduction to Weft Knitting*" Ege Univ. Tkaum, Publication No.9, Izmir, Turkey.

[58] Lau, Y., Tao, X., Dhingra.R. (1995, August). "Spirality in Single-Jersey Fabrics" *Textile Asia*, 95-102.

[59] Hatch, K. L. (1993). "*Textile Science*" St. Paul, MN: West Publishing Company,

[60] Yakartepe, M., Yakartepe, Z. (1995). "*Tekstil Teknolojisi*" T.K.A.M. Tekstil ve Konfeksiyon Araştırma Merkezi Yayın no: 46 Cilt 9 Istanbul

[61] Smirfitt, J.A. (1965). "Worsted 1x1 Rib Fabrics Part II Some Physical Properties" *Journal of Textile Institute*, **56(6)**: T298-T313.

[62]http://www.knitting.umist.ac.uk/Lectures_knitting/basic_structures/basic_structures.htm

[63] Smith, G.W. & Hudson, P. (1983, June). "Weft Knitting: A Primer for Manufacturers" Part 1. Bobbin, 122-138.

[64] Abou, N., M., Iiana, Youssef, S., Pastore, C., Gowayed, Y.(2003,Jun). "Assessing Structural Changes in Knits During Processing" *Textile Research Journal*

[65]Makinen, M., Meinander, H., Luible, C., Magnenat, T.,N., "Influence of Physical Parameters on Fabric Hand" *Tampere University of Technology*, SmartWear Lab, University of Geneva, MIRALab.

[66] Çoruh, H., E. (2004, January). "*Investigation of Dimensional Stability of Knitted Fabrics*" M.Sc. Thesis Textile Engineering University of Gaziantep

[67] Hepworth, B. (1982, January). "The Dimensional and Mechanical Properties of Plain Weft Knits." *Knitting International*, 33-35.

[68]Gravas, E., Kiekens, P., Langenhove, L.,V. (2005, Dec.). "An Approach to the Proknit System and Its Value in the Production of Weft Knitted Fabrics" *AUTEX Research Journal,* Vol.**5**, No:4, p.219-226

[69]Araujo, M., Fangueiro, R., Hong, H.(2003, Dec.). "Modelling and Simulation of the Mechanical Behaviour of Weft – Knitted Fabrics for Technical Applications" Part II:3D Model Based on the Elastica Theory. *Autex Research Journal*, Vol.**3**, No4,

[70]Dias, T. (2002, Nov.). "Stitch Length Variation in Circular Knitting Machines Due to Yarn Winding Tension Variation in the Storage Yarn Feed Wheel" *Textile Research Journal,*

[71]Ucar, N. (2002, Nov.). "Objective and Subjective Analysis of Knitted Fabric Bagging" *Textile Research Journal*,

[72]Onal, L. (2003, Mar.). "Contribution of Fabric Characteristics and Laundering to Shrinkage of Weft Knitted Fabrics" *Textile Research Journal*,

[73] Abou, N., M.(4/2001). Iiana "The Dimensional Instability of Knitted Structures" *ITB International Textile Bulletin* 75-80

[74] Ertugrul, S., Ucar, N. (2002, April). "Predicting Circular Knitting Machine Parameters for Cotton Plain Fabrics using Conventional and Neuro-Fuzzy Methods" *Textile Research Journal*,

[75] Kugler, G., Liebold, R., Hallmann, K.(1992)."Determination of Shrinkage Behaviour of Synthetic Filament Yarns by Tensile Tests" *Translation of Melliand Textillberichte* **73**, p.232

[76] AATC Test Method 179-1996 Skewness Change in Fabric and Garment Twisting Resulting from Automatic Home Laundering

[77] Anand, S., C., Brown, K.,S.,M., Higgins, L.,G., Holmes, D.,A., Hall, M.,E., Conrad, D. (2002, June) “Effective of Laundering on the Dimensional Stability and Distortion of Knitted Fabrics” *Autex Research Journal*, Vol.**2**, No2,

[78]Çeken F., Bal, S., Kuş, S.,(2002, Eylül-Ekim) “The Spirallity of Single Jersey Fabrics and Its Effects on Garments” *Tekstil Maraton* **5**, p47-56

[79] Candan, C., Nergis, V., B., Iridag, Y. (2000) “Performance of O.E. and Ring Spun Yarns in Weft Knitted Fabrics” *Textile Research Journal* **70**:177-181

[80] Ertugrul, S., Ucar, N. (2000). “Predicting Bursting Strength of Cotton Plain Knitted Fabrics using Intelligent Techniques” *Textile Research Journal* **70**:845-851

[81] Shahbaz, B., Jamil, A., N., Farooq, A., Saleem, F., (2005) “Comparative Study of Quality Parameters of Knitted Fabric from Air Jet and Ring Spun Yarn” *Journal of Applied Sciences* **5 (2)**:277-280

[82]Kavuşturan, Y. (2002, Eylül-Ekim). “The Effects of Some Knit Structures on the Fabric Properties in Acrylic Weft Knitted Outwear Fabrics” *Tekstil Maraton* **5** p40-46

[83] Candan, C., Onal, L.(2002, February). “Dimensional, Pilling and Abrasion Properties of Weft Knits Made from O.E. and Ring Spun Yarns” *Textile Research Journal*.

[84] Uçar, M. (2003). “Mechanical Behaviour of Knitted Fabrics under Bending and Shear Deformation” *Turkish J. Eng. Env. Sci.* **27** pp177-181

[85] Nielson, R., Endrusick, T.,L. (1989, September). “Sensation of Temperature and Humidity during Intermittent Exercise and the Influence of Underwear Knit Structure” *Army Research Inst. of Environmental Medicine* Natick MA, 22 Pentagon Reports Storming Media Ref No: A582512, pp22

[86] Li, Z., Wang, Y., Kowk, Y.,L., Yeung, C.,Y. (2002, April). “Mathematical Simulation of the Perception of the Fabric Thermal and Moisture Sensations” *Textile Research Journal*

[87] Leigh-Matic, R., S. (1993, April-June). “Dimensional Stability, Aesthetic and Mechanical Properties of Micro-Fiber Blended Knitting Fabrics” National Textile Center Quarterly Report:

[88]Smirtiff, J., A. (1965). *Journal of Textile Inst.* pp56-24.

[89] TS 5720 EN ISO 6330. (2002, April). “Textiles-Domestic Washing and Drying Procedures for Textile Testing”,

[90]TS 4073/EN ISO 3759. (1999,Nisan). “Teskstil-Boyut Değişmesinin Tayini için Deneylerde Kullanılacak Kumaş Parçaları ile Giysilerin Hazırlanması, İşaretlenmesi ve Ölçülmesi”

[91] Debinhams Test Method – PD 14a “Resistance to Snagging of Knitted and Woven Fabric”

[92] BS EN ISO 13938-2:(1999). “Textiles-Bursting Properties of Fabrics” pneumatic Method for Determination of Bursting Strength and Bursting Distention.

[93] TS EN ISO 12945-2.(2002, April). “Textiles-Determination of Fabric Propensity to Surface Fuzzing and to Pilling-Part 2: Modified Martindale Method (ISO 12945-2:2000)

[94]Tvarijonaviciene, B., Saulyte, I., Laureckiene, G. (2004). “The Effect of Knitting Wearing Conditions on the Tensile Characteristics of Blended Yarns” *Materials Science (Medziagotyra)* Vol.**10**, No. 1,

[95]Corbman, B., P., “*Textile Fibre to Fabric*” McGraw Hill Book Co. Singapore, pp:104-123

[96] Ömeroğlu, S.(2005). “Kompact ve Ring İpliklerden Elde Edilmiş Örme Kumaşların Patlama Mukavemeti ve Boncuklanma Performansı Üzerine bir Çalışma” *Journal of Engineering Sciences*, Vol.**11/3**, p357-360

[97] Meriç B., Demirhan F., (2005) “The Searching of Dimensional Changes on the Knitted Fabrics and Garments After Washing and Drying” *Journal of Engineering Sciences*, Vol.**11/3**, 381-390.

