ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

DEVELOPMENT OF A DRYING ALGORITHM FOR RECYCLED TEXTILES

M.Sc. THESIS

Bilge MELİKOĞLU

Department of Textile Engineering

Textile Engineering Programme

“

JUNE 2025

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

DEVELOPMENT OF A DRYING ALGORITHM FOR RECYCLED TEXTILES

M.Sc. THESIS

Bilge MELİKOĞLU
(503221802)

Department of Textile Engineering

Textile Engineering Programme

Thesis Advisor: Assoc. Prof. Umut Kıvanç ŞAHİN

JUNE 2025

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

GERİ DÖNÜŞTÜRÜLMÜŞ TEKSTİLLER İÇİN KURUTMA ALGORİTMASI GELİŞTİRİLMESİ

YÜKSEK LİSANS TEZİ

Bilge MELİKOĞLU
(503221802)

Tekstil Mühendisliği Anabilim Dalı

Tekstil Mühendisliği Programı

Tez Danışmanı: Doç. Dr. Umut Kıvanç ŞAHİN

HAZİRAN 2025

Bilge Melikoğlu, a M.Sc. student of İTU Graduate School student ID 503221802, successfully defended the thesis/dissertation entitled "DEVELOPMENT OF A DRYING ALGORITHM FOR RECYCLED TEXTILES", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assoc. Dr.Umut Kıvanç ŞAHİN**
....
İstanbul Technical University

Jury Members : **Assist. Prof. Dr. Pelin Altay**
....
Istanbul Technical University

Prof. Dr. Burcu YILMAZ
....
Marmara University

Date of Submission : 23 May 2025
Date of Defense : 2 June 2025

FOREWORD

First of all, this master's thesis was supported by TUBITAK 2210-D programme with grant number 1649B022301111, and the author of this thesis is really appreciated for their support. Also, I would like to thank companies for sending chemicals, fabrics, and machines for this study.

June 2025

Bilge MELİKOĞLU
Textile Engineer

TABLE OF CONTENTS

Page

ABBREVIATIONS

MCRC	**:** Nm 20/1 60% conv. cot. 40% recycled cotton fabric
MCRP	**:** Nm 30/1 60% cot. 40% recycled polyester
MCP	**:** Nm 30/1 60% cotton 40% polyester fabric
RP	**:** Nm 30/1 100% recycled polyester
RC	**:** Nm 20/1 100% recycled cotton fabric
30C1	**:** Nm 30/1 100% cotton fabric
20C1	**:** Nm 20/1 100% cotton fabric
Cot.	**:** Cotton
Pet.	**:** Polyester
Conv.	**:** Conventional
Rcot	**:** Recycled Cotton
Rpet	**:** Recycled Polyester
Rec.	**:** Recycled

LIST OF TABLES

Page

LIST OF FIGURES

DEVELOPMENT OF A DRYING ALGORITHM FOR RECYCLED TEXTILES

SUMMARY

It is a fact that most people complain about how their clothes’ quality decreases after multiple washing & drying steps. Decrease on quality of clothes after washing & drying could result from change in size, color, seam strength, fabric strength and pilling/abrasion formation. In this thesis, quality change of 7 different quality t-shirts were investigated in order to find better drying algortihm for recycled textiles. Tests were made before washing, after 3 times washing & drying and after 6 times washing&drying and results were analyzed & compared via Minitab. Mixture design analysis had been used on Minitab to analyze results. For each washing step, neither detergent nor softener were used, and hard water with water hardness 14 (in English degrees) was used. Also, 70% of machine was full (approxiamately 5 kg) in each washing &drying step. For drying step, 3rd level drying was used to obtain cupboard dryness for all t-shirts. For blended fabrics, mixed programme was used, for cotton fabrics cotton cupboard programme was used and for synthetic fabrics, synthetic drying programme was used. During testing, it was found that recycled polyester t-shirts dried poorly under the synthetic program and excessively under the cotton program. These results suggested that a new drying algorithm designed especially for recycled polyester textiles was required. Therefore, based on the results of the tests that were carried out, the ideal parameters for temperature, duration, and energy consumption for this algorithm were established. After conduction of all the washing& drying cycles and quality tests, t-shirts were dried in cot eco programme to investigate drying performance of this programme. According to test results, recycled polyester has the greatest fabric strength results while recycled cotton and their blends’ quality became better after 3 washing and drying cycles. In terms of energy performance of drying programmes, it could be said that cotton cupboard uses the highest energy and with too much drying, it could affect quality performance of fabric adversely. Cot eco uses higher energy than mixed programme, yet clothes were still damp at the end of cot eco programme. Synthetic programme uses the lowest energy and it did not even dry the synthetic t-shirts, so a new drying algorithm had been developed in order to dry recycled polyester t-shirts while using less time and less energy, and this new programme is a shorter version of a cotton cupboard programme.

It could be stated that the mixed program is the most suitable for all fabric types, as it is the most efficient option in terms of energy performance. Considering all these results, it is concluded that recycled cotton and recycled polyester can be used more extensively in textile production without compromising fabric quality. Furthermore, while the mixed program appears ideal for all fiber types, it is anticipated that new drying algorithms could be developed in the future based on the fiber type and fiber content used in garments.

This master’s thesis was supported by TUBITAK 2210-D programme with grant number 1649B022301111, and the author is grateful for this support.

GERİ DÖNÜŞTÜRÜLMÜŞ TEKSTİLLER İÇİN KURUTMA ALGORİTMASI GELİŞTİRİLMESİ

ÖZET

Birçok kişi yıkama ve kurutma işlemleri sonrasında kıyafetlerinin kalitesinin olumsuz olarak etkilendiği konusunda şikayet etmektedir. Kıyafet kalitesi genellikle renk solması, tüylülüğün artması, boncuklanma, boyutsal değişim (kıyafetin çekmesi ya da bollaşması) gibi durumlardan olumsuz etkilenmektedir. Bu tezin yazılma amacı geri dönüştürülmüş pamuk, geri dönüştürülmüş polyester, konvansiyonel pamuk ve polyester ve bunların karışımından elde edilmiş tişörtlerin çeşitli kumaş kalite özelliklerinin yıkama ve kurutma öncesi ve sonrası şeklinde karşılaştırılarak farklı iplik numarası ve elyaf türünün yıkama ve kurutma sonrası performansa olan etkisinin incelenmesi, çeşitli kurutma programlarının harcadığı enerji seviyeleri ve kurutma performansları karşılaştırılarak ihtiyaç görüldüğü takdirde örme süprem kumaşlar için en uygun kurutma algoritmasının belirlenmesidir.

Bu çalışmada kumaş kalite özelliklerini belirlemek için boncuklanma dayanımı, aşınma dayanımı, kumaş ağırlığı, kumaş kalınlığı, kumaş sertliği, boyutsal değişim, may dönmesi, dikey ve yatay kılcal ıslanma, kurutma hızı, su buharı geçirgenliği, hava geçirgenliği, patlama mukavemeti, dikiş mukavemeti, yıkmaya bağlı renk haslığı, sürtme haslığı, ışık haslığı, ısıl iletkenlik ve dsc testleri yapılmış ve kurutma sonrası çıkan hav miktarı incelenmiştir. Bütün bu laboratuvar çalışmaları boyunca İTÜ Tekstil Teknolojileri ve Tasarımı fakültesindeki 5 tekstil kalite laboratuvarı aktif olarak kullanılmıştır. Bütün tişörtlerin yıkama testlerinde 30 derece 800 rpm olan 30 dk'lık program tercih edilirken yıkamalarda deterjan ya da yumuşatıcı kullanılmamıştır ve bütün yıkamalarda su sertliği 14 (İngiliz sistemi) olacak şekilde ayarlanmıştır. Kurutma bütün tişörtler için 3. seviyede yapılırken karışım kaliteler için 3. Seviye karma program, pamuklu kaliteler için 3. seviye pamuklu dolap programı ve sentetik kaliteler için sentetik program kullanılmış ve kurutma sırasında makinenin harcadığı enerji ölçülüp kayıt altına alınmıştır. Kurutma sonrası testler öncesinde tişörtler 1 gün laboratuvar şartlarında bekletilmiştir. Yıkama ve kurutma sürecinde makinenin %70'nin(yaklaşık 5 kg) dolu olmasına dikkat edilmiş ve testler için ayrılan tişörtler yerine aynı ağırlıkta olacak şekilde dolgu yükü eklenmiştir.

Yıkanmamış kumaş ve yıkanmış tişörtlerin test sonuçları Minitab'te karışım tasarımı analizi kullanılarak karşılaştırılmış ve analiz edilmiştir, karışım tasarımı analizinin kullanılma sebebi birden fazla lifin ve kumaştaki lif karışımının test sonuçlarına olan etkisini daha iyi bir şekilde incelemektir. Bu analiz türünün tekstille ilgili neredeyse hiçbir çalışmada kullanılmamış olması bu tezin özgünlüğünü de göstermektedir. Birçok testte R-sq ve R-sq (adj) değerlerinin sonuçları %75 üzerinde bulunmuş olup tekstil kalite test sonuçlarının doğruluğu bu şekilde ispatlanmıştır. Tişört kalite testleri tamamlandıktan sonra kurutma makinesi üreticisinin önerisiyle bütün tişörtler pamuk eko programında tekrar kurutulup bu programın kurutma ve enerji performansı seviyeleri diğer programlarla karşılaştırılarak bütün tişört kaliteleri için en ideal kurutma programı tespit edilmiştir.

Kurutma testleri sonucunda pamuklu dolap 3.seviye programının diğer programlara kıyasla 2 kat fazla enerji harcadığı ve tişörtleri aşırı kuru bir hale getirdiği ve dolayısıyla tişörtlerin aşırı kuruluk sebepli lif kopuşlarına ve hasarlanmaya daha fazla meyilli olabileceği ve boyusal değişimi negatif etkileyebileceği testler sonucunda gözlemlenmiştir. Kalite testleri bittikten sonra bütün tişörtler ayrıca deneme amaçlı pamuk eko programında kurutulmuştur, fakat bu programda kurutma öncesi ve sonrası tişört ağırlıkları aynı olsa da tişörtlerde, özellikle de yaka kısımlarında bir miktar nemlilik tespit edilmiş olup bu programın pamuklu dolap programına kıyasla enerji verimliliği iyi olsa da hiçbir tişört kalitesinde dolap kuruluğu vaat etmediği için kullanılması önerilmemektedir. Kullanılan bütün kurutma programları karşılaştırıldığında, karma 3.seviye programının enerji verimliliği açısından pamuk eko ve pamuklu dolap 3.seviyeden daha iyi olduğu ve kurutma seviyesi açısından en iyi program olduğu gözlemlenmiş olup hem normal hem geri dönüştürülmüş liflerden elde edilmiş giysilerde ideal kuruluğu sağlayacağı saptanmıştır. Buna ek olarak, karma programında kuruyan %60 pamuk %40 polyester ve %60 pamuk %40 geri dönüştürülmüş polyester içerikli iki farklı kalitenin de kurutma esnasında 591 WH enerji harcadığı görülmüştür, yani kurutma makinesi geri dönüştürülmüş polyester ve normal polyester arasında bir fark görmeyip aynı miktarda enerjiyle kurutmuştur.

Sentetik programında ise sadece %100 geri dönüştürülmüş polyester içerikli tişörtler kurutulmuş olup programın kurutma için yetersiz kaldığı tespit edilmiştir, bunun sebebi programın kurutma standardının pamuk-polyester karışımlı kumaşlara göre oluşturulması sonucunda makinenin %100 geri dönüştürülmüş polyester tişörtü ıslak olduğu halde kuru gibi algılamasıdır. Diğer kurutma programları ise sentetik içerikli kumaşlar için fazla uzun olup çok fazla enerji harcamaktadır, bu yüzden 100% geri dönüştürülmüş polyester için yeni bir kurutma algoritması geliştirilmesine dair bir ihtiyaç doğmuştur. Bu yüzden sentetik programı yarım saat sürmekte olup yaklaşık 150 wh enerji harcamaktadır, bu da tişört kuruluğu için son derece yetersizdir. Bu sebeple geri dönüştürülmüş polyester için yeni bir kurutma algoritması geliştirilmesi gerektiği kararlaştırılmıştır. Bu sebeple %100 geri dönüştürülmüş polyester hem pamuklu dolap 3.seviye hem pamuk eko programlarında kurutularak hem tişörtlerin kuruma performansı hem de programların harcadığı enerji karşılaştırılmıştır. %100 geri dönüştürülmüş polyester pamuk eko programında 103 dk boyunca 771 wh enerji harcayarak kurutulmasına rağmen kurutma sonu kendi ağırlığında hafif nemli olarak çıkmıştır, fakat pamuklu dolap 3.seviye programında 70 dk boyunca kurutulup program 50 dk erken bitirildiğinde 491 wh enerji harcayarak ideal kuruluk seviyesine erişmiştir. Bu sonuçlar ışığında, Arçelik sentetik kurutma programı için 70 dk boyunca 491 wh enerji harcayacak yeni bir kurutma algoritması geliştirmiş ve yeni kurutma makinelerinde geliştirdiğimiz bu yeni algoritmayı kullanmayı tercih etmişlerdir ve geliştirilen yeni kurutma algoritması ve yıkama-tamburlu kurutma öncesi ve sonrası test sonuçları için bildiri ve makale süreci başlatılmıştır. Yapılan tekstil kalite testleri sonucunda birçok testte geri dönüştürülmüş pamuk ve geri dönüştürülmüş polyesterin normal pamuk ve polyestere kıyasla daha iyi performansa sahip olduğu gözlenmiş olup genellikle 3.çevrimden sonra kumaş kalite özelliklerinin sabit kaldığı ve yıkanmamış kumaşa kıyasla büyük bir kalite kaybı yaşanmadığı, tam aksine kumaş kalitesinin iyileştiği gözlemlenmiştir. Renkli geri dönüştürülmüş pamuk tişörtlerde tişört renginin 6 yıkama ve kurutma sonrası dahi gayet iyi durumda olduğu gözlemlenmiştir ve ışık haslığı sonuçlarının 3 ve 6.çevrim sonunda değişmeyip aynı kaldığı görülmüştür.

Neredeyse bütün çevrimlerde 100% geri dönüştürülmüş polyester t-shirtlerin test sonuçları gayet olumlu çıkarken renk ve haslık test sonuçlarında 100% geri dönüştürülmüş pamuklu t-shirtlerin ön plana çıktığı görülmüştür. Bu sonuçlar sürdürülebilir tekstil üretimi için umut verici olup geri dönüştürülmüş pamuk ve polyesterden elde edilmiş ürünlere olan talebi arttıracağı öngörülmektedir. Ayrıca pamuk ve geri dönüştürülmüş pamuk için dolap kuruluğunu sağlayan enerji miktarı ve ideal kurutma süresinin hesaplanması, geri dönüştürülmüş polyester için daha kısa süreli ve daha az enerji harcayan bir kurutma algoritmasının yazılmasıyla birlikte tamburlu kurutma makinelerinde enerji verimliliğinin artması ve aşırı kurutma sonucu oluşan yoğun giysi hasarlanmasının da azalacağı ve bu yeni kurutma programlarında kurutulan giysilerin daha uzun ömürlü olacağı tahmin edilmektedir. Bu yüksek lisans tezi proje numarası 1649B022301111 olarak TÜBİTAK 2210-D programı tarafından desteklenmiştir ve bu tezin yazarı TÜBİTAK desteği için müteşekkirdir.

1. INTRODUCTION

1.1 Purpose of Thesis

The purpose of thesis is to investigate effect of each fiber on textile quality performance after washing & tumble drying via mixture design analysis, and determine if there is a need for a new drying algorithm, and to achieve best quality results for recycled cotton and recycled polyester, after multiple washing and drying steps. In this thesis, it is aimed to achieve t-shirts with cupboard dryness (0% +-1 humidity) while remaining the fundamental textile quality properties. According to the results, best drying algorithm will be selected and used in industry. In this thesis, textile quality tests had been made while following standards carefully. For washing, 30 min 30 degree 800 rpm washing program had been used. In order to find out how much the recycled fabric's quality could degrade after six wash cycles, detergent and fabric softener were not used during the washing process. For drying, synthetic, mixed, cotton cupboard and cot eco programs had been used in order to understand effect of different drying programs on recycled textile quality.

Sample ID	Fiber Content	Yarn Count	Fabric Unit Weight (gsm)
MCRC	60% conv. cot. 40% rec. cot.	Nm 20	173
30C1	100% conv. cot.	Nm 30	168
RC	100% rec. cot.	Nm 20	174
20C1	100% conv. cot.	Nm 20	171
MCP	60% cot. 40% pet.	Nm 30	166
RP	100% rec. pet.	Nm 30	164
MCRP	60% cot. 40% rec. pet.	Nm 30	172

Table 1.1.1: Fabric qualities that were used in this study.

1.2 Literature Review

Yılmaz & Keleş (2024)'s study is one of the most interesting and comprehensive research about this issue, they researched about air permeability and bursting strength results of washed, tumble dried and line dried 50% recycled cotton-50% recycled pes, 50% recycled cotton 50% virgin pes, 50% virgin cotton-50% virgin pes single jersey knitted fabrics, and according to the authors' results, it could be said that air permeability of these fabrics drastically change at first 5 cycles, and they did not observe significant changes in air permability after 5 cycles. Also, Yılmaz & Keleş (2024) stated that effect of washing temperature does not have a significant effect on air permeability of single jersey knitted fabrics, and line dried recycled fabrics have higher air permeability comparing to tumble-dried recycled fabrics, at all cycles. Moreover, Yılmaz & Keleş (2024) observed that recycled cotton & recycled polyester blend fabric's bursting strength affected by higher washing temperatures more adversely than natural fabrics, so using lower washing temperatures (for instance, 30 degrees) could be advised in order to decrease damage in recycled cotton, recycled polyester and their blends. For bursting strength, Yılmaz & Keleş (2024) claimed that bursting strength of tumble dried recycled single jersey fabrics changes approxiamately +-5% for all 20 cycles, that result corrects hypothesis of this master's thesis. Mazari et. Al (2021) compared thermal properties of 8 different knitted shirts in their study. It could be stated that water vapour permeability of 100% linen is quite same with unwashed 100%cotton fabrics in this thesis, also this thesis' water vapour permeability values for 100%cotton is approximately 10% higher than 100%cotton and 100%organic cotton fabrics in this article. The difference could be result from yarn type, yarn number, fabric structure or fabric thickness. Also, it could be said that increase in polyester in fabric could increase air permeability of fabric and 100% recycle polyester fabric's air permeability and water vapour permeability is quite same with 100%linen fabric, which is quite satisfactory to use as t-shirt. Since air permeability of 100%recycle cotton is 2 times higher than 100% cotton, wearing a 100% recycle cotton t-shirt could be more comfortable than 100% cotton in summer.

Yu & Ding (2023) investigated fabric damage of polyester woven fabric during tumble drying, and they found out that dimensional stability of polyester woven fabric did not influence from tumble drying, which is similar result with 100% recycled knitted polyester fabric. Necef et. al (2023) investigated thermal behavior of recycled cotton and their blends. It could be seen that for unwashed fabrics, thermal resistance and thermal absorptivity of 50%cotton 50% pes blend is lower than 60% cotton 40%polyester with same yarn number & fabric structure, so it could be stated that increase in cotton improves thermal properties of fabric. Also, in our work thermal resistance of Nm 30/1 100%cotton is higher than Nm 20/1 100%cotton, so when yarn becomes thinner thermal resistance increases. Also, it could be stated that even the amount of recycle cotton is similar, conv. Cotton-recycle cotton blend fabric has higher thermal resistance and thermal absorptivity than recycle cotton-polyester blend fabric, so it could be said that increase in amount of polyester reduces thermal properties of fabrics. According to Marmaralı & Sevgi (2023)'s work, even the yarn number changes, cotton- recycle polyester blend fabric has same thermal resistance properties but Nm 30/1 100% recycle polyester has lower thermal resistance than Nm 50/1 100% recycle polyester. Marmaralı & Sevgi (2023) stated that increase in recycle polyester increases thermal resistance even after multiple washes, but according to our results, only conv. Cotton- recycle polyester blend fabric's thermal resistance increases both 3rd and 6th cycle while 100% recycle polyester has the lowest thermal resistance at 6th cycle.

Also, Marmaralı & Sevgi (2023) stated that high air permeability result from low fabric density so polyester fabrics have higher air permeability compared to cotton fabrics, which is compatible with our results. Both they and us observed that cotton-polyester's air permeability increases with multiple washing, but it can be also stated that cotton-recycle polyester's air permeability decreases with multiple washing so if the fabric will be made with blend of fibers, polyester could achieve higher air permeability than recycled polyester. For bursting strength, Marmaralı &Sevgi (2023) achieved 20% decrease in 100%cotton fabric after 20 washing, this severe bursting strength reduce could be result from using thinner yarn.

Since this study uses more thicker yarns than they have, this study’s bursting strength results for Nm 30/1 100% cotton fabric slightly increased after multiple washing cycles. For recycle cotton, recycle cotton and cotton blend and cotton- recycle pes blend fabrics, 6th cycle bursting strength results are higher than the unwashed fabric. Uyanık and Kaya Nacarkahya (2024) also have study about recycled textiles’ pilling resistance and bursting strength, and they stated that if two fabrics have same recycled fiber blend, the fabric with coarser yarns will probably have higher pilling resistance & higher bursting strength. Since having coarser yarns also increase fabric weight, recycled fabrics with coarser yarns (such as Ne 10) could not use in summer cloth, so achievement of optimum fabric strength and optimum fabric thickness is very crucial for recycled fabrics. Also, Uyanık and Kaya Nacarkahya (2024) said that Ne 30 recycled fabrics have slightly lower bursting strength than Ne 20 recycled fabrics, while pilling resistance of Ne 20 & Ne 30 recycled fabrics remain same, so having thinner yarns could affect bursting strength, yet it could not have a prominent effect on pilling resistance. This master’s thesis is actually unique because most researches about this topic includes 20 washings with detergent, and line drying, and former researches mostly include simple excel graphs for a few textile tests, yet this master’s thesis had used mixture design analysis to analyse test results more effectively. A.A. Chekdid et al. (2021) had a research about mixture design analysis of 3 different flours to find most economical, healthy and nutritional option, and the authors both researched the characterization of each flour and usability of mixtures, so mixture design analysis is a very healthy way to analyze effect of each variable and each mixture.

2. FABRIC QUALITY TEST RESULTS & DISCUSSION

2.1 Pilling Resistance

Martindale machine was used for pilling resistance test, with TS EN ISO 12945-2 standard. For unwashed fabrics, Nm 20/1 40%precons. Cot. 60% conventional cot. has the lowest pilling resistance, while Nm 30/1 100% recycled Pes and Nm 30/1 100% cot. has the highest pilling resistance (4) even after 7000 cycles. According to these results, it could be stated that for unwashed fabrics, recycled polyester and conventional cotton's pilling resistance are better than recycled cotton, cot-pes and cot-rcy.pes blends. Also, for 100% cotton fabrics, Nm 30/1 fabric has better pilling resistance than Nm 20/1 fabric, so it could be said that when yarn number increases better pilling resistance results can be achieved.

After 3 cycles of washing&drying, Nm 30/1 60%cot 40%pes fabric has the lowest pilling resistance (1), while Nm 30/1 and Nm 20/1 100%cotton fabrics have the highest pilling resistance (4). It could be said that after washing, rcy. cot, cot-rcy.pes and rcy.cot blend fabrics' pilling resistance had slightly improved while cot-pes blend fabric's pilling resistance had decreased, so it can be understood that unlike conventional fibers, recycled fiber's pilling resistance performans could be improved after 3 washing&drying cycles.

After 6 cycles of washing and drying, Nm 20/1 40%precons. Cot. 60% conventional cot. t-shirts have increased pilling resistance to 4. Also, Nm 30/1 60%cot 40%pes and 60%cot 40%rec pes fabrics have the lowest pilling resistance compared to all qualities. It could be said that 100% cot fabrics' pilling resistance did not change after 3rd cycle, so difference in yarn number does not affect pilling resistance for 100% cot fabrics after 3rd cycle. Also, cot-rcy cot fabric's pilling resistance slightly increased after 3rd cycle.

Figure 2.1.1 : Nm 20/1 100% recycle cotton fabric in color blue, end of 7000 cycles in pilling (6th cycle).

Figure-2.1.2.: Nm 20/1 100% cotton, at the end of 7000 cycles in pilling (6th cycle).

Figure-2.1.3.: Nm 20/1 40% preconsumer cot. 60% conventional cot. at the end of 7000 cycle in pilling (6th cycle)

Figure-2.1.4.: Nm 30/1 100% cot. at the end of 7000 cycle in pilling (6th cycle)

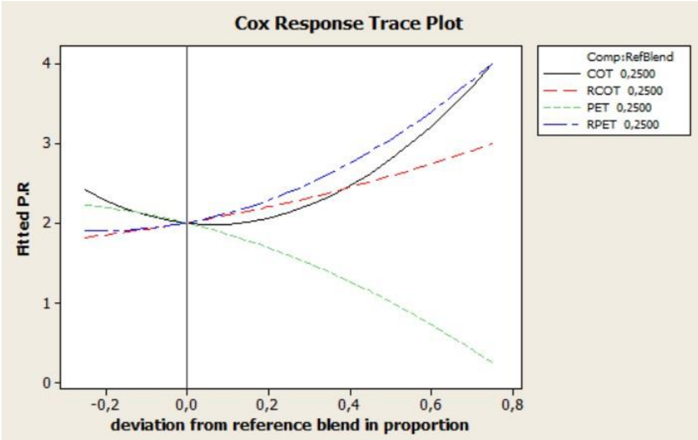

Figure-2.1.5.: Cox response plot for pilling resistance of unwashed fabrics.

According to cox response trace plot of pilling resistance of unwashed fabrics, it could be stated that polyester has higher strength compared to cotton, it resists to abrasion but it also collects small fibers which causes to pilling formation, so that's why increasing polyester decreases pilling resistance. Recycled cotton's pilling resistance is lower than conventional cotton, because it has more short fibers that cause pilling formation. Uyanık and Kaya Nacarkahya (2024) stated that 60% cotton 40% recycled cotton blend have pilling degree of 2/3, and MCRC fabric also have same pilling degree, so this test result is also harmonius with literature. Also, RC have pilling degree of 3, and Acar et.al (2023) stated that 70% recycled cotton 30% virgin polyester single jersey fabric also have pilling degree of 3, so it could be stated that in literature, increasing amount of polyester does not have a significant effect on recycled cotton fabrics.

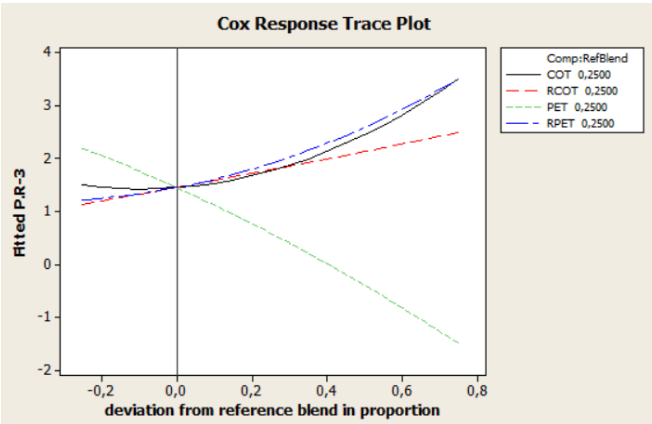

Figure-2.1.6.: Cox response plot for 3rd cycle of pilling resistance.

According cox response trace plot of 3rd cycle, it could be said that cotton & recycled polyester's pilling resistance almost same with unwashed fabrics, but 3 cycles of washing & drying make them having more shorter fibers, and because of this, pilling resistance of cotton & recycled polyester became more closer to recycled cotton.Since polyester blends with cotton in our t-shirts, while cotton having more and more shorter fibers, polyester has to hold more short fibers results with decreasing pilling resistance in polyester. B. Utebay et. al (2024) claimed that enzymatic treatments and scouring could increase the pilling resistance of 80% recycled cotton 20% cotton fabric, so it could be understood that maybe washing have a good effect on pilling resistance properites of recycled fabrics, and that could be the reason of similar pilling degrees between 3rd cycle and unwashed fabrics.