APPENDIX A
PHOTOGRAPHIC VIEW OF SAMPLES

Table A1.1 Set of Samples for Pilling Test

First Set of Samples				
Knitting Structure Fiber & Yarn Type	S.Jersey	Ribana	Lacoste	Interlock
OE Rotor CO	1.1	1.2	1.3	1.4
Carded CO	2.1	-	-	2.4
Combed CO	3.1	3.2	3.3	3.4
Carded CV	4.1	-	-	-
OE Rotor PAN	5.1	5.2	5.3	5.4
PP Delta 1	6.1	6.2	6.3	6.4
PP Delta 2	7.1	7.2	7.3	7.4

APPENDIX A1:PHOTOGRAPHIC VIEW OF SAMPLE OF PILLING GRADES

Before washing Pilling (B.W.) Pilling (A.W)

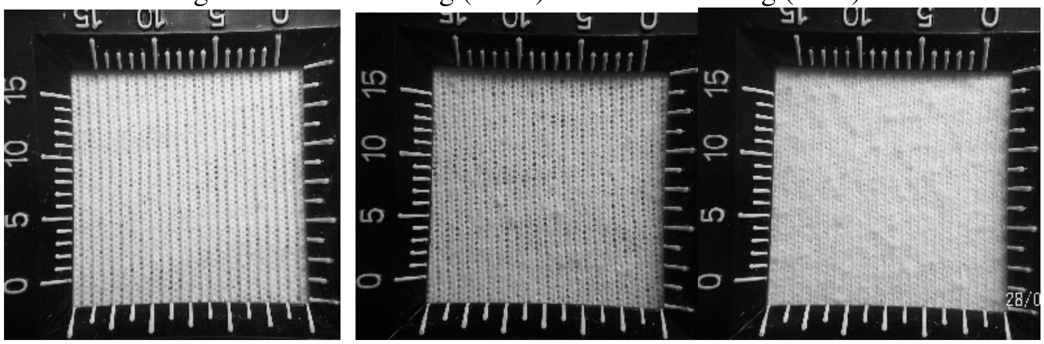


Figure A1.1. Photographic View of Sample OE Rotor CO S. Jersey (sample 1.1)

Before washing Pilling (B.W.) Pilling (A.W)

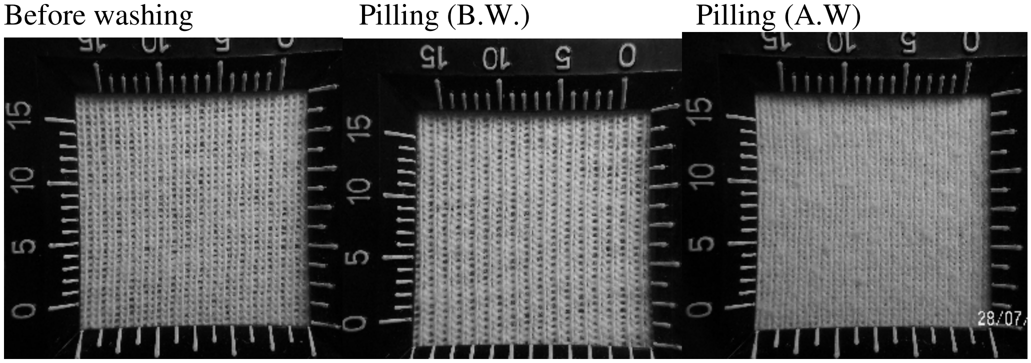


Figure A1.2 Photographic View of Sample OE Rotor CO Ribana (sample 1.2)

Before washing Pilling (B.W.) Pilling (A.W)

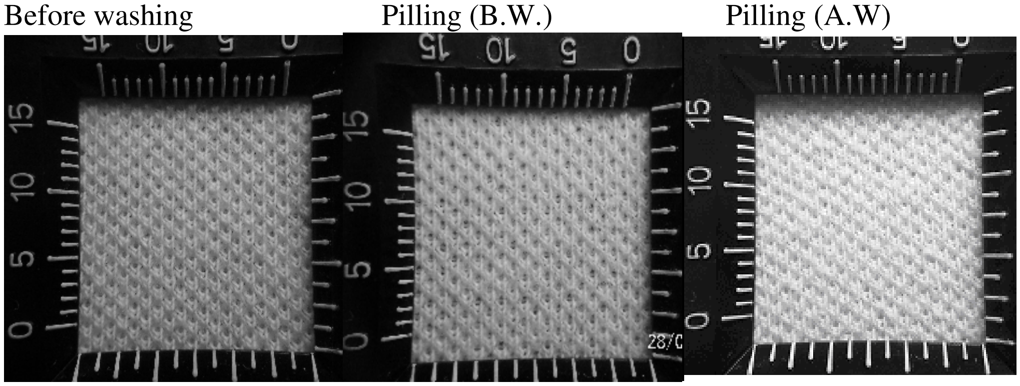


Figure A1. Photographic View of Sample OE Rotor CO Lacoste (sample 1.3)

Before washing Pilling (B.W.) Pilling (A.W)

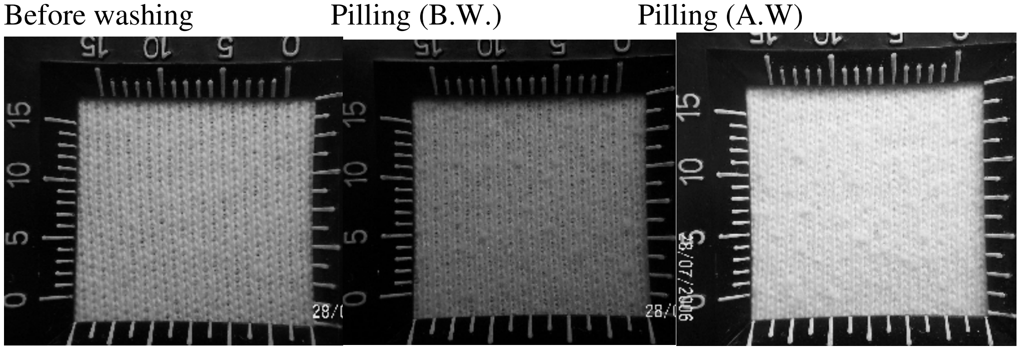


Figure A1.4 Photographic View of Sample OE Rotor CO Interlock (sample 1.4)

Before washing Pilling (B.W.) Pilling (A.W)

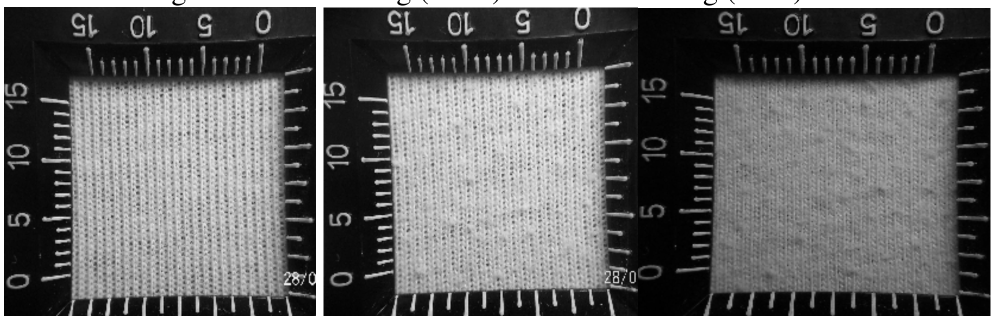


Figure A1.5 Photographic View of Sample Carded CO S. Jersey (sample 2.1)

Before washing Pilling (B.W.) Pilling (A.W)

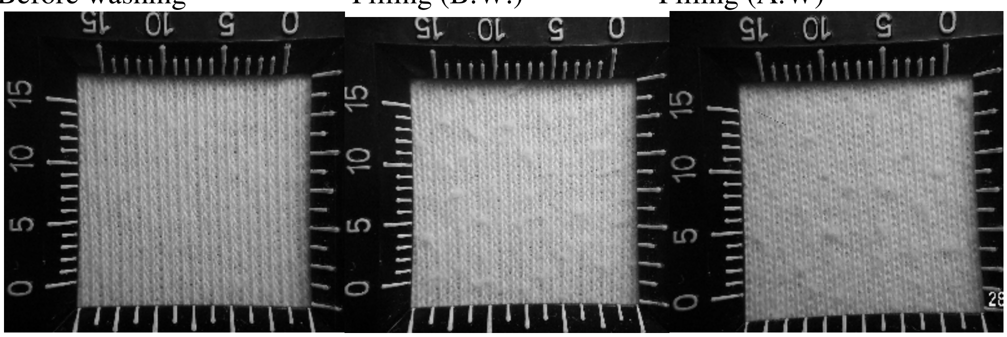


Figure A1.6 Photographic View of Sample Carded CO Interlock (sample 2.4)

Before washing Pilling (B.W.) Pilling (A.W)