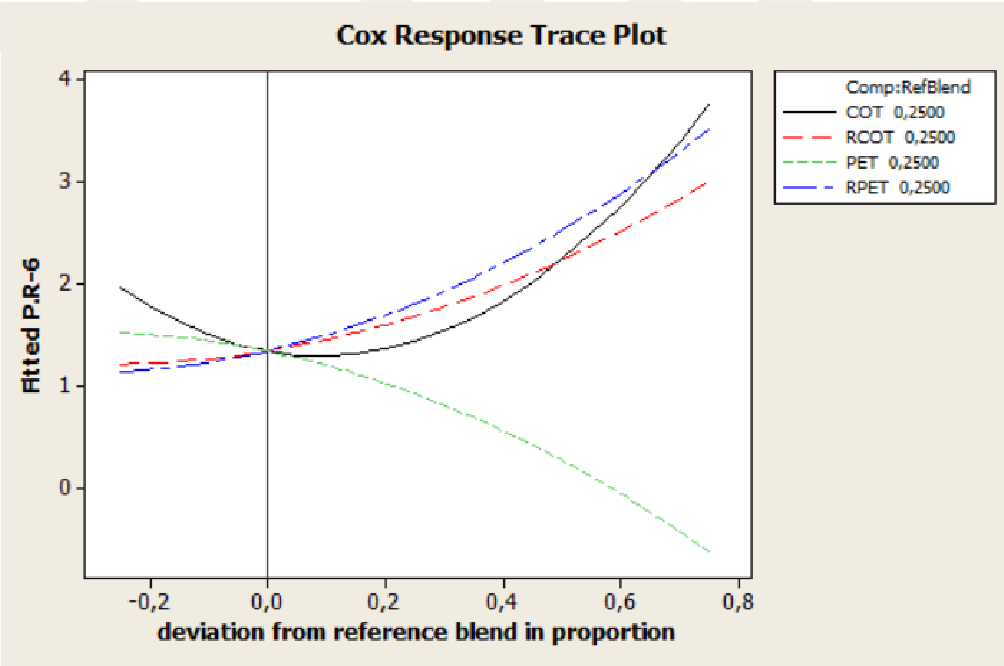

Figure-2.1.7.: Cox response plot for 6th cycle of pilling resistance.

According to cox response trace plot of 6th cycle, the pilling resistance results may have improved comparing to 3rd cycle, because the pills detached from the t-shirts after multiple cycles of washing & drying. After 6 cycles of washing, cotton still have almost same pilling resistance as recycled polyester, which seems interesting. Also, it could be stated that multiple washing & drying cycles do not significantly affect pilling resistance of none of the qualities since pilling degrees at 6th cycle were almost same with unwashed fabrics, yet hairiness of t-shirts increases a little, as expected.

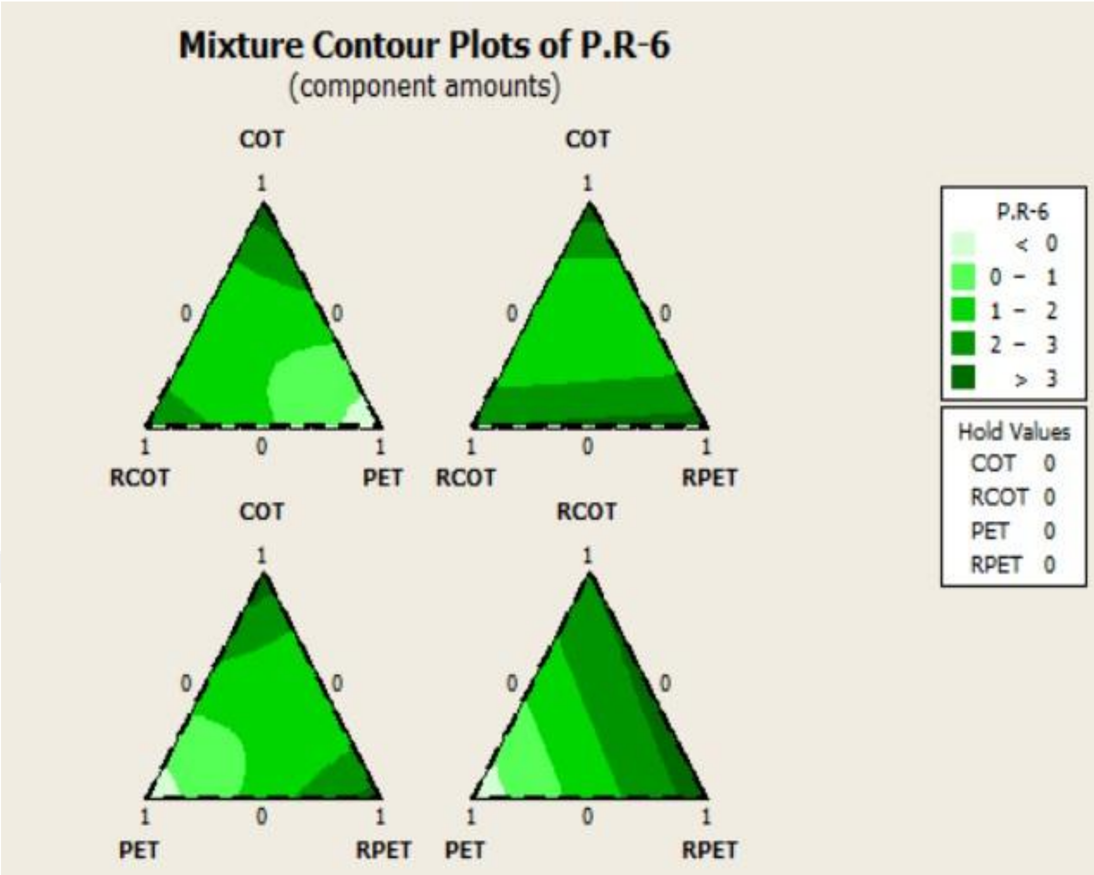

Figure 2.1.8 : Mixture contour plot of pilling resistance of 6th cycle t-shirts.

Mixture contour plots could give estimated test results of fabrics that are not existed yet, so according to these test results, a recycled textile fabric's test result could be predicted even before production, which is a significant information for textile companies. According to mixture contour plot of pilling resistance of 6th cycle t- shirts, it could be stated that if there is a Nm 30/1 33% cotton, 33%recycled cotton, and 33% recycled polyester, this fabric would probably have pilling degree of 1/2 at the end of 6 washing and drying cycles. If there is a Nm 30 90% recycled cotton 10% polyester or Nm 30 90% recycled cotton 10% recycled polyester, these 2 fabrics would probably same pilling degree of 2/3, at the end of 6 washing &tumble-drying cycles. If there is a Nm 30 30% polyester 70% recycled cotton fabric, this fabric probably would have pilling degree of 2/3, at the end of 6 cycles. To conclude, it could be understood that recycled cotton & recycled polyester blends, 100% cotton and 100% recycled polyester have highest pilling resistance even after 6 washing & drying cycles.

2.2 Abrasion Resistance Test

For abrasion resistance test, TS EN ISO 12947-2 standard had been followed.

Figure-2.2.1: Nm 30/1 100% cotton fabric, at the end of 20000 cycles in abrasion (6th cycle).

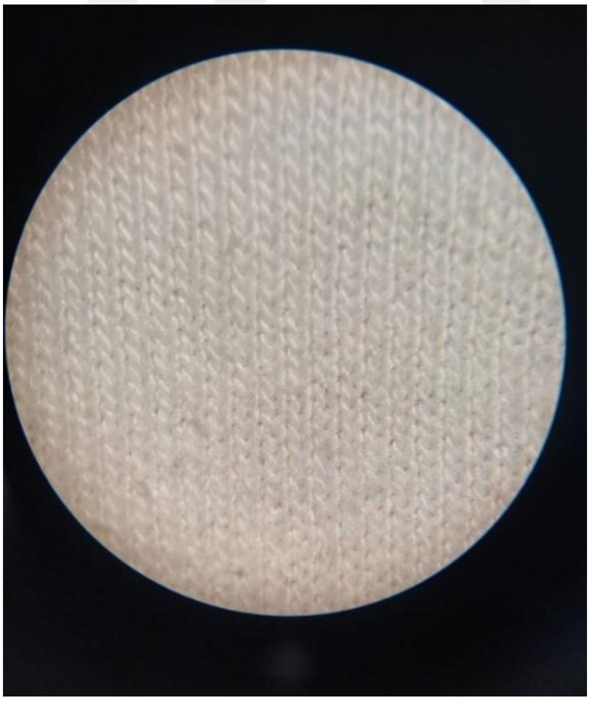

Figure-2.2.2: Nm 20/1 100% cotton fabric, at the end of 20000 cycles in abrasion (6th cycle).

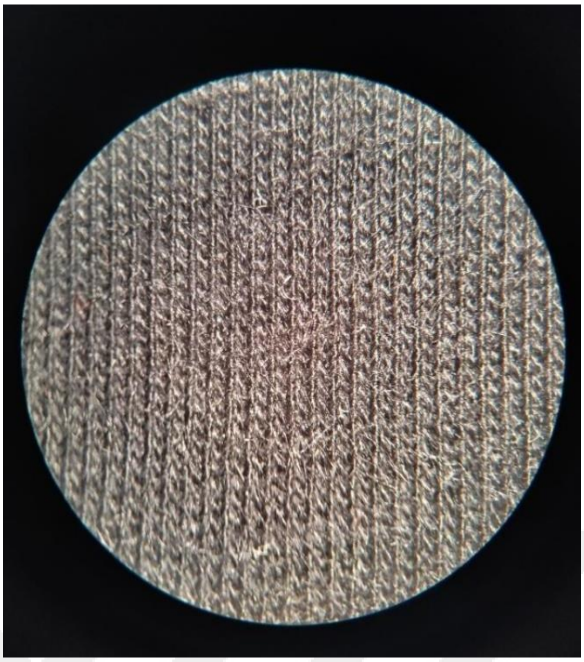

Figure-2.2.3: Nm 30/1 60%cotton 40% rec pes fabric, at the end of 45000 cycle in abrasion (6th cycle).

Regression for Mixtures: A.R versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.R (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	52500	2500	*	*	1,540
RCOT	64000	3536	*	*	1,160
PET	71250	9601	*	*	1,180
RPET	23500	3536	*	*	1,160
COT*RCOT	-112917	17053	-6,62	0,095	1,340
COT*RPET	-132917	17053	-7,79	0,081	1,340

S = 3535,53   PRESS = *
R-Sq = 99,52%   R-Sq(pred) = *%   R-Sq(adj) = 97,13%

Analysis of Variance for A.R (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	2602857143	2602857143	520571429	41,65	0,117
Linear	3	1447860319	1009500000	336500000	26,92	0,141
Quadratic	2	1154996824	1154996824	577498412	46,20	0,103
COT*RCOT	1	395586376	548067164	548067164	43,85	0,095
COT*RPET	1	759410448	759410448	759410448	60,75	0,081
Residual Error	1	12500000	12500000	12500000		
Total	6	2615357143				

Figure-2.2.4.: Regression analysis of abrasion resistance,

from Minitab.

Regression analysis of unwashed textiles' abrasion resistance indicates that the model is not statistically significant overall if the F-value is greater than 1 but the p-value is greater than 0.05. Still, the model appears to account for a sizable amount of the variance in the dependent variable because the R-squared and adjusted R-squared values are both greater than 95%, and the margin of error is set at 95%. Excessive fitting, multicollinearity, or a small sample size may be the cause of the discrepancy between high explanatory power and low statistically significant results.

Regression for Mixtures: A.R-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.R-3 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	40000	5000	*	*	1,540
RCOT	68000	7071	*	*	1,160
PET	60000	19203	*	*	1,180
RPET	35000	7071	*	*	1,160
COT*RCOT	-163333	34106	-4,79	0,131	1,340
COT*RPET	-58333	34106	-1,71	0,337	1,340

S = 7071,07 PRESS = *
R-Sq = 97,42% R-Sq(pred) = *% R-Sq(adj) = 84,53%

Analysis of Variance for A.R-3 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1888857143	1888857143	377771429	7,56	0,269
Linear	3	684133005	680800000	226933333	4,54	0,329
Quadratic	2	1204724138	1204724138	602362069	12,05	0,200
COT*RCOT	1	1058455481	1146746269	1146746269	22,93	0,131
COT*RPET	1	146268657	146268657	146268657	2,93	0,337
Residual Error	1	50000000	50000000	50000000		
Total	6	1938857143				

Figure-2.2.5.: Regression analysis of abrasion resistance of 3rd cycle, from Minitab.

If the F-value is greater than 1 but the p-value is greater than 0.05, the regression analysis of the third cycle's abrasion resistance indicates that the model is not statistically significant overall. Nevertheless, since the confidence interval is set at 95% and the R-squared and modified R-squared values are both higher than 80%, the model seems to explain an important portion of the variance in the variable of interest. A limited sample size, multicollinearity, or overfitting could be the reason for the disparity between inadequate statistical significance and high power of explanation.

Regression for Mixtures: A.R-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.R-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	44000	1000	*	*	1,540
RCOT	55000	1414	*	*	1,160
PET	46500	3841	*	*	1,180
RPET	5000	1414	*	*	1,160
COT*RCOT	-180833	6821	-26,51	0,024	1,340
COT*RPET	27500	6821	4,03	0,155	1,340

S = 1414,21   PRESS = *
R-Sq = 99,92%   R-Sq(pred) = *%   R-Sq(adj) = 99,51%

Analysis of Variance for A.R-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	2441428571	2441428571	488285714	244,14	0,049
Linear	3	918368680	1497200000	499066667	249,53	0,046
Quadratic	2	1523059891	1523059891	761529946	380,76	0,036
COT*RCOT	1	1490552428	1405641791	1405641791	702,82	0,024
COT*RPET	1	32507463	32507463	32507463	16,25	0,155
Residual Error	1	2000000	2000000	2000000		
Total	6	2443428571				

Figure-2.2.6.: Regression analysis of abrasion resistance of 6th cycle, from Minitab.

The regression analysis's F-value of more than 1 and p-value of less than 0.05 indicate that the sixth cycle of abrasion resistance model is statistically significant. Additionally, with R-squared and modified R-squared values above 95%, the model appears to account for a sizable portion of the variance in the dependent variable. These results suggest that there is a strong potential for explanation of the independent variables.