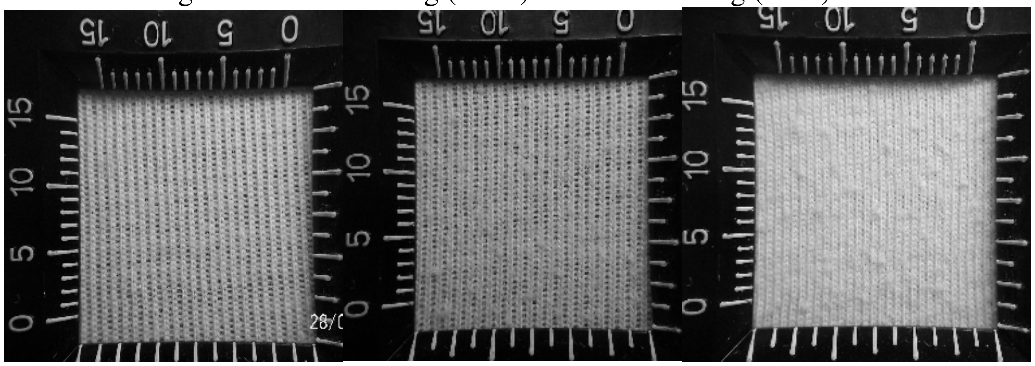


Figure A1.7 Photographic View of Sample Combed CO S. Jersey (sample 3.1)

Before washing Pilling (B.W.) Pilling (A.W)

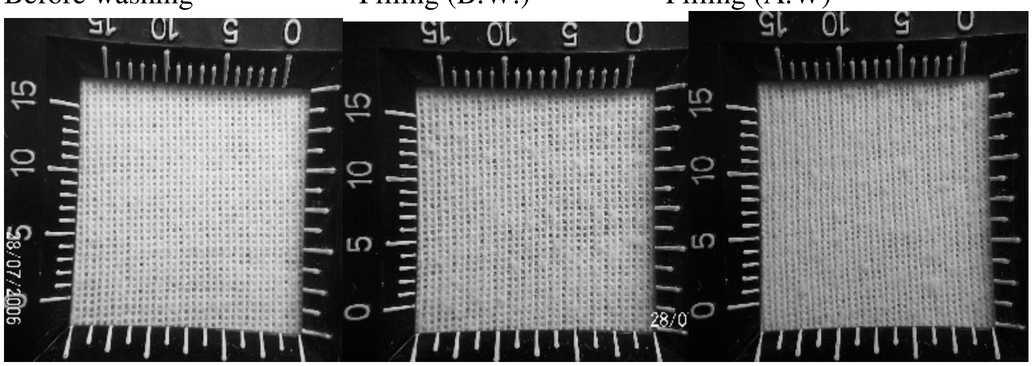


Figure A1.8 Photographic View of Sample Combed CO Ribana (sample 3.2)

Before washing Pilling (B.W.) Pilling (A.W)

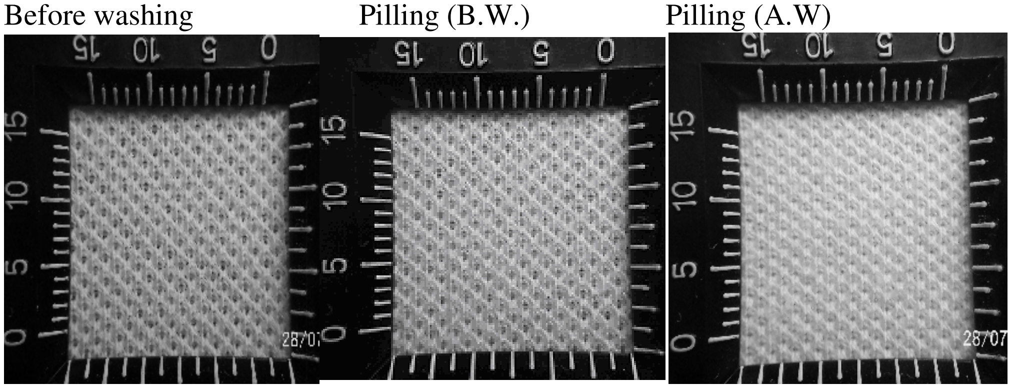


Figure A1.9 Photographic View of Sample Combed CO Lacoste (sample 3.3)

Before washing Pilling (B.W.) Pilling (A.W)

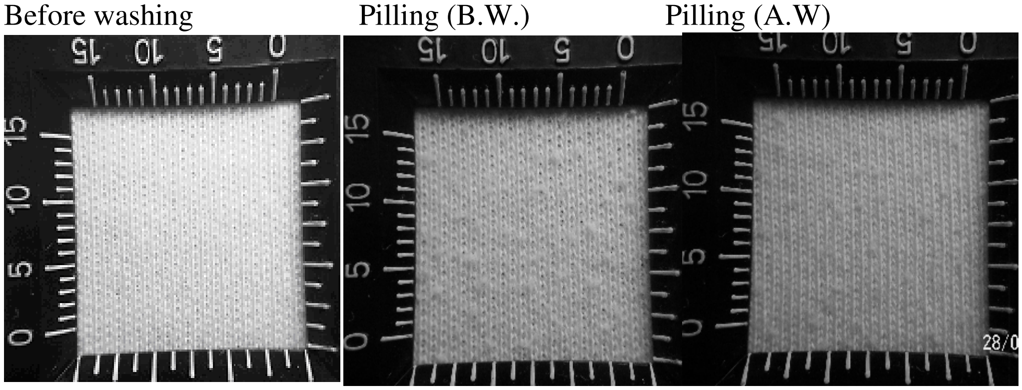


Figure A1.10 Photographic View of Sample Combed CO Interlock (sample 3.4)

Before washing Pilling (B.W.) Pilling (A.W)

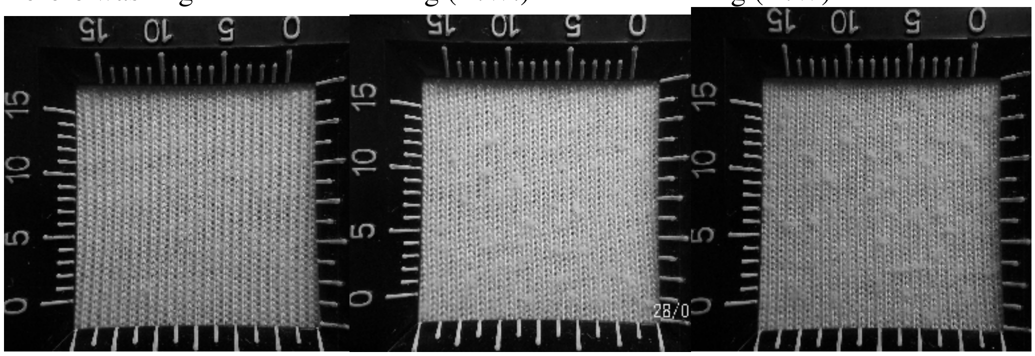


Figure A1.11 Photographic View of Sample Carded CV S. Jersey (sample 4.1)

Before washing Pilling (B.W.) Pilling (A.W)

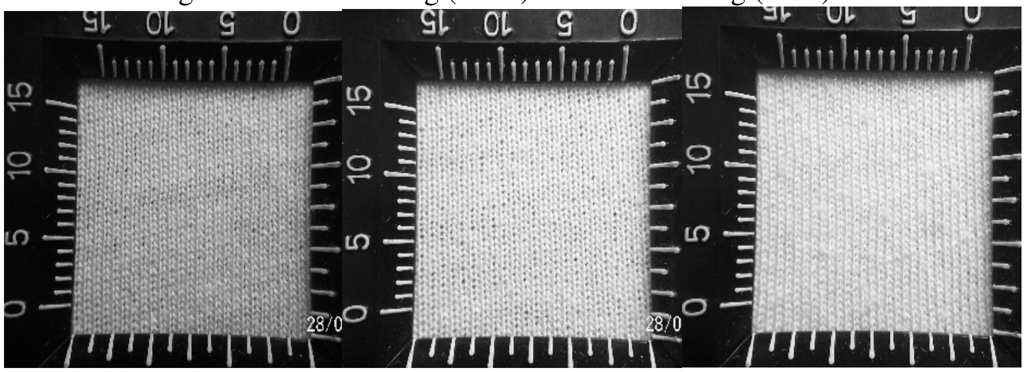


Figure A1.12 Photographic View of Sample OE Rotor PAN S. Jersey (sample 5.1)

Before washing Pilling (B.W.) Pilling (A.W)