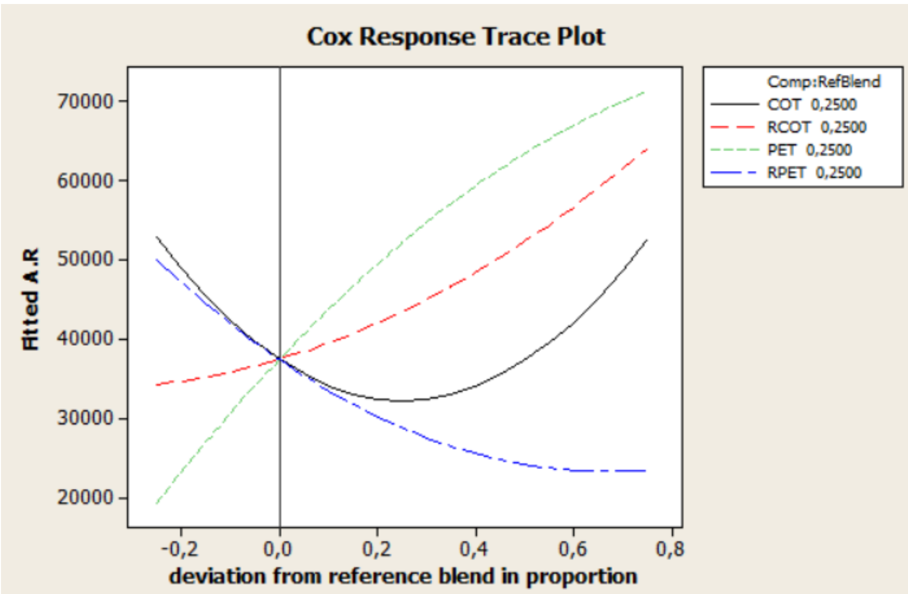

Figure-2.2.7: Cox response plot for abrasion resistance of unwashed fabrics.

According to cox response trace plot of abrasion resistance of unwashed fabrics, as it previously said before, polyester's higher strength results with higher abrasion resistance & lower pilling resistance. Also, since recycled polyester have higher pilling resistance, it results with lower abrasion resistance as it could be seen in graph. Recycled cotton has higher abrasion resistance than cotton, because recycled cotton fabrics were a little coarser than cotton. According to this figure, polyster-rcot blend fabric could have the highest abrasion resistance. Yilmaz, Fulya & Tetik, Gamze & Celep, Gizem. (2022) stated that both conventional & recycled cotton denim fabrics started to damage at 15000 cycles, while MCRC knitted fabric in this research started to damage at 30000 cycles, since MCRC have 10% higher recycled cotton than their recycled fabric, so maybe recycled cotton have a better effect on abrasion resistance as above figure suggests.

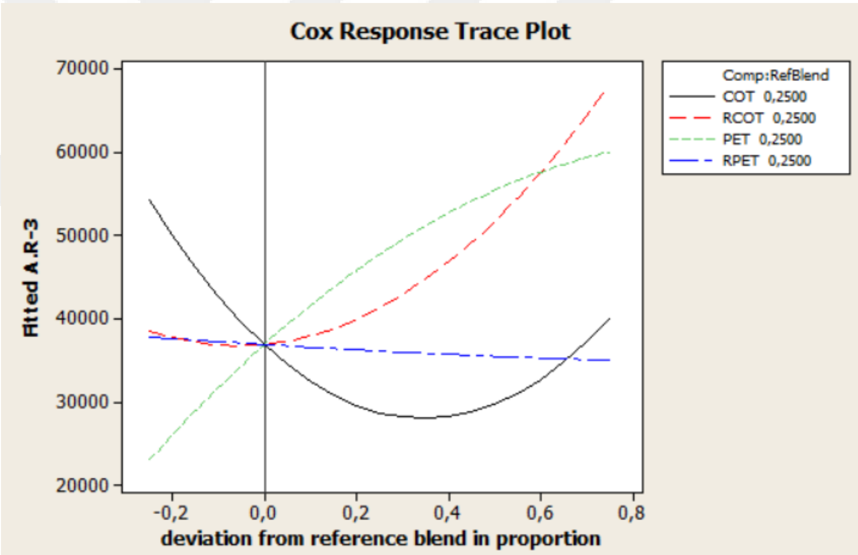

Figure-2.2.8: Cox response trace plot of abrasion Resistance of 3rd cycle t-shirts.

According to cox response trace plot of 3rd cycle of abrasion resistance, it could be said that polyester's A.R reduces from 70000 to 60000, yet recycled cotton's A.R almost did not change after 3 cycles of washing & tumble drying. At 3rd cycle, recycled cotton's A.R is 1.5 times higher than cotton, the gap between their A.R increased after washing, so washing & drying cycles affect cotton more adversely than recycled cotton. At 3rd cycle, 30C1's abrasion resistance is higher than 20C1, so having thinner yarn could be advantageous at 3rd cycle.

Also, RC's abrasion resistance is almost 51% higher than 30C1, so recycled cotton could be more resistant to abrasion than cotton at 3rd cycle.

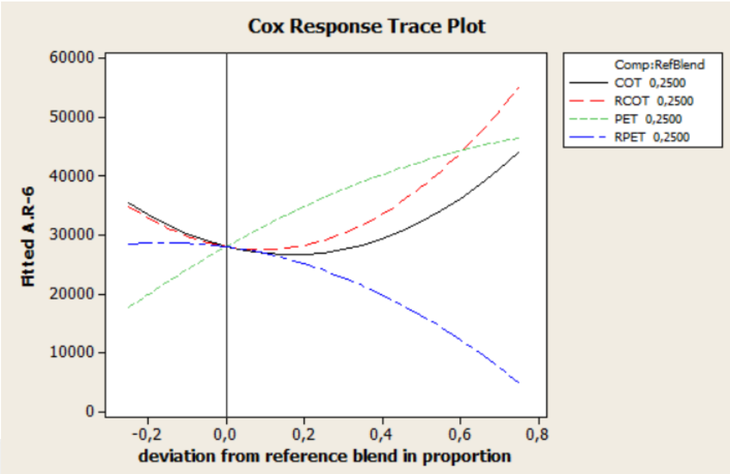

Figure-2.2.9: Cox response plot for abrasion resistance of 6th cycle t-shirts.

According to cox response trace plot of 6th cycle of abrasion resistance, it could be claimed that recycled polyester's A.R decreases approximately 62 % after 3rd cycle, the reason could be recycled polyester's filament yarns in fabric structure and fabric thinness. While cotton's A.R is almost same with 3rd cycle, polyester's A.R decreases approximately 30 % after 3rd cycle. Even the recycled cotton's A.R decreases 20% after 3rd cycle, it is still higher than conventional cotton's A.R. According to these results, probably a normal polyester-recycled cotton blend fabric would have the highest abrasion resistance amongst all.

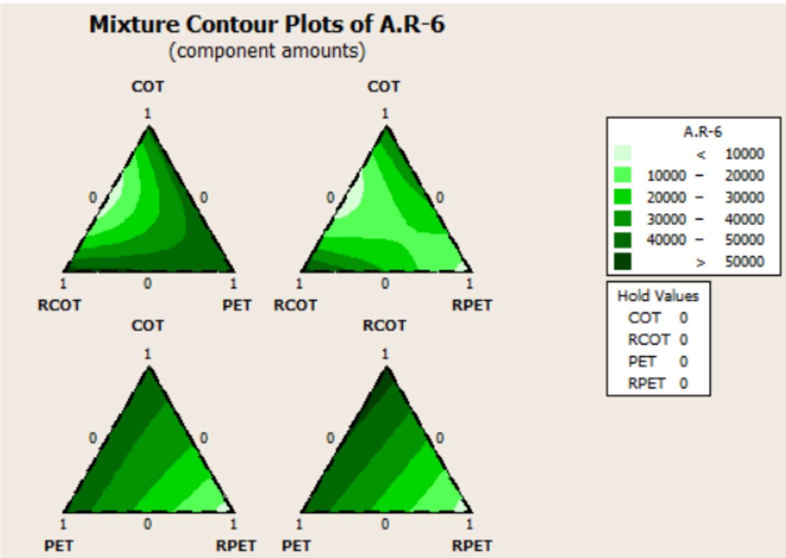

Figure-2.2.10: Mixture contour plot of abrasion resistance of 6th cycle t-shirts.

According to mixture contour plot of abrasion resistance of 6th cycle t-shirts, it could be claimed that Nm 30 33% cotton 33% recycled cotton 33% recycled polyester would probably have 10000-20000 cycles of abrasion resistance at the end of 6th cycle. If there is a Nm 30 50% polyester 50% recycled polyester fabric, it’s abrasion resistance at 6th cycle would probably between 20000 to 30000 cycles. Also, Nm 30 cot-pet-rpet blend & Nm 30 rcot-pet-rpet blend would probably have same abrasion resistance at 6th cycle, approximately between 30000-40000 cycles. To conclude, it could be understood that while 100% polyester and 100% recycled cotton has highest abrasion resistance at 6th cycle, while 100% recycled polyester and cotton-recycled cotton blends have lowest abrasion resistance.

2.3 Weight Loss in Abrasion Resistance

Regression for Mixtures: W.L versus RPET; PET; COT; RCOT

Estimated Regression Coefficients for W.L (component proportions)

Term	Coef	SE Coef	T	P	VIF
RPET	0,00860	0,004028	*	*	1,160
PET	0,00639	0,010826	*	*	1,156
COT	0,03607	0,002650	*	*	1,333
RCOT	0,01673	0,003780	*	*	1,021
RPET*COT	-0,09201	0,019252	-4,78	0,041	1,316

S = 0,00402809 PRESS = *
R-Sq = 96,88% R-Sq(pred) = *% R-Sq(adj) = 90,65%

Analysis of Variance for W.L (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	0,001009	0,001009	0,000252	15,55	0,061
Linear	3	0,000639	0,000594	0,000198	12,21	0,077
Quadratic	1	0,000371	0,000371	0,000371	22,84	0,041
RPET*COT	1	0,000371	0,000371	0,000371	22,84	0,041
Residual Error	2	0,000032	0,000032	0,000016		
Lack-of-Fit	1	0,000013	0,000013	0,000013	0,64	0,572
Pure Error	1	0,000020	0,000020	0,000020		
Total	6	0,001042				

Figure-2.3.1.: Regression analysis of weight loss in abrasion resistance, from Minitab.

According to the regression analysis, the model of weight loss in abrasion resistance is statistically significant if the F-value is larger than 1 and the p-value is less than 0.05. Additionally, with R-squared and modified R-squared values above 90%, the model appears to account for a sizable portion of the variance in the dependent variable. It can be inferred from these results that the independent variables are highly explicable.

```
Regression for Mixtures: W.L-3 versus RPET; PET; COT; RCOT

Estimated Regression Coefficients for W.L-3 (component proportions)

Term          Coef   SE Coef      T      P    VIF
RPET       0,00750  0,001700      *      *  1,160
PET       -0,01787  0,004570      *      *  1,156
COT        0,02575  0,001119      *      *  1,333
RCOT       0,01183  0,001596      *      *  1,021
RPET*COT  -0,05395  0,008127  -6,64  0,022  1,316


S = 0,00170044   PRESS = *
R-Sq = 98,76%    R-Sq(pred) = *%   R-Sq(adj) = 96,27%


Analysis of Variance for W.L-3 (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       4  0,000459  0,000459  0,000115  39,71  0,025
   Linear        3  0,000332  0,000355  0,000118  40,88  0,024
   Quadratic     1  0,000127  0,000127  0,000127  44,06  0,022
     RPET*COT    1  0,000127  0,000127  0,000127  44,06  0,022
Residual Error   2  0,000006  0,000006  0,000003
   Lack-of-Fit   1  0,000002  0,000002  0,000002   0,48  0,616
   Pure Error    1  0,000004  0,000004  0,000004
Total            6  0,000465
```

Figure-2.3.2.: Regression analysis of 3rd cycle t-shirts' weight loss in abrasion resistance, from Minitab.

Regression analysis shows that if the F-value is greater than 1 and the p-value is under 0.05, then the prediction of the third cycle of weight loss in abrasion resistance is considered significant. In addition, the model appears to clarify a significant amount of the variance in the dependent variable, as seen by R-squared and modified R-squared values above 95%. The results presented demonstrate that the independent variables have an excellent level of explicability.

```
Regression for Mixtures: W.L-6 versus RPET; PET; COT; RCOT

Estimated Regression Coefficients for W.L-6 (component proportions)

Term          Coef   SE Coef      T      P    VIF
RPET       0,00130  0,001035      *      *  1,160
PET        0,00425  0,002783      *      *  1,156
COT        0,01450  0,000681      *      *  1,333
RCOT       0,00907  0,000972      *      *  1,021
RPET*COT  -0,02259  0,004949  -4,56  0,045  1,316


S = 0,00103549   PRESS = *
R-Sq = 98,67%    R-Sq(pred) = *%   R-Sq(adj) = 96,00%


Analysis of Variance for W.L-6 (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       4  0,000159  0,000159  0,000040  37,00  0,026
   Linear        3  0,000136  0,000122  0,000041  37,91  0,026
   Quadratic     1  0,000022  0,000022  0,000022  20,83  0,045
     RPET*COT    1  0,000022  0,000022  0,000022  20,83  0,045
Residual Error   2  0,000002  0,000002  0,000001
   Lack-of-Fit   1  0,000000  0,000000  0,000000   0,07  0,833
   Pure Error    1  0,000002  0,000002  0,000002
Total            6  0,000161
```

Figure-2.3.3.: Regression analysis of 6th cycle t-shirts' weight loss in abrasion resistance, from Minitab.

According to 6th cycle of regression analysis of weight loss in abrasion resistance, An F-value greater than 1 and a p-value less than 0.05 in the regression analysis show that the model is statistically significant. Furthermore, the model appears to explain an important proportion of the variance in the dependent variable, with R-squared and adjusted R-squared values exceeding 90%. These findings imply that each of the variables have great potential for explanation.