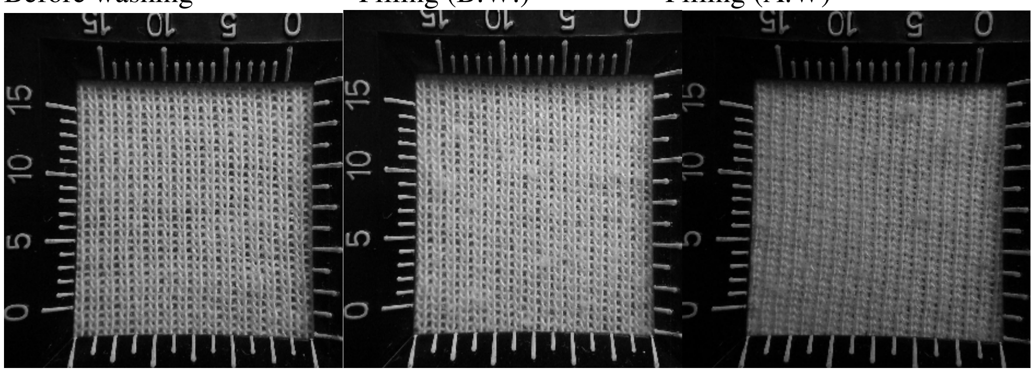


Figure A1.13 Photographic View of Sample OE Rotor PAN Ribana (sample 5.2)

Before washing Pilling (B.W.) Pilling (A.W)

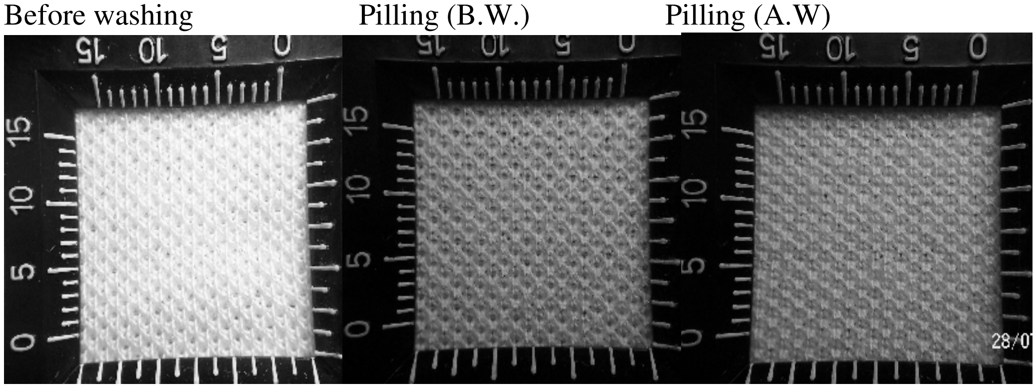


Figure A1.14 Photographic View of Sample OE Rotor PAN Lacoste (sample 5.3)

Before washing Pilling (B.W.) Pilling (A.W)

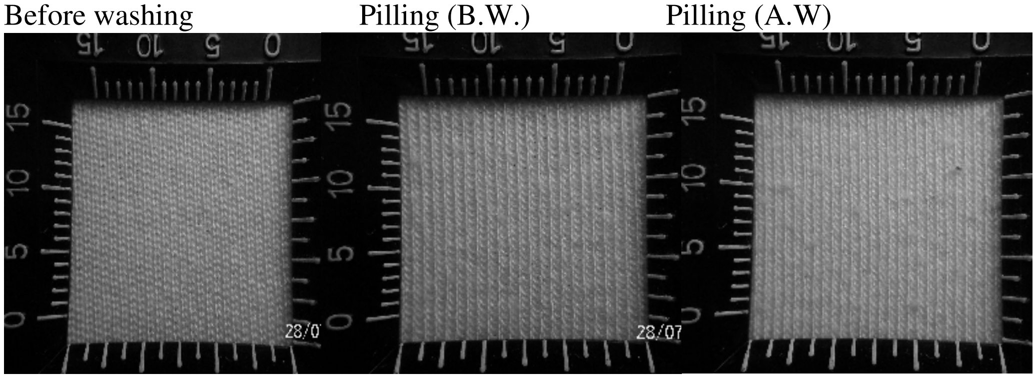


Figure A1.15 Photographic View of Sample OE Rotor PAN Interlock (sample 5.4)

Before washing Pilling (B.W.) Pilling (A.W)

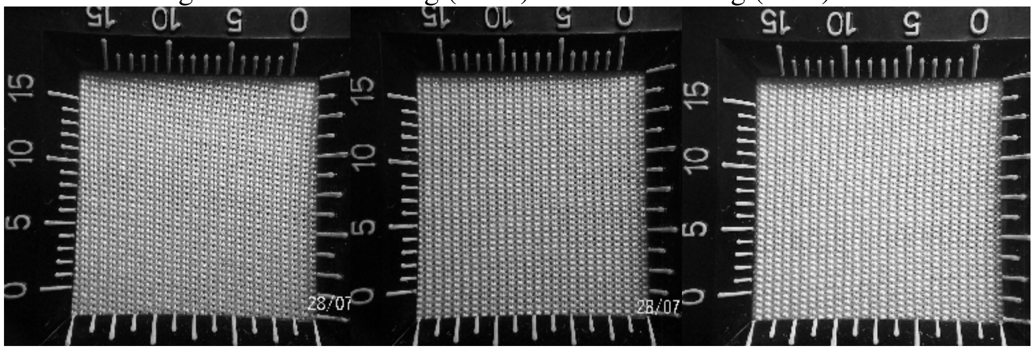


Figure A1.16 Photographic View of Sample PP Delta 1 S. Jersey (sample 6.1)

Before washing Pilling (B.W.) Pilling (A.W)

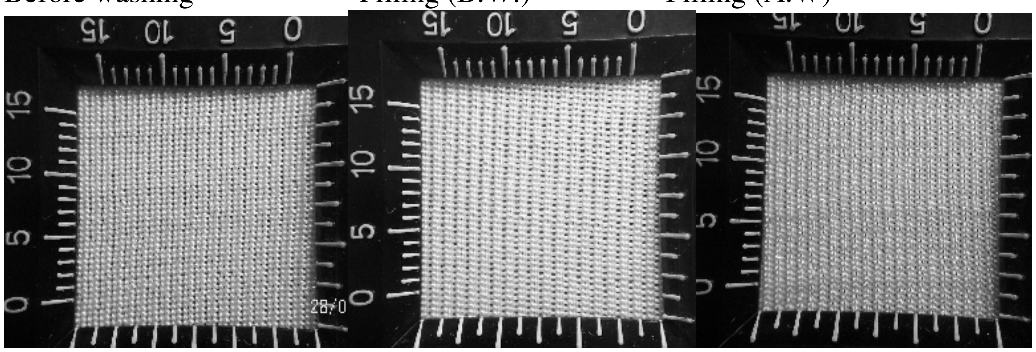


Figure A1.17 Photographic View of Sample PP Delta 1 Ribana (sample 6.2)

Before washing Pilling (B.W.) Pilling (A.W)

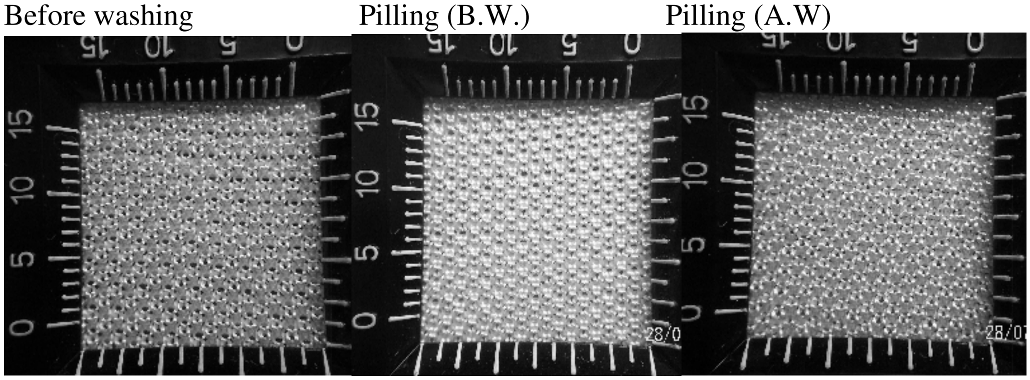


Figure A1.18 Photographic View of Sample PP Delta 1 Lacoste (sample 6.3)

Before washing Pilling (B.W.) Pilling (A.W)

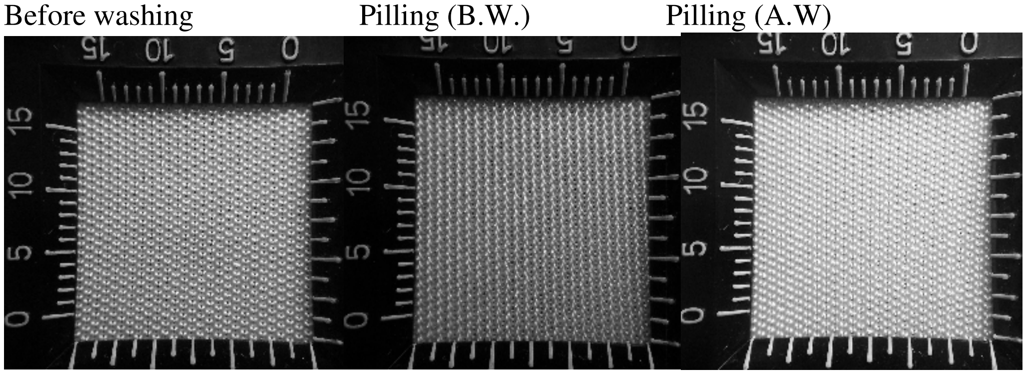


Figure A1.19 Photographic View of Sample PP Delta 1 Interlock (sample 6.4)

Before washing Pilling (B.W.) Pilling (A.W)

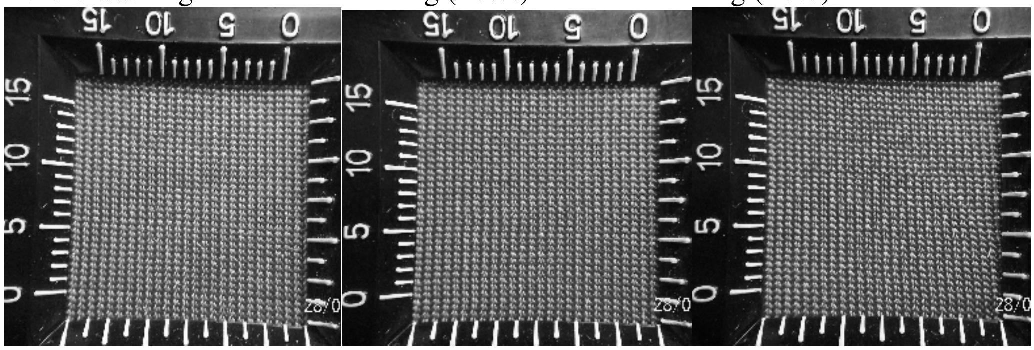


Figure A1.20 Photographic View of Sample PP Delta 2 S. Jersey (sample 7.1)

Before washing Pilling (B.W.) Pilling (A.W)

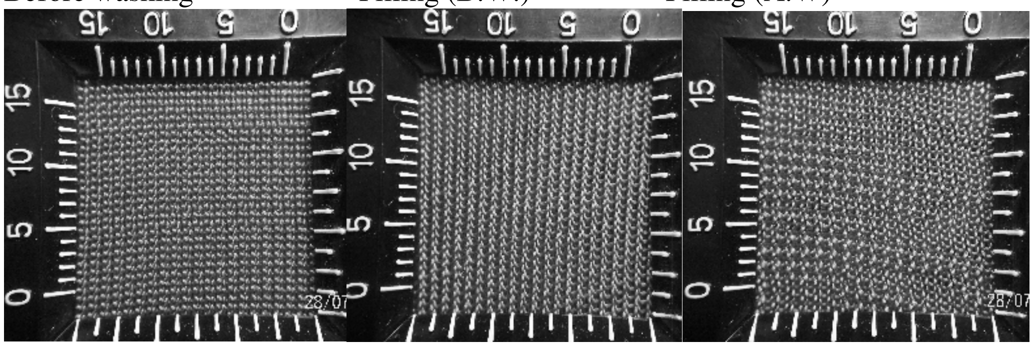


Figure A1.21 Photographic View of Sample PP Delta 2 Ribana (sample 7.2)

Before washing Pilling (B.W.) Pilling (A.W)

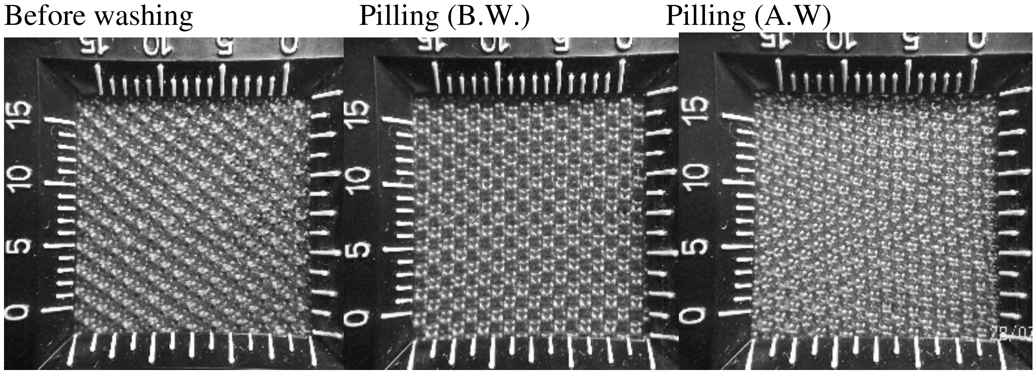


Figure A1.22 Photographic View of Sample PP Delta 2 Lacoste (sample 7.3)

Before washing Pilling (B.W.) Pilling (A.W)

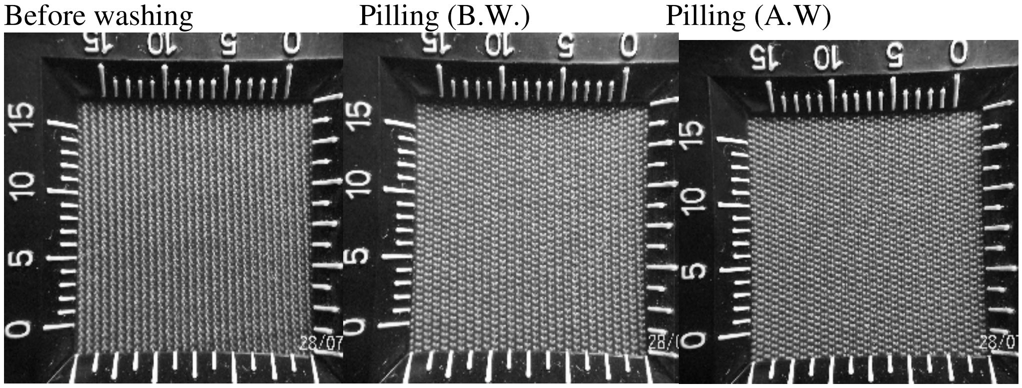


Figure A1.23 Photographic View of Sample PP Delta 2 Interlock (sample 7.4)

Table A2.1 Sets of Samples for Snagging Tests

First Set of Samples				
Knitting Structure / Fiber & Yarn Type	S.Jersey	Ribana	Lacoste	Interlock
PP Delta 1	6.1	6.2	6.3	6.4
PP Delta 2	7.1	7.2	7.3	7.4

Second Set of Samples			
Tightnesses / Fiber & Yarn Type	Tight	Medium	Loose
PP Delta 1	8.1	8.2	8.3
PP Delta 2	9.1	9.2	9.3
PP Round	10.1	10.2	10.3
PES Delta	11.1	11.2	11.3

APPENDIX A2:PHOTOGRAPHIC VIEW OF SAMPLE OF SNAGGING GRADE

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

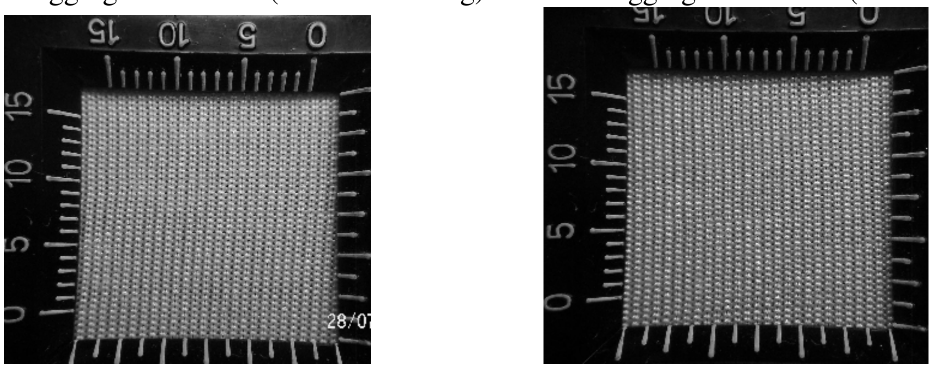


Figure A2.1. Photographic View of Sample PP Delta 1 S. Jersey (sample 6.1)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