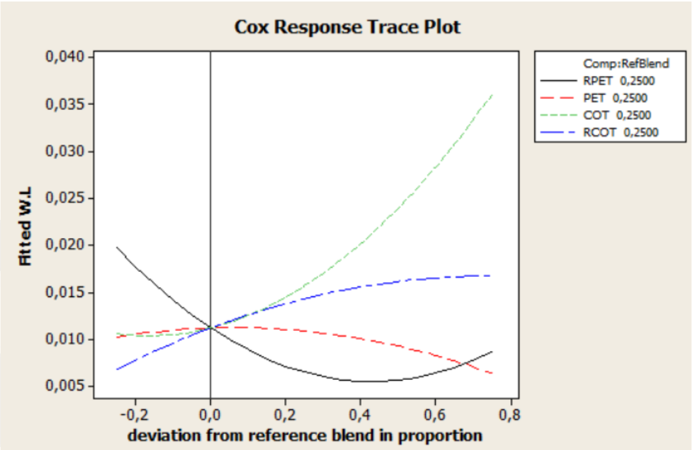

Figure-2.3.4.: Cox response trace plot of weight loss in abrasion resistance of unwashed fabrics.

According to cox response trace plot of weight loss in abrasion resistance, it could be stated that when amount of cotton & recycled cotton increases, weight loss also increases. In order to decrease weight loss, using polyester & recycled polyester is highly significant.

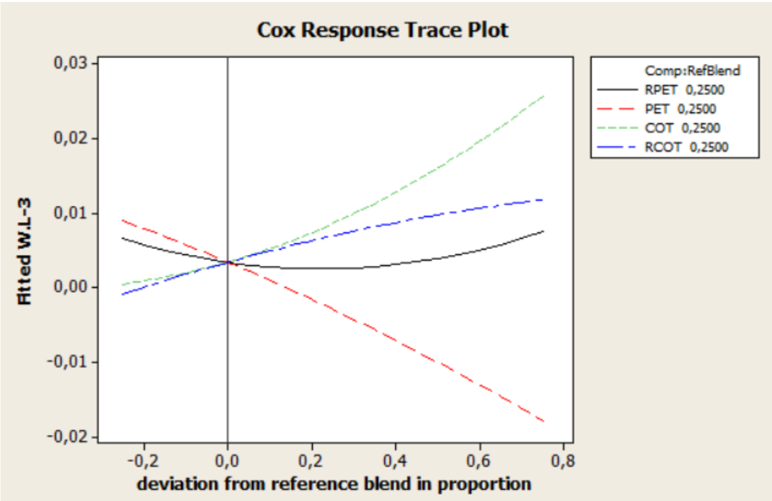

Figure-2.3.5.: Cox response trace plot of weight loss in abrasion resistance of 3rd cycle t-shirts.

According to cox response trace plot of 3rd cycle, it could be said that weight loss for cotton decreased almost 20%, and for recycled cotton it decreased 35%, after washing & drying, respectively. Amount of recycled polyester does not significantly affect the results at 3rd cycle. Polyester and polyester blend fabrics seem like they do not affect by multiple washing & drying adversely, thanks to higher strength properties of polyester.

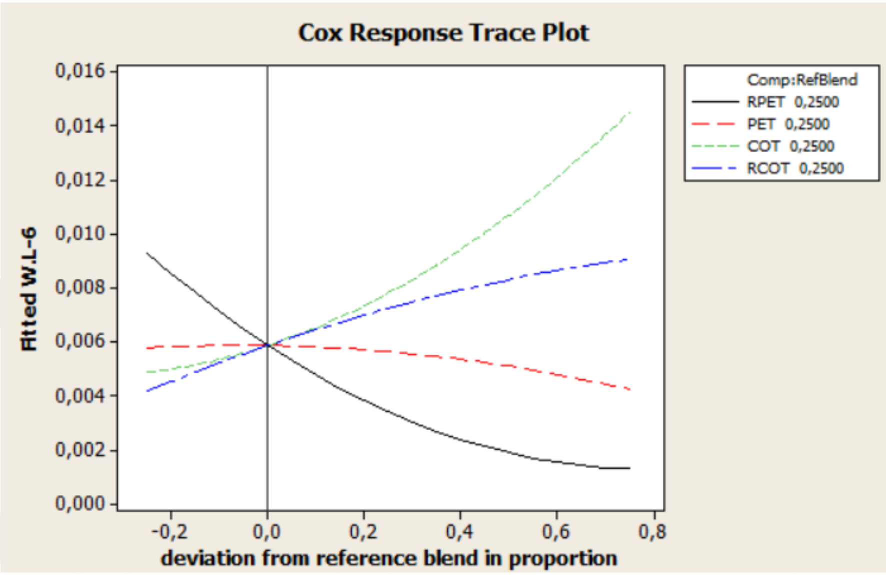

Figure-2.3.6.: Cox response trace plot of weight loss in abrasion resistance of 6th cycle t-shirts.

According to cox response trace plot of 6^{th} cycle of weight loss at abrasion resistance, it could be said that cotton & recycled cotton's weight loss decreases comparing to 3^{rd} cycle and unwashed fabrics, so if authors continued to wash for more cycles, probably weight loss will be stopped eventually. Polyester and recycled polyester's weight loss at 6^{th} cycle is almost same with unwashed polyester fabrics, which is also a great result. All the results are in harmonious with abrasion resistance results, so results of this thesis also correct each other.

2.4 Dimensional Change Test

For dimensional change test, TS EN ISO 5077 standard had been followed.

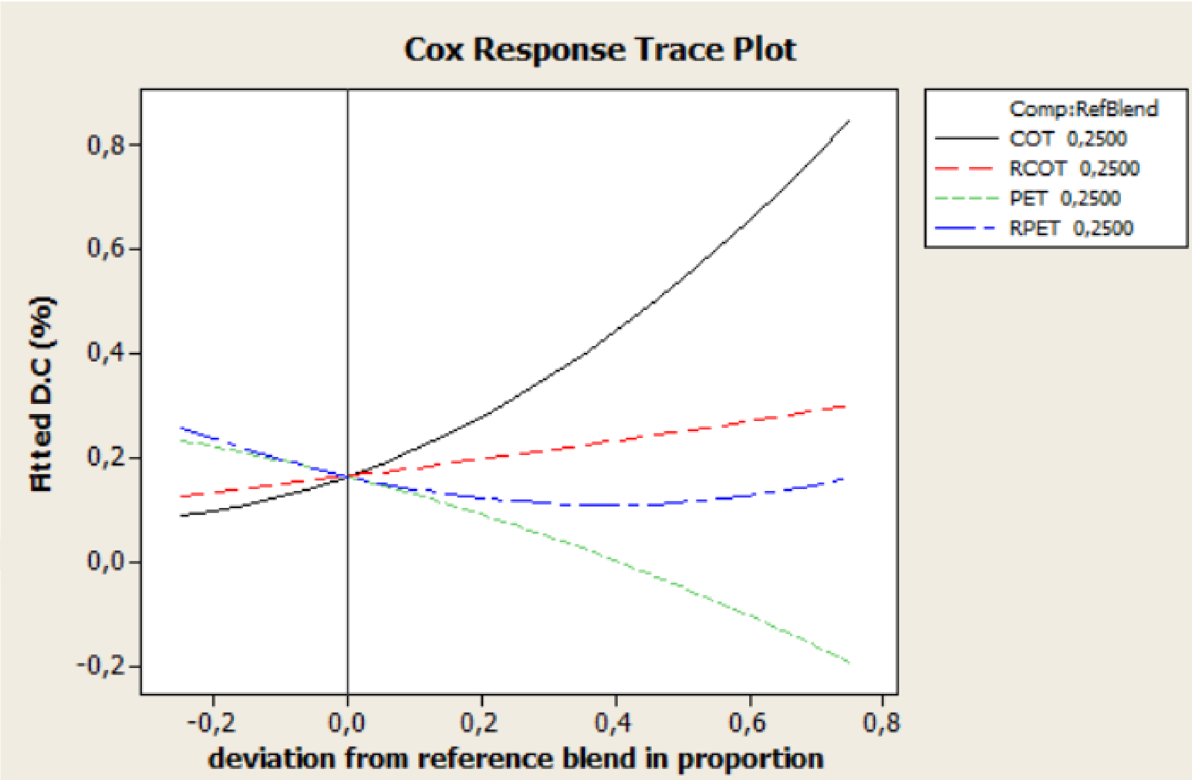

Figure-2.4.1.: Cox response plot of dimensional change (%) of unwashed fabrics.

According to cox response plot of dimensional change (%) of unwashed fabrics, increasing amount of cotton and recycled cotton increases dimensional change, and increasing amount of polyester and recycled polyester decreases dimensional change.

Dimensional change (%) of cotton seems 4 times higher than recycled cotton, but Yılmaz and Keleş (2023) claimed that they observed highest dimensional change (%) on %50 Recycled Cotton – %50 Recycled polyester blend fabric, and they observed lowest dimensional change on 50% cotton-50% polyester blend, so probably higher dimensional change result from lower seam strength & lower bursting strength properties. Our results are quite different than Yılmaz &Keleş (2023), this could be result from yarn type or fiber mixture amount in fabric. Also, Sari et.al (2024) claimed that single jersey fabrics with coarser yarns have better dimensional stability than fabrics with thinner yarns, yet in this research the results show the opposite, so it could be thought that coarser yarns with higher twist tend to have higher % of dimensional stability.

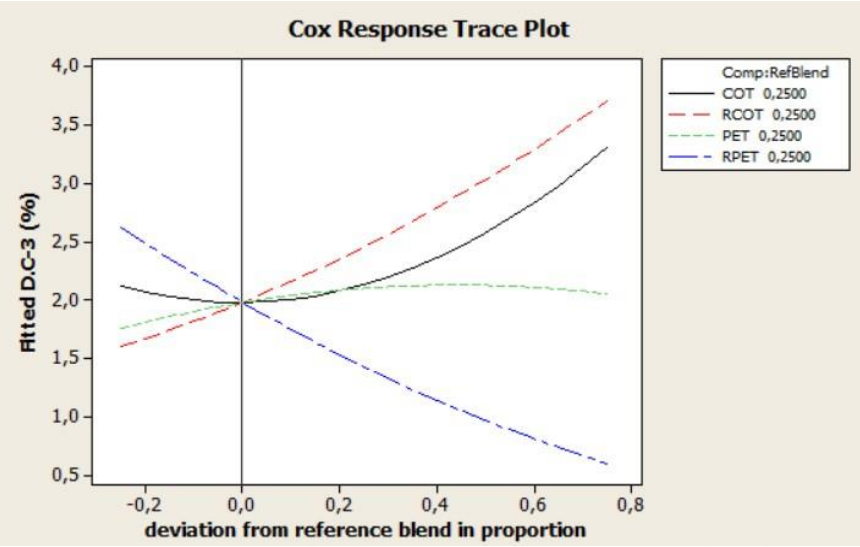

Figure-2.4.2.: Cox response trace plot of dimensional change (%) of 3rd cycle.

According to cox response trace plot of dimensional change (%) of 3rd cycle, it could be said that dimensional change of cotton & recycled cotton increases a lot with multiple washing cycles, and according to Uttam and Sethi (2016), fabric shrinkage of cotton increases a lot at the first 4 wash, and there is no significant increase after first 4 wash, so our results also similar with literature. Polyester's dimensional change increases 10x after 3 cycles, yet according to graph, increasing amount of polyester does not increase dimensional change (%) at 3rd cycle.

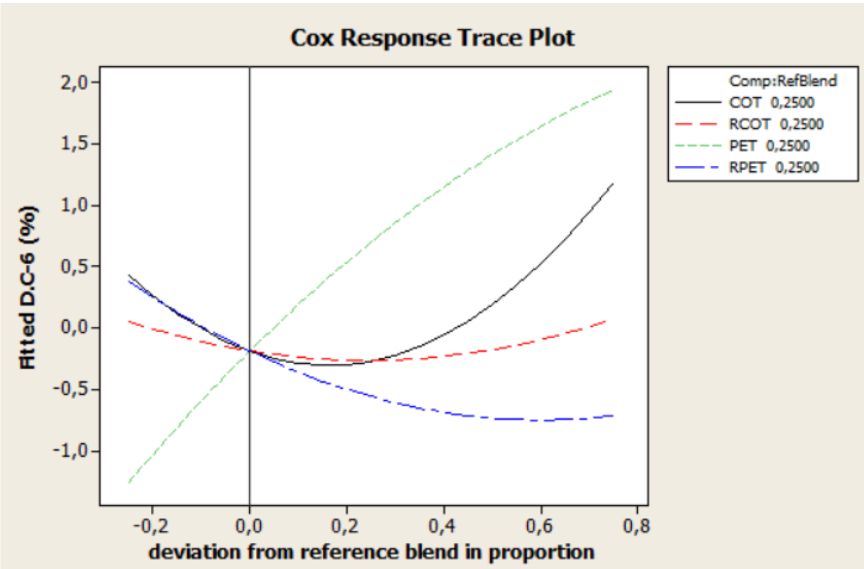

Figure-2.4.3.: Cox response trace plot of dimensional change (%) of 6th cycle.

According to cox response trace plot of dimensional change (%) of 6th cycle, it could be stated that increasing amount of polyester increases dimensional change at this cycle, but highest dimensional change for polyester does not change after 3 more cycles. Also, conventional cotton & recycled cotton's dimensional change is almost same with unwashed cotton & recycled cotton, so it could be said that after multiple cycles of washing &drying, conventional cotton & recycled cotton t-shirts can recover and return to its original shape.

2.5 Spirality Test

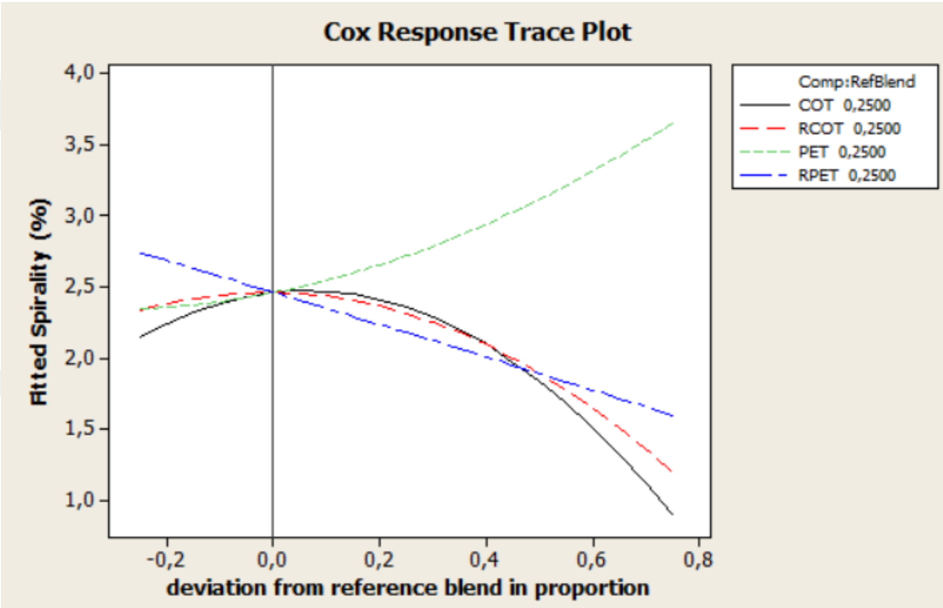

Figure-2.5.1.: Cox response trace plot of spirality (%) of unwashed fabrics.