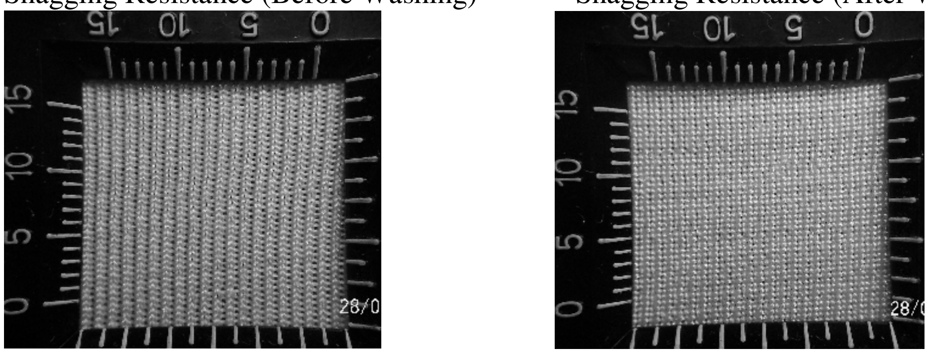


Figure A2.2 Photographic View of Sample PP Delta 1 Ribana (sample 6.2)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

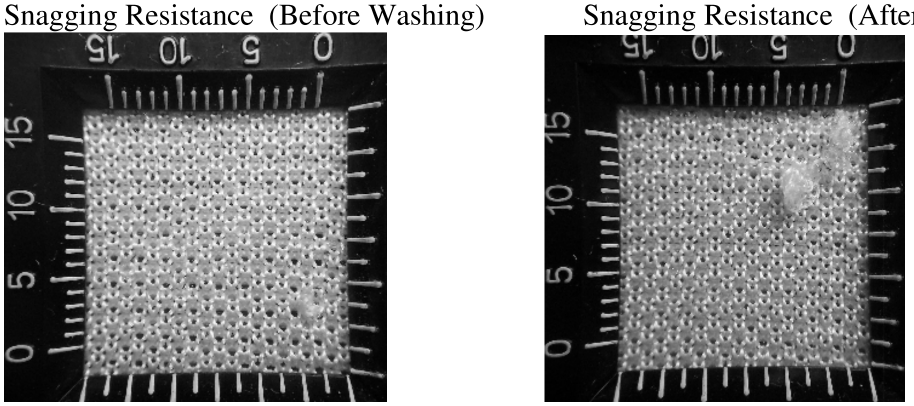


Figure A2.3 Photographic View of Sample PP Delta 1 Lacoste (sample 6.3)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

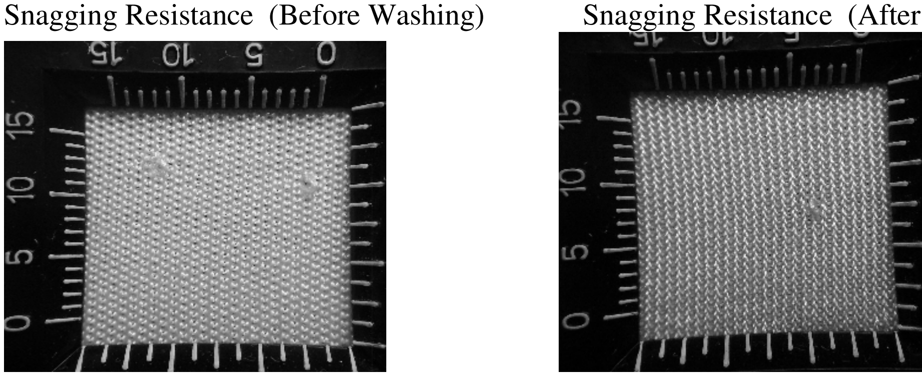
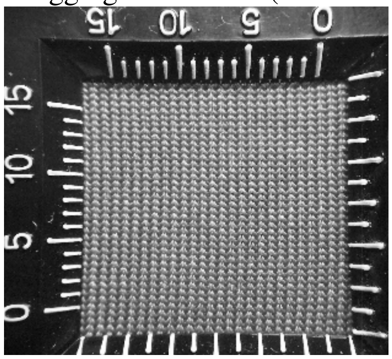


Figure A2.4 Photographic View of Sample PP Delta 1 Interlock (sample 6.4)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)



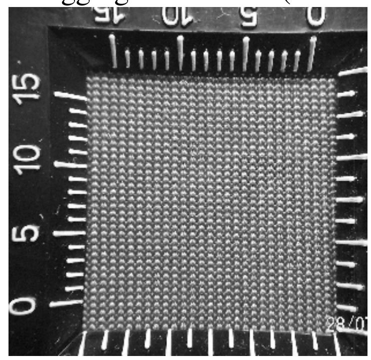
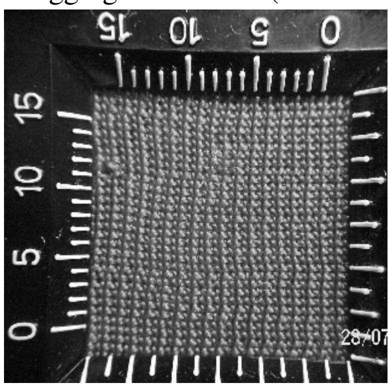


Figure A2.5 Photographic View of Sample PP Delta 2 S. Jersey (sample 7.1)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)



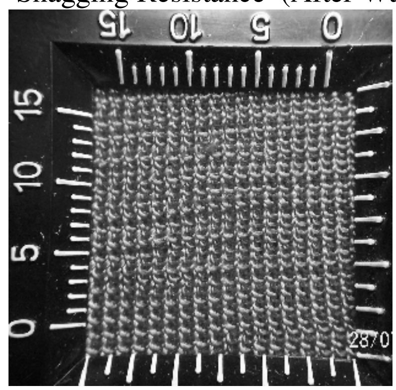
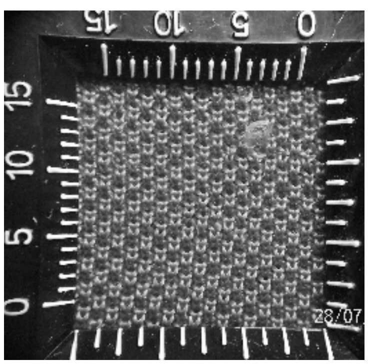


Figure A2.6 Photographic View of Sample PP Delta 2 Ribana (sample 7.2)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)



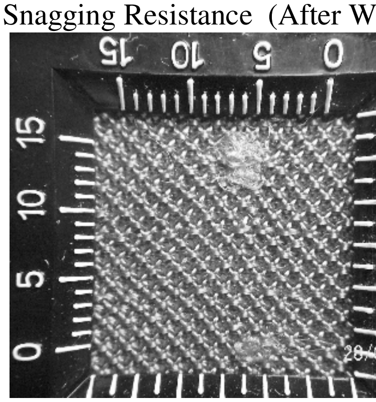
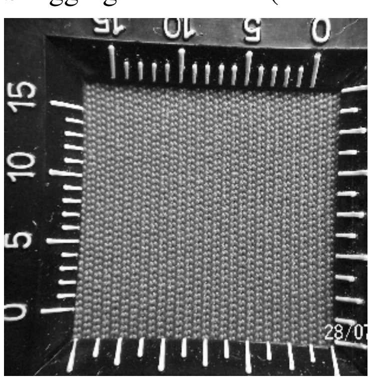


Figure A2.7 Photographic View of Sample PP Delta 2 Lacoste (sample 7.3)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)



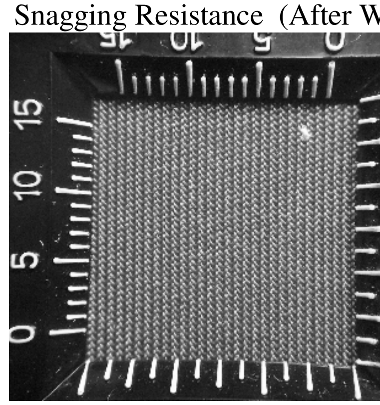


Figure A2. Photographic View of Sample PP Delta 2 Interlock (sample 7.4)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

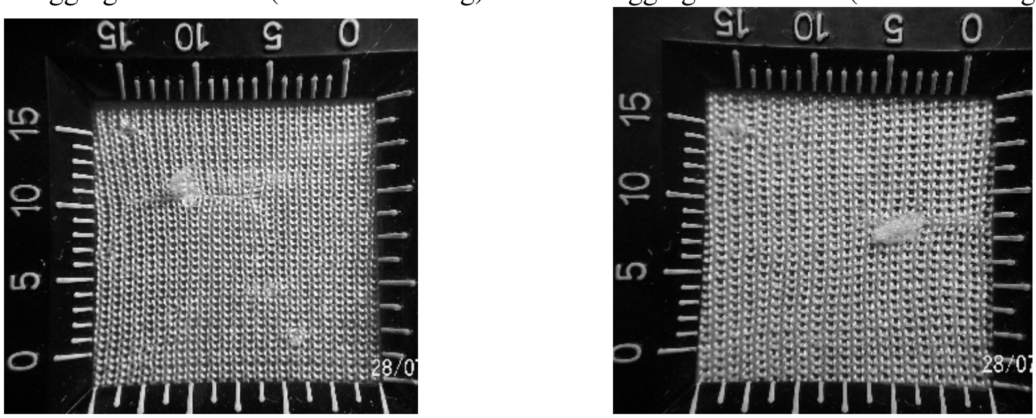


Figure A2.9 Photographic View of Sample PES 1/70 Denier S.jersey (sample 14.1)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

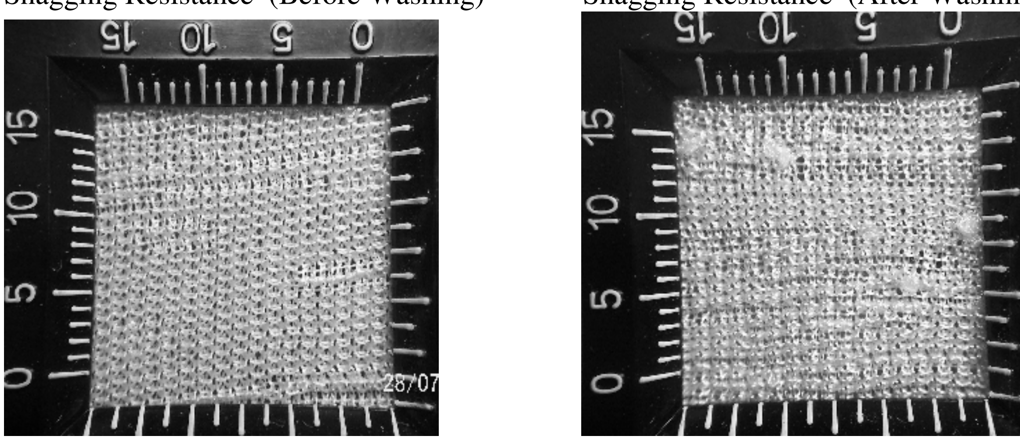


Figure A2.10 Photographic View of Sample PES 1/70 Denier ribana (sample 14.2)

Snagging Resistance (Before Washing) Snagging Resistance (After Washing)

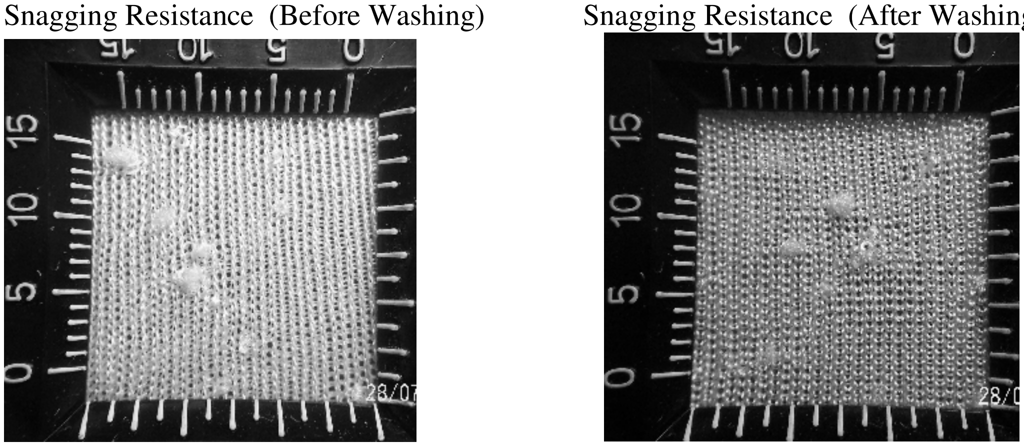


Figure A2.11 Photographic View of Sample PES 1/70 Denier Interlock (sample 14.3)

Snagging Resistance (Tight – Medium – Loose)

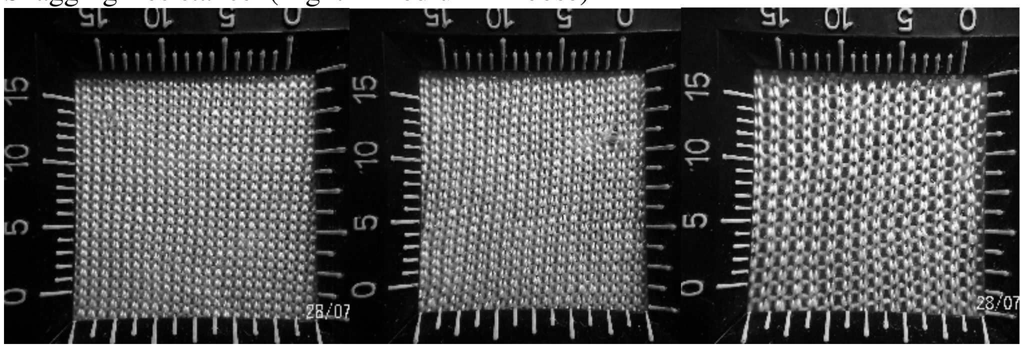


Figure A2.12. Photographic View of Sample PP Delta 1 S. Jersey (sample 8.1-2-3)

Snagging Resistance (Tight – Medium – Loose)

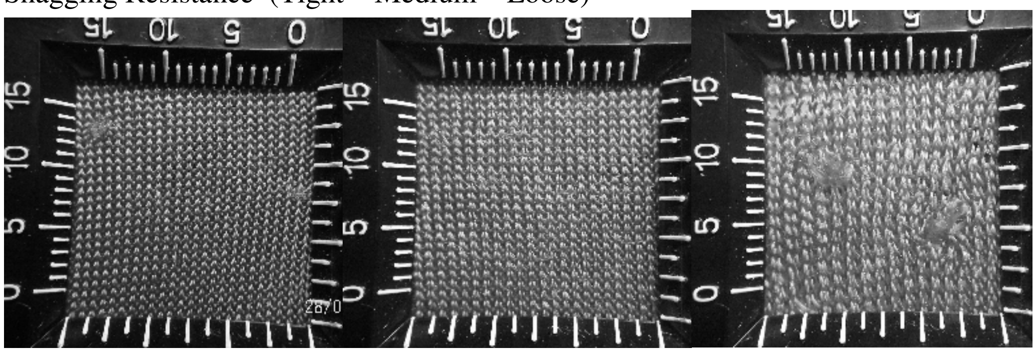


Figure A2.13 Photographic View of Sample PP Delta 2 S. Jersey (sample 9.1-2-3)

Snagging Resistance (Tight – Medium – Loose)

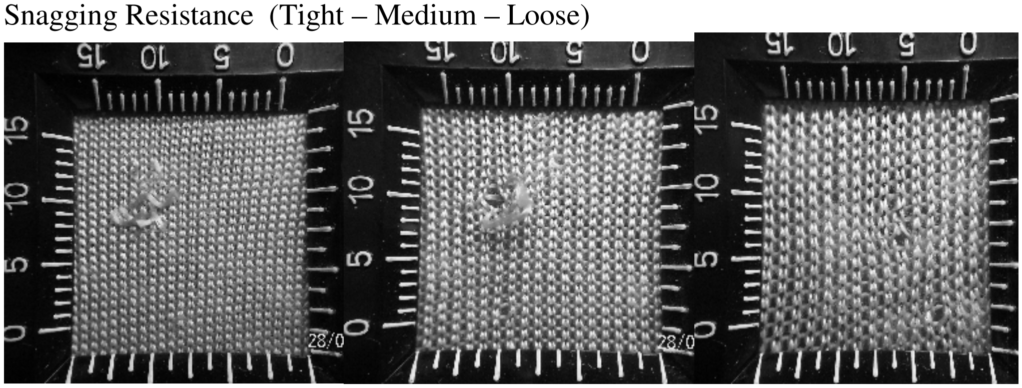


Figure A2. Photographic View of Sample PP Round S. Jersey (sample 10.1-2-3)

Snagging Resistance (Tight – Medium – Loose)

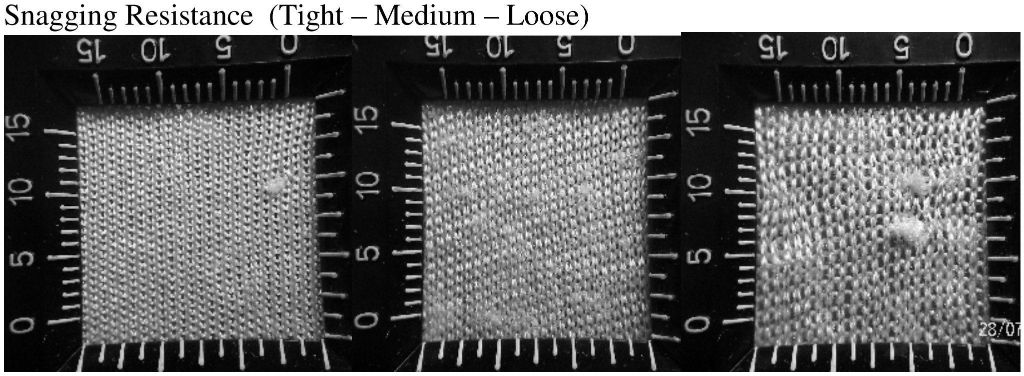


Figure A2.15 . Photographic View of Sample PES Delta S. Jersey (sample 11.1-2-3)