According to cox response trace plot of spirality (%), it could be stated that while increasing recycled polyester, recycled cotton and cotton decreases spirality, increasing polyester increases spirality. Jamshaid H (2018) claimed that spun yarns have higher spirality than filament yarns, since our polyester is spun yarn and recycled polyester is filament yarn, that could be the reason for higher spirality of polyester. Jamshaid H (2018) also said that fabrics with open end yarns & higher twist yarns have higher spirality, since our cotton fabrics have ring spun yarns, their spirality results are lower than expected. Moreover, Araujo & Smith (1989) stated that spirality results of cotton fabrics could be inconsistent at dry state, so in order to see correct spirality, probably washed knitted fabric results should be investigated.

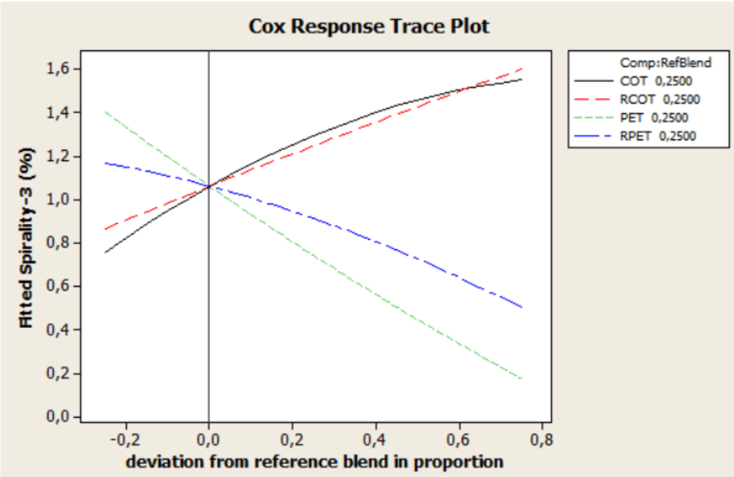

Figure-2.5.2.: Cox response trace plot of spirality (%) of 3rd cycle t-shirts.

According to cox response trace plot of 3rd cycle of spirality (%), it could be said that after washing & drying, graph becomes more harmonius with literature, as Araujo & Smith (1989) stated that cotton-polyester blend has lower spirality than 100% cotton, so increasing amount of polyester in fabric could decrease spirality. Even Ramasubramaniam and Chezliyan (2019) stated that washing treatments increases spirality, our results show that cotton & recycled cotton's spirality almost did not change and polyester & recycled polyester's spirality decreased after washing & drying cycles.

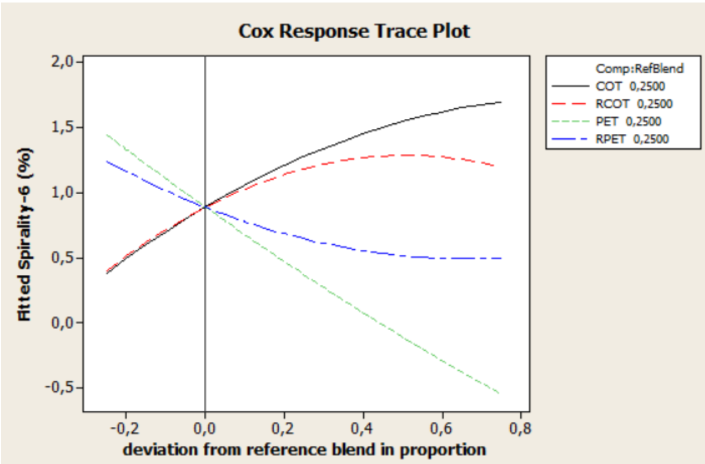

Figure-2.5.3.: Cox response trace plot of spirality (%) of 6th cycle t-shirts.

According to cox response trace plot of 6th cycle of spirality (%), it could be stated that graph seems almost same with 3rd cycle. Cotton has the highest spirality amongst all fibers, and 6th cycle results show that cotton-polyester blend and 100% recycled polyester's spirality were quite closer. Also, cotton-polyester blend and cotton-recycled polyester blend have similar spirality results at 6th cycle, so polyester and recycled polyester have no distinctive effect on spirality values. Moreover, cotton-recycled cotton fabric has 2 times higher spirality than 100% recycled cotton, so actually conventional cotton could increase spirality of fabric more than recycled cotton, so lower spirality could be achieved both using recycled cotton, recycled polyester and normal polyester.

2.6 Color Fastness to Washing

For color fastness to washing test, TS EN ISO 105 C06 standard had been followed.

Figure-2.6.1.: Measurement machine for color fastness to washing test.

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	W.F. to wool	W.F to cotton	W.F. to other
40	0	60	0	20	4,5	3,5	4,5
0	0	60	40	30	4,5	3	4
0	40	60	0	30	4	4	4
0	0	100	0	30	4	4	4
100	0	0	0	20	4,5	3,5	4,5

Table-2.6.1.: Washing fastness of unwashed fabrics.

According to washing fastness of unwashed fabrics, it could be stated that at Nm 30, 100% cotton and MCRP behave same, so it could be said that recycled polyester did not affect washing fastness adversely. Also, RC & MCRC have same results, so it could be stated that increase of amount of recycled cotton did not affect washing fastness adversely. Sari et. al (2024) also stated that increased amount of recycled cotton in fabric does not have a significant effect on fastness to washing, this test result also corrects their finding.

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	W.F-3 to wool	W.F-3 to cotton	W.F.-3 to other
40	0	60	0	20	4,5	4,5	4,5
0	0	60	40	30	4,5	4,5	4
0	40	60	0	30	4,5	4,5	4
0	0	100	0	30	4,5	5	4
100	0	0	0	20	4,5	4,5	4,5

Table-2.6.2.: Washing fastness of 3rd cycle.

It could be said that after 3 cycles of washing, all qualities' washing fastness results became better, so even the washing was made in harsh conditions & drying programmes were quite long, washing fastness of recycled fabrics did not affect adversely, which is an interesting result. At 3rd cycle, still highest results belong to RC & MCRC, use of recycled cotton should be advised to achieve higher washing fastness results even after multiple washing & drying cycles.

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	W.F-6 to wool	W.F-6 to cotton	W.F.-6 to other
40	0	60	0	20	4,5	4,5	4,5
0	0	60	40	30	4	4,5	4,5
0	40	60	0	30	4,5	4,5	4,5
0	0	100	0	30	4,5	5	5
100	0	0	0	20	4,5	4,5	5

Table-2.6.3.: Washing fastness of 6th cycle.

According to 6th cycle, it could be stated that washing fastness of all qualities' did not change adversely after 3rd cycle, and t-shirts' colors even became better as it could be seen in below photographs, so use of recycled cotton & recycled polyester do not have an adverse effect on washing fastness of washed & tumble dried t-shirts.

Even the highest washing fastness belongs to Nm 30 100% conventional cotton, other qualities have quite similar results with conventional cotton, so at last cycle maybe fiber type and yarn count became insignificant, all the washing & drying cycles affect the fabrics in same way.

2.7 Color Fastness to Rubbing

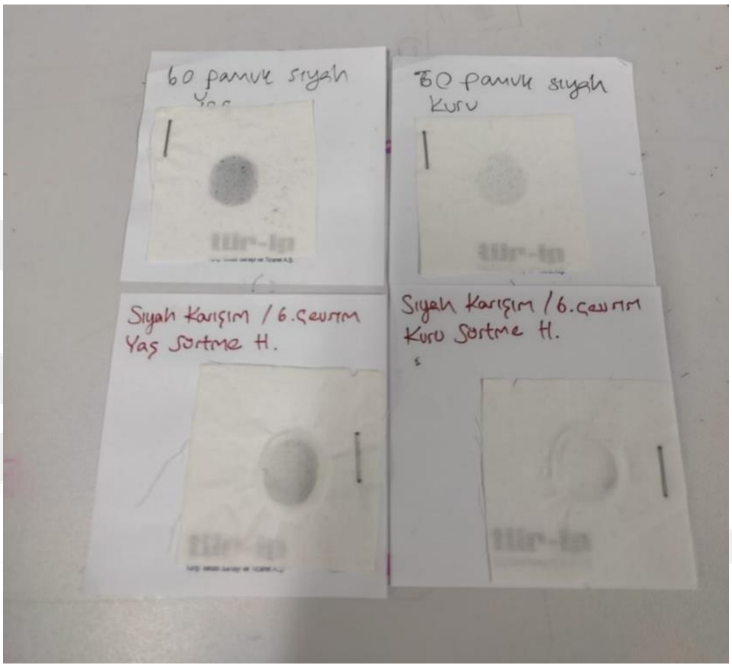

Figure 2.7.1: Dry & Wet rubbing fastness of MCRP;

at 0^{th} & 6^{th} cycle.

For color fastness to rubbing test, TS EN ISO 105 X12 standard had been followed.

2.7.1 Wet rubbing fastness

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	NW-W.R.F	W.R.F-3	W.R.F-6
40	0	60	0	20	2,5	3,5	3,5
0	0	60	40	30	3	3,5	3,5
0	40	60	0	30	3,5	4	3
0	0	100	0	30	3	3	2,5
100	0	0	0	20	4	3,5	3,5

Table-2.7.1.: Wet rubbing fastness of nonwashed, 3^{rd} cycle, and 6^{th} cycle t-shirts.

According to wet rubbing fastness table, it could be stated that at unwashed state, 100 % recycled cotton has better wet rubbing fastness than all t-shirts. After washing and drying cycles, recycled cotton's w.r.f became similar with cotton-recycled cotton and cotton-polyester blends. At 3rd cycle, cotton-recycled polyester blend has highest w.r.f, so it could be claimed that using recycled polyester has positive effect on wet rubbing fastness. Natural 100% cotton has the lowest wet rubbing fastness at 6th cycle, while cotton-recycled cotton, cotton-polyester blends have higher w.r.f, so to maintain higher wet rubbing fastness even after multiple washing cycles, it is not recommended to use natural cotton in fabric structure. Also, wet rubbing fastness of 15 % recycled cotton-85% cotton and 100% recycled cotton fabrics are same, since their yarn counts are also same, it could be stated that higher amount of recycled cotton does not affect wet rubbing fastness adversely (Sari et.al (2024)).

2.7.2 Dry rubbing fastness

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	NW-D.R.F	D.R.F-3	D.R.F-6
40	0	60	0	20	4	4,5	4,5
0	0	60	40	30	4,5	4,5	4,5
0	40	60	0	30	4	4,5	4
0	0	100	0	30	4	4,5	4,5
100	0	0	0	20	4,5	4,5	4,5

Table-2.7.2.: Dry rubbing fastness of nonwashed, 3rd cycle, and 6th cycle t-shirts.

According to dry rubbing fastness table, it could be stated that dry rubbing fastness almost did not change after 3 cycles, so even if there were 10 cycles, dry rubbing fastness of all t-shirts would be quite similar at last cycle. Also, cotton-polyester blend and 100% recycled cotton have same results at all cycles, and 100 % recycled cotton has better results compared to blended fabrics, so it could be said that 100% recycled cotton would be a better option for both higher rubbing fastness and sustainable production. Sari et.al (2024) also claimed that even the amount of recycled cotton changes, the fabrics have same dry rubbing fastness of 4/5, even the yarn counts were different.

2.8 Color Fastness to Light

For color fastness to light test, TS EN ISO 105 B04 standard had followed.

For unwashed fabrics, highest light fastness score 4 belongs to Nm 20/1 100% rcy. cot fabric while other fabrics have 3/4. After 3rd cycle, only rcy cot-conv. Cot fabric's light fastness value slightly increases to 4, while other qualities' light fastness value was decreasing. At the end of 6th cycle, lowest light fastness values belong to Nm 30/1 60%cot 40%rec pes and 60%cot 40%pes qualities, so it could be stated that cot-pes blend fabrics tend to have lower light fastness after 6 cycles of washing, compared to 100% cot quality in same yarn number. Also, for this test, lower yarn number (Nm 20/1) has better results than higher yarn number (Nm 30/1). According to results, it could be understood that all the qualities' light fastness value was same after 3rd cycle & after 6th cycle, so even the yarn number and fiber types are different, light fastness did not change after 3rd cycle for all fabrics. Also, it could be said that higher color fastness to light in cotton fabrics could result from higher dye exhaustion during dyeing (Alam et.al (2008)).

Rcy cot	Rcy pet	Conv. cot	Normal pet	Yarn count Nm	L.F	L.F-3	L.F-6
40	0	60	0	20	3,5	4	4
0	0	60	40	30	3,5	2,5	2,5
0	40	60	0	30	3,5	2,5	2,5
0	0	100	0	30	3,5	3	3
100	0	0	0	20	4	3,5	3,5

Table-2.8.1.: Light fastness of nonwashed, 3rd cycle, and 6th cycle t-shirts.

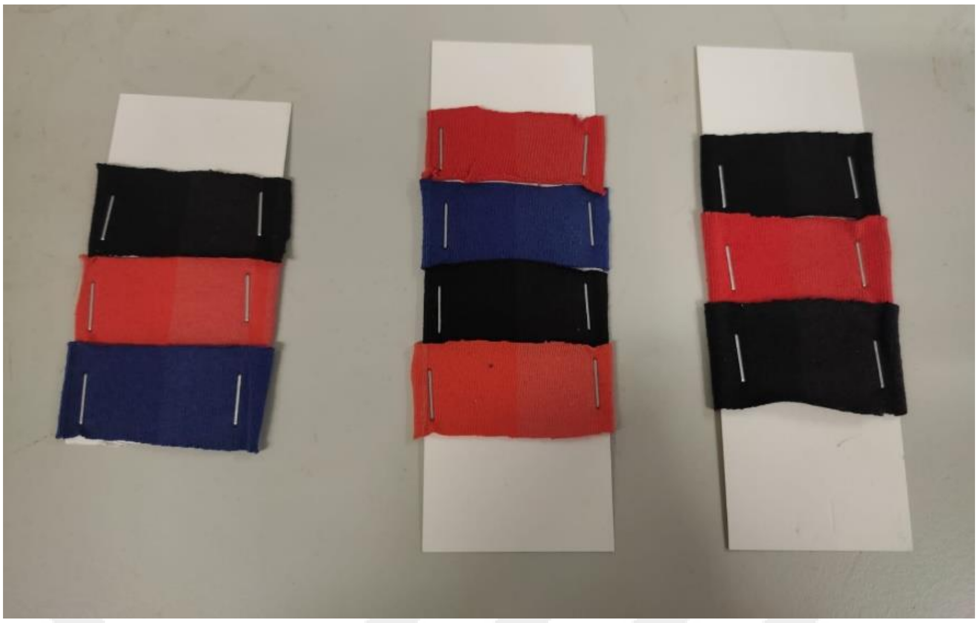

Figure 2.8.1.: Color fastness to light testing of various qualities and their names (3rd & 6th cycle).

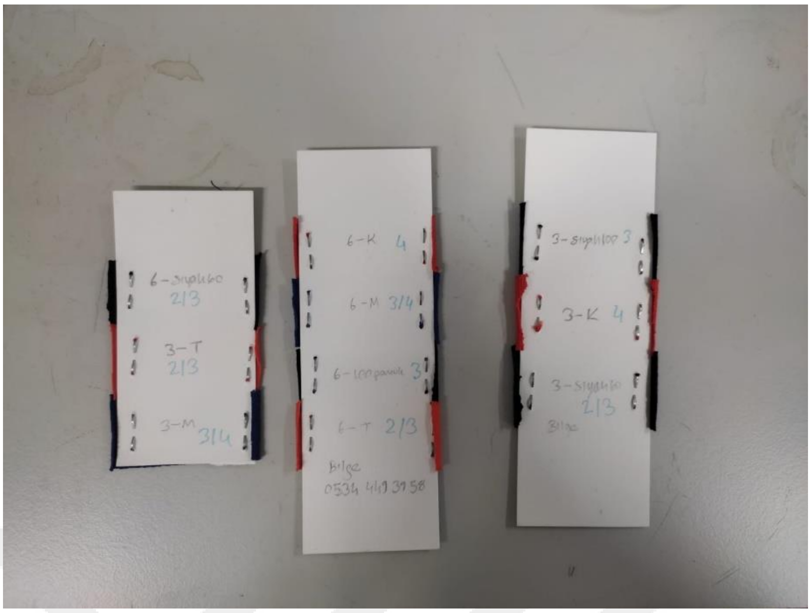

Figure 2.8.2.: Color fastness to light testing of various qualities and their names (3rd & 6th cycle).

Figure 2.8.3.: Reference fabric for color fastness to light testing.

2.9 Fabric Stiffness

For fabric stiffness, ASTM D4032-8 standard had been followed.

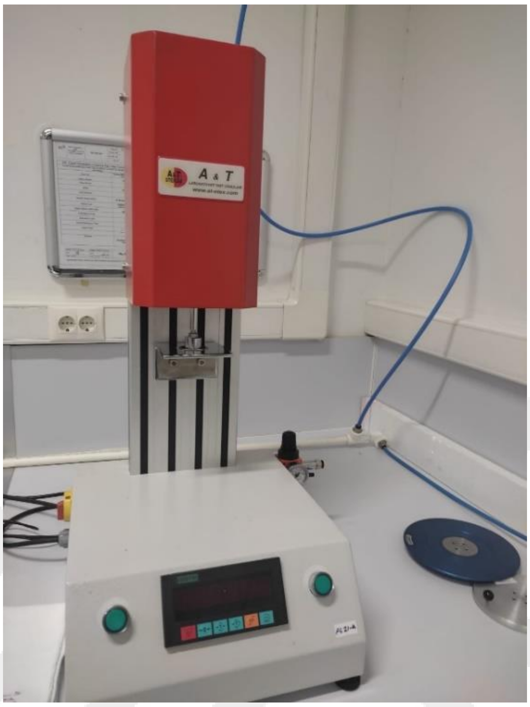

Figure-2.9.1: Fabric Stiffness Testing Machine.

Regression for Mixtures: F.S versus COT; RCOT; PET; RPET

```
Estimated Regression Coefficients for F.S (component proportions)

Term          Coef    SE Coef       T       P    VIF
COT        0,04330   0,000200       *       *  1,540
RCOT       0,04520   0,000283       *       *  1,160
PET        0,04405   0,000768       *       *  1,180
RPET       0,01930   0,000283       *       *  1,160
COT*RCOT   0,02183   0,001364   16,00   0,040  1,340
COT*RPET   0,01917   0,001364   14,05   0,045  1,340
|

S = 0,000282843    PRESS = *
R-Sq = 99,99%      R-Sq(pred) = *%    R-Sq(adj) = 99,92%


Analysis of Variance for F.S (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS        F      P
Regression       5  0,000579  0,000579  0,000116  1447,24  0,020
   Linear        3  0,000547  0,000485  0,000162  2019,38  0,016
   Quadratic     2  0,000032  0,000032  0,000016   200,17  0,050
     COT*RCOT    1  0,000016  0,000020  0,000020   256,13  0,040
     COT*RPET    1  0,000016  0,000016  0,000016   197,39  0,045
Residual Error   1  0,000000  0,000000  0,000000
Total            6  0,000579
```

Figure-2.9.2.: Regression analysis of fabric stiffness of unwashed fabrics, from Minitab.

The results of the regression analysis of Fabric stiffness demonstrate that the model holds statistical significance, as indicated by an F-value exceeding 1 and a p-value lower than 0.05. Furthermore, with R-squared and adjusted R-squared values surpassing 95%, the model appears to account for a considerable portion of the variance in the dependent variable. These results suggest that the independent variables possess strong explanatory power.

Regression for Mixtures: F.S-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for F.S-3 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	0,0783	0,003435	*	*	1,540
RCOT	0,1674	0,004858	*	*	1,160
PET	0,0121	0,013192	*	*	1,180
RPET	0,0205	0,004858	*	*	1,160
COT*RCOT	-0,1173	0,023431	-5,00	0,126	1,340
COT*RPET	0,0077	0,023431	0,33	0,799	1,340

S = 0,00485782   PRESS = *
R-Sq = 99,81%   R-Sq(pred) = *%   R-Sq(adj) = 98,87%

Analysis of Variance for F.S-3 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0,012482	0,012482	0,002496	105,78	0,074
Linear	3	0,011866	0,011979	0,003993	169,21	0,056
Quadratic	2	0,000615	0,000615	0,000308	13,03	0,192
COT*RCOT	1	0,000613	0,000591	0,000591	25,05	0,126
COT*RPET	1	0,000003	0,000003	0,000003	0,11	0,799
Residual Error	1	0,000024	0,000024	0,000024		
Total	6	0,012505				

Figure-2.9.3.: Regression analysis of 3rd cycle of Fabric Stiffness, from Minitab.

According to regression analysis of 3^{rd} cycle of Fabric Stiffness, it could be stated that if the F-value is greater than 1 but the p-value is above 0.05, the model lacks overall statistical significance. However, since both the R-squared and adjusted R- squared values exceed 95%, and the confidence interval is set at 95%, the model seems to capture a significant portion of the variance in the dependent variable. The inconsistency between high explanatory power and low statistical significance could be attributed to factors such as overfitting, multicollinearity, or an inadequate sample size.

Regression for Mixtures: F.S-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for F.S-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	0,0947	0,005215	*	*	1,540
RCOT	0,1683	0,007375	*	*	1,160
PET	0,0294	0,020029	*	*	1,180
RPET	0,0644	0,007375	*	*	1,160
COT*RCOT	-0,1445	0,035572	-4,06	0,154	1,340
COT*RPET	-0,0498	0,035572	-1,40	0,395	1,340

S = 0,00737512 PRESS = *
R-Sq = 99,29% R-Sq(pred) = *% R-Sq(adj) = 95,74%

Analysis of Variance for F.S-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0,007608	0,007608	0,001522	27,98	0,143
Linear	3	0,006670	0,006963	0,002321	42,67	0,112
Quadratic	2	0,000938	0,000938	0,000469	8,62	0,234
COT*RCOT	1	0,000831	0,000898	0,000898	16,50	0,154
COT*RPET	1	0,000107	0,000107	0,000107	1,96	0,395
Residual Error	1	0,000054	0,000054	0,000054		
Total	6	0,007663				

Figure-2.9.4.: Regression analysis of the 6th cycle of Fabric Stiffness, from Minitab.

Regression analysis of the 6th cycle of Fabric Stiffness suggests that the model is not statistically significant overall if the F-value is more than 1 but the p-value is above 0.05. Nonetheless, the model appears to account for a sizable amount of the variance in the dependent variable because the R-squared and modified R-squared values are both greater than 95%, and the confidence interval is set at 95%. Overfitting, multicollinearity, or a small sample size may be the cause of the discrepancy between high explanatory power and low statistical significance.

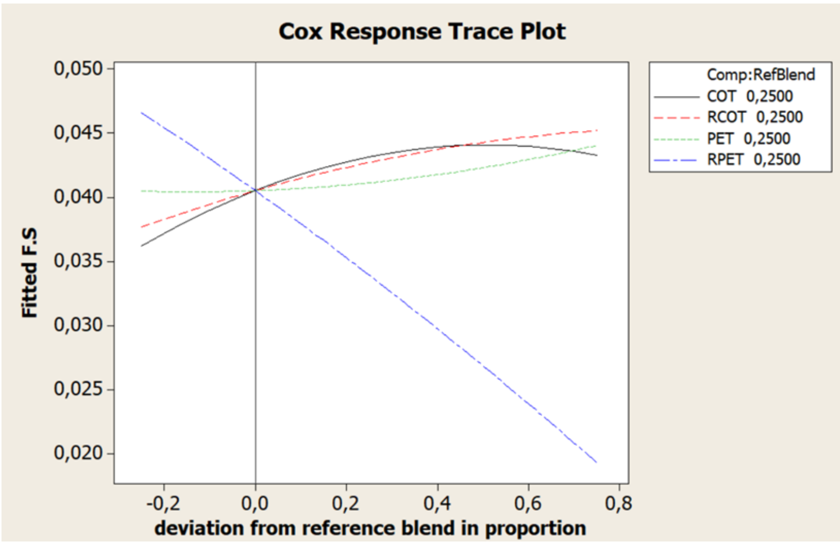

Figure-2.9.5.: Cox response trace plot of fabric stiffness of unwashed fabrics.

According to cox response trace plot of fabric stiffness, it could be stated that increasing of cotton, recycled cotton and polyester increases fabric stiffness, while increase of recycled polyester decreases fabric stiffness. Lower fabric stiffness of recycled polyester result from filament yarns in fabric structure, which gaves a smooth, luster fabric surface to 100% recycled polyester. Higher fabric stiffness of cotton and recycled cotton could be result from higher twist yarns in fabric structure. Generally, fabric stiffness is influenced by a combination of fiber properties, yarn structure, fabric construction, and finishing treatments. The inherent rigidity of fibers, such as polyester or linen, contributes to higher fabric stiffness compared to softer fibers like cotton or silk (Hu, 2008). Yarn twist and thickness also play a crucial role, as tightly twisted and coarser yarns increase stiffness by enhancing structural integrity (Grosberg & Swani, 1966).

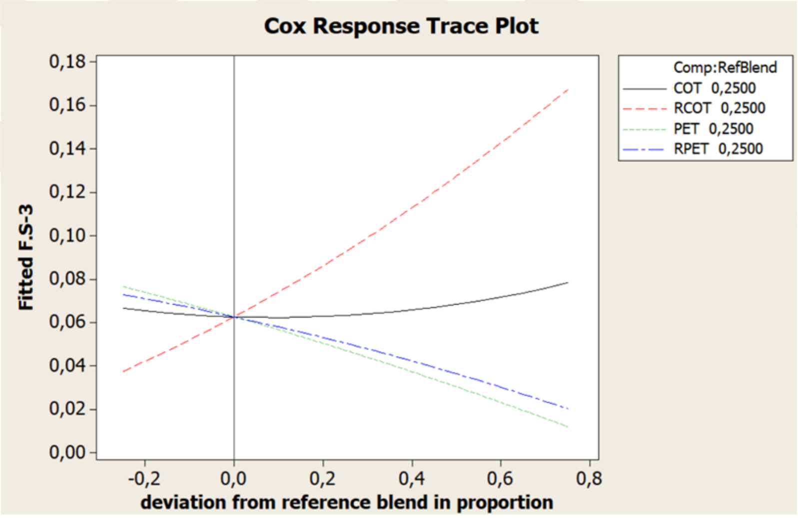

Figure-2.9.6.: Cox response trace plot of Fabric Stiffness of 3rd cycle t-shirts.

According to cox response trace plot of Fabric Stiffness of 3rd cycle, it could be understood that polyester and recycled polyester has almost same fabric stiffness with unwashed ones, yet cotton's fabric stiffness increased 100% and recycled cotton's fabric stiffness increased 4 times approximately after 3 cycles of washing and tumble drying, so water treatments without detergent & softener affects cotton & recycled cotton's fabric stiffness adversely, but it does not affect polyester & recycled polyester at all. Also, reduced fabric stiffness could result from higher bursting and seam strength.

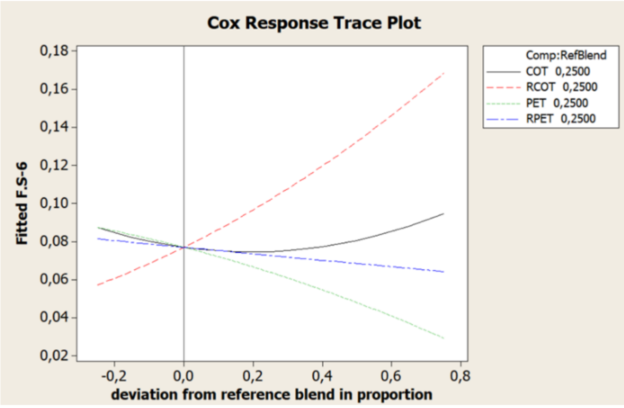

Figure-2.9.7.: Cox response trace plot of fabric stiffness of 6th cycle t-shirts.