APPENDIX B

STATISTICAL ANALYSIS RESULTS FOR EXPERIMENTAL STUDY

APPENDIX B1: ANOVA AND TUKEY TABLES FOR BURSTING STRENGTH OF YARN TYPES

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OE ROTORCO	Between Groups	25309,661	3	8436,554	127,483	,000
	Within Groups	1058,848	16	66,178		
	Total	26368,509	19			
COM.CO	Between Groups	54322,109	3	18107,370	73,490	,000
	Within Groups	3942,290	16	246,393		
	Total	58264,399	19			
PPDELTA1	Between Groups	233555,498	3	77851,833	78,398	,000
	Within Groups	15888,440	16	993,028		
	Total	249443,938	19			
PPDELTA2	Between Groups	436576,980	3	145525,660	282,273	,000
	Within Groups	8248,800	16	515,550		
	Total	444825,780	19			
OE ROTOR PAN	Between Groups	59428,958	3	19809,653	96,543	,000
	Within Groups	3283,052	16	205,191		
	Total	62712,010	19			

OE ROTOR CO

Tukey HSD

KNITSRC	N	Subset for alpha = .05		
		1	2	3
3,00	5	154,600		
2,00	5		195,900	
1,00	5		202,820	
4,00	5			254,700
Sig.		1,000	,549	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

COMBED CO

Tukey HSD

KNITSRC	N	Subset for alpha = .05		
		1	2	3
3,00	5	237,260		
1,00	5		270,220	
2,00	5		273,500	
4,00	5			376,148
Sig.		1,000	,987	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

PP DELTA 1

Tukey HSD

KNITSRC	N	Subset for alpha = .05		
		1	2	3
3,00	5	465,640		
1,00	5		562,480	
2,00	5		592,380	
4,00	5			765,060
Sig.		1,000	,460	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

PP DELTA 2

Tukey HSD

KNITSRC	N	Subset for alpha = .05		
		1	2	3
3,00	5	415,820		
1,00	5		492,380	
2,00	5		494,560	
4,00	5			800,840
Sig.		1,000	,999	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

OE ROTOR PAN

Tukey HSD

KNITSRC	N	Subset for alpha = .05	
		1	2
3,00	5	198,860	
1,00	5	199,220	
2,00	5	217,640	
4,00	5		329,900
Sig.		,204	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

APPENDIX B2: ANOVA AND TUKEY TABLES FOR BURSTING STRENGTH OF KNITTING STRUCTURES

ANOVA

S.JERSEY

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	707119,252	6	117853,209	270,997	,000
Within Groups	12176,828	28	434,887		
Total	719296,080	34			

S.JERSEY
Tukey HSD

FIBERTYP	N	Subset for alpha = .05				
		1	2	3	4	5
4,00	5	191,7000				
5,00	5	199,2200	199,2200			
1,00	5	202,8200	202,8200			
2,00	5		238,5800	238,5800		
3,00	5			270,2200		
7,00	5				492,380	
6,00	5					562,480
Sig.		,978	,076	,236	1,000	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

ANOVA
RIBANA&LACOSTE

		Sum of Squares	df	Mean Square	F	Sig.
RIBANA	Between Groups	627565,422	4	156891,355	341,176	,000
	Within Groups	9197,092	20	459,855		
	Total	636762,514	24			
LACOSTE	Between Groups	380014,294	4	95003,573	350,190	,000
	Within Groups	5425,824	20	271,291		
	Total	385440,118	24			

RIBANA
Tukey HSD

FIBERTYP	N	Subset for alpha = .05			
		1	2	3	4
1,00	5	195,9000			
5,00	5	217,6400			
3,00	5		273,5000		
7,00	5			494,5600	
6,00	5				589,9800
Sig.		,512	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

LACOSTE
Tukey HSD

FIBERTYP	N	Subset for alpha = .05				
		1	2	3	4	5
1,00	5	154,6000				
5,00	5		198,8600			
3,00	5			237,2600		
7,00	5				415,8200	
6,00	5					465,640
Sig.		1,000	1,000	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

ANOVA
INTERLOCK

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1456677,039	5	291335,408	986,229	,000
Within Groups	7089,682	24	295,403		
Total	1463766,721	29			

INTERLOCK

Tukey HSD

FIBERTYP	N	Subset for alpha = .05				
		1	2	3	4	5
1,00	5	254,7000				
5,00	5		324,2200			
2,00	5		333,6000			
3,00	5			376,1480		
6,00	5				765,0600	
7,00	5					800,8400
Sig.		1,000	,952	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 5,000.

APPENDIX B3: ANOVA AND TUKEY TABLES FOR BURSTING STRENGTH OF CONTINUOUS FILAMENT YARNS VERSUS TIGHTNESS FACTOR

ANOVA

YARNTYPE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	75090,069	3	25030,023	55,079	,000
Within Groups	7271,076	16	454,442		
Total	82361,145	19			

YARNTYPE

Tukey HSD

SAMPLE	N	Subset for alpha = .05			
		1	2	3	4
11,00	5	312,9600			
10,00	5		359,4400		
9,00	5			410,5600	
8,00	5				477,9000
Sig.		1,000	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 5,000.

APPENDIX B4: ANOVA AND TUKEY TABLES FOR BURSTING STRENGTH OF CONTINUOUS FILAMENT YARNS, PRODUCED ON 22E KNITTING MACHINE

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PPDELTA1	Between Groups	45225,497	2	22612,749	23,269	,000
	Within Groups	11661,780	12	971,815		
	Total	56887,277	14			
PPDELTA2	Between Groups	36887,761	2	18443,881	52,286	,000
	Within Groups	4233,032	12	352,753		
	Total	41120,793	14			
PPROUND	Between Groups	21577,257	2	10788,629	21,180	,000
	Within Groups	6112,432	12	509,369		
	Total	27689,689	14			
PESDELTA	Between Groups	9247,068	2	4623,534	22,302	,000
	Within Groups	2487,816	12	207,318		
	Total	11734,884	14			

PPDELTA1

Tukey HSD

TIGHTNSS	N	Subset for alpha = .05	
		1	2
3,00	5	344,8200	
2,00	5		428,2400
1,00	5		477,9000
Sig.		1,000	,065

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 5,000.

PPDELTA2
Tukey HSD

TIGHTNSS	N	Subset for alpha = .05	
		1	2
3,00	5	300,3800	
2,00	5		399,7600
1,00	5		410,5600
Sig.		1,000	,645

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

PPROUND
Tukey HSD

TIGHTNSS	N	Subset for alpha = .05	
		1	2
3,00	5	267,6600	
2,00	5	301,0800	
1,00	5		359,4400
Sig.		,088	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

PESDELTA
Tukey HSD

TIGHTNSS	N	Subset for alpha = .05	
		1	2
3,00	5	254,6400	
2,00	5	268,8600	
1,00	5		312,9600
Sig.		,299	1,000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 5,000.

APPENDIX B5: PEARSON CORRELATION TABLE FOR RKM – BURSTING STRENGHT

Correlations(a)

		RKM	BRSTSTR
RKM	Pearson Correlation	1	,966(**)
	Sig. (1-tailed)	.	,000
BRSTSTR	Pearson Correlation	,966(**)	1
	Sig. (1-tailed)	,000	.

** Correlation is significant at the 0.01 level (1-tailed).
a Listwise N=35

APPENDIX B6: PEARSON CORRELATION TABLE FOR UNWASHED BURSTING STRENGHT VALUE – WASHED BURSTING STRENGHT VALUE

Correlations(a)

		UNWASHED	WASHED
UNWASHED	Pearson Correlation	1	,987(**)
	Sig. (2-tailed)	.	,000
WASHED	Pearson Correlation	,987(**)	1
	Sig. (2-tailed)	,000	.

** Correlation is significant at the 0.01 level (2-tailed).
a Listwise N=100

APPENDIX B7: PEARSON CORRELATION TABLE FOR TIGHTNESS FACTOR – BURSTING STRENGHT VALUE

Correlations(a)

		TIGTHNESS	BRTSTR
TGHTNSS	Pearson Correlation	1	,856(**)
	Sig. (2-tailed)	.	,000
BRTSTR	Pearson Correlation	,856(**)	1
	Sig. (2-tailed)	,000	.

** Correlation is significant at the 0.01 level (2-tailed).
a Listwise N=15