According to cox response trace plot of 6th cycle of fabric stiffness, it could be said that recycled polyester's fabric stiffness increases 2 times after 3 more cycles while polyester, cotton and recycled cotton's fabric stiffness stays same with 3rd cycle. Also, 6th cycle recycled cotton's fabric stiffness is 4 times higher than unwashed one, this could be result from hard water used during washing cycles. 6th cycle cotton's fabric stiffness is approximately 2.5 times higher than unwashed cotton, and 6th cycle recycled polyester's fabric stiffness is 3 times higher than unwashed recycled polyester, so it could be said that using hard water in washing could affect recycled cotton more adversely than conventional cotton & recycled polyester.

2.10 Fabric Thickness

For fabric thickness, TS 7128 EN ISO 5084 standard had been followed.

Figure 2.10.1 : Fabric thickness test of Nm 20/1 100% cot. fabric (After 3rd cycle).

```
Regression for Mixtures: F.T versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for F.T (component proportions)

Term          Coef  SE Coef     T       P    VIF
COT         0,5250  0,01500     *       *  1,540
RCOT        0,5900  0,02121     *       *  1,160
PET         0,4375  0,05761     *       *  1,180
RPET        0,3900  0,02121     *       *  1,160
COT*RCOT    0,1625  0,10232  1,59   0,358  1,340
COT*RPET    0,2042  0,10232  2,00   0,296  1,340


S = 0,0212132    PRESS = *
R-Sq = 98,40%    R-Sq(pred) = *%    R-Sq(adj) = 90,39%


Analysis of Variance for F.T (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       5  0,027636  0,027636  0,005527  12,28  0,213
   Linear        3  0,025045  0,021470  0,007157  15,90  0,182
   Quadratic     2  0,002590  0,002590  0,001295   2,88  0,385
     COT*RCOT    1  0,000799  0,001135  0,001135   2,52  0,358
     COT*RPET    1  0,001792  0,001792  0,001792   3,98  0,296
Residual Error   1  0,000450  0,000450  0,000450
Total            6  0,028086
```

Figure 2.10.2.: Regression analysis of fabric thickness of unwashed fabrics, from Minitab.

Based on Fabric Thickness regression analysis, it can be said that the model is not statistically significant overall if the F-value is higher than 1 but the p-value is higher than 0.05. However, the model appears to capture a sizable amount of the variance in the dependent variable because the adjusted R-squared and R-squared values both surpass 90%, and the confidence interval is set at 95%. Overestimation, variation, or a lack of sample size may be the cause of the error between high explanatory power and low statistical significance.

```
Regression for Mixtures: F.T-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for F.T-3 (component proportions)

Term          Coef  SE Coef      T       P    VIF
COT         0,5900  0,02000      *       *  1,540
RCOT        0,6900  0,02828      *       *  1,160
PET         0,5900  0,07681      *       *  1,180
RPET        0,4000  0,02828      *       *  1,160
COT*RCOT   -0,4167  0,13642  -3,05   0,201  1,340
COT*RPET    0,4000  0,13642   2,93   0,209  1,340


S = 0,0282843    PRESS = *
R-Sq = 98,35%    R-Sq(pred) = *%    R-Sq(adj) = 90,10%


Analysis of Variance for F.T-3 (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       5  0,047686  0,047686  0,009537  11,92  0,216
   Linear        3  0,031122  0,044480  0,014827  18,53  0,169
   Quadratic     2  0,016564  0,016564  0,008282  10,35  0,215
     COT*RCOT    1  0,009686  0,007463  0,007463   9,33  0,201
     COT*RPET    1  0,006878  0,006878  0,006878   8,60  0,209
Residual Error   1  0,000800  0,000800  0,000800
Total            6  0,048486
```

Figure 2.10.3.: Regression analysis of the 3rd cycle of fabric thickness, from Minitab.

According to the regression analysis of the third cycle of fabric thickness, if the F-value is larger than one but the p-value is greater than 0.05, the prediction fails comprehensive statistical importance. Though the confidence interval is set at 95% and the R-squared and modified R-squared values both surpass 90%, the model appears to account for a sizable amount of the variance in the dependent variable. The discrepancy between low statistical significance and strong explanatory power may be caused by overestimation, complexity, or poor sample size.

Regression for Mixtures: F.T-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for F.T-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	0,60500	0,01500	*	*	1,540
RCOT	0,63000	0,02121	*	*	1,160
PET	0,49250	0,05761	*	*	1,180
RPET	0,41000	0,02121	*	*	1,160
COT*RCOT	-0,06250	0,10232	-0,61	0,651	1,340
COT*RPET	0,34583	0,10232	3,38	0,183	1,340

S = 0,0212132   PRESS = *
R-Sq = 98,70%   R-Sq(pred) = *%   R-Sq(adj) = 92,19%

Analysis of Variance for F.T-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0,034121	0,034121	0,006824	15,17	0,192
Linear	3	0,028461	0,031430	0,010477	23,28	0,151
Quadratic	2	0,005661	0,005661	0,002830	6,29	0,271
COT*RCOT	1	0,000520	0,000168	0,000168	0,37	0,651
COT*RPET	1	0,005141	0,005141	0,005141	11,42	0,183
Residual Error	1	0,000450	0,000450	0,000450		
Total	6	0,034571				

Figure 2.10.4.: Regression analysis of 6th cycle of Fabric thickness, from Minitab.

Regression analysis of the sixth cycle of Fabric Thickness indicates the regression equation is not statistically significant overall if the F-value is more than 1 but the p-value is above 0.05. Nevertheless, the regression model seems to be responsible for a substantial proportion of the variance in the dependent variable because the R- squared and modified R-squared values both surpass 90%, and the confidence interval is set at 95%. Excessive fitting, multicollinearity, or an insufficient number of samples may be the reason of the mismatch between high predictive power and low statistically significant results.

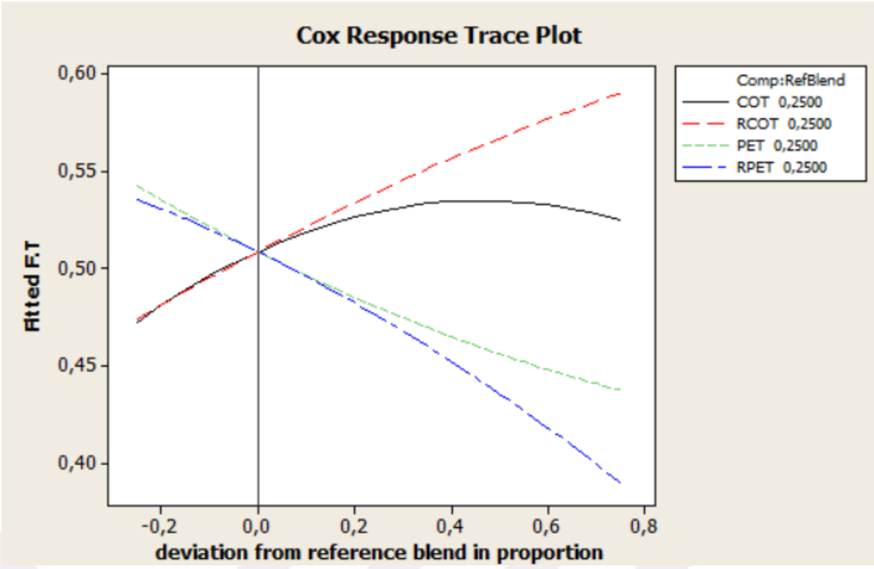

Figure 2.10.5.: Cox response trace plot of Fabric thickness of unwashed fabrics.

According to cox response trace plot of Fabric thickness of unwashed fabrics, it could be said that while highest fabric thickness belongs to cotton and recycled cotton, lowest fabric thickness result from using polyester and recycled polyester. In order to preserve enough strength, yarns used in cotton, recycled cotton, and their mixtures usually have a higher twist. As a result, fabrics made of cotton and recycled cotton are often thicker than those made of polyester and recycled polyester. In contrast to cotton-based fabrics, recycled polyester fabrics have a finer fabric structure due to their filament-based yarns, which have less twist.

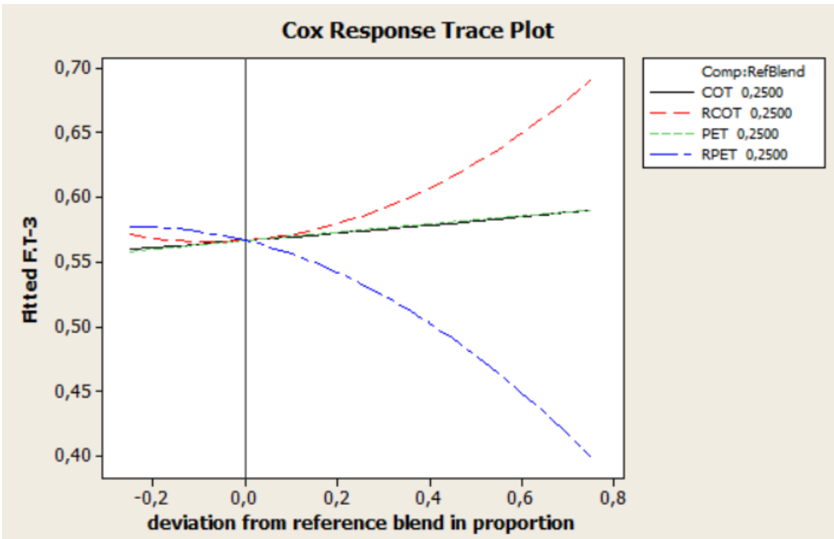

Figure 2.10.6.: Cox response trace plot of fabric thickness of 3rd cycle t-shirts.

According to cox response trace plot of 3rd cycle of fabric thickness, it could be stated that recycled cotton's fabric thickness increased 15%, while recycled polyester's fabric thickness remain same after 3 cycles. This increase is 30 % for polyester and 18% for cotton, so effect of 3 cycles of water treatment on fabric thickness is quite same for cotton and recycled cotton, yet still recycled cotton has the highest fabric thickness compared to others.

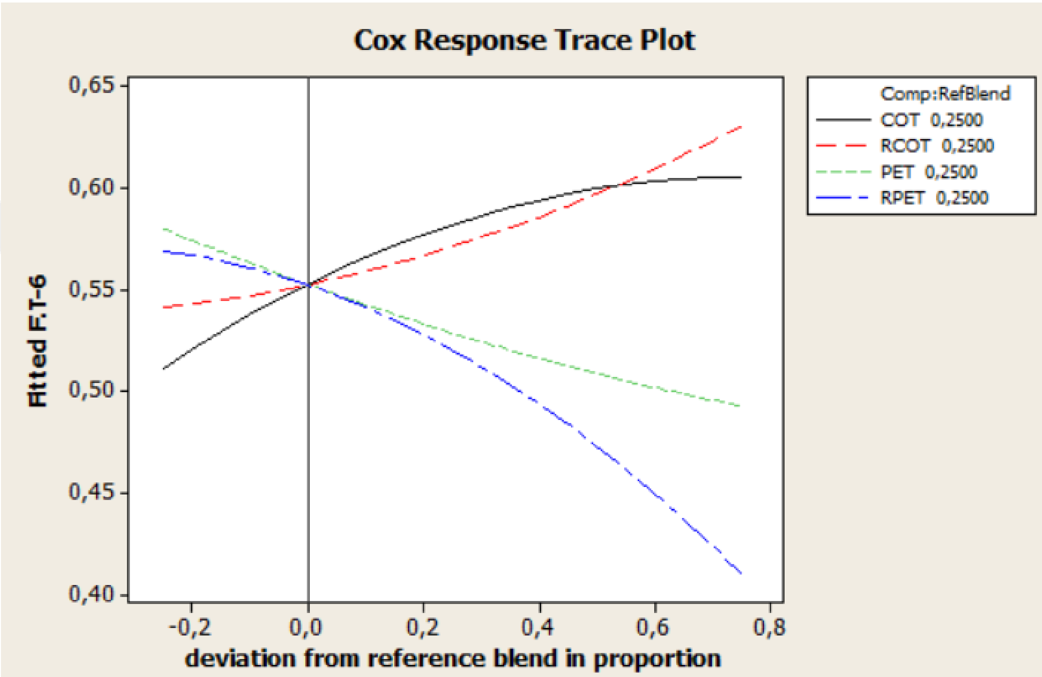

Figure 2.10.7.: Cox response trace plot of fabric thickness of 6th cycle t-shirts.

According to cox response trace plot of 6th cycle of fabric thickness, it could be said that recycled polyester's fabric thickness remains same at all cycles, despite harsh conditions of washing cycles. Polyester's fabric thickness decreased 20% at last 3 cycles, yet still 10% higher than unwashed polyester, which is an ignorable rise. While cotton's fabric thickness remains same with 3rd cycle, recycled cotton's fabric thickness declines as 11% at last 3 cycles and become quite same with unwashed fabric thickness value.

2.11 Bursting Strength

For bursting strength test, TS EN ISO 13938-1 standard had been followed.

Figure 2.11.1: Bursting strength test of Nm 30/1 100%cot fabric (After 6th cycle).

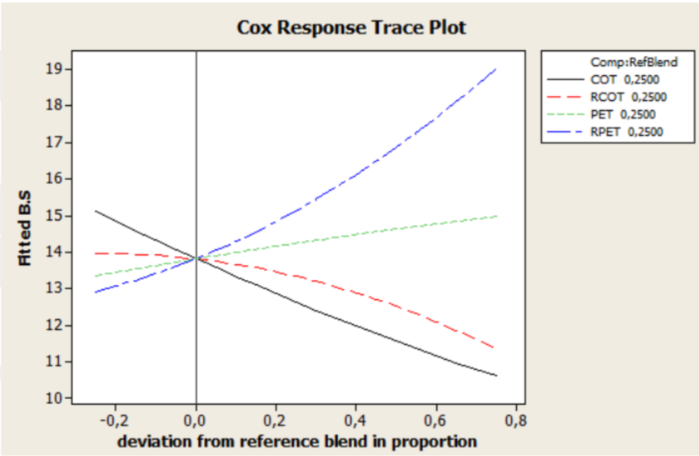

Figure 2.11.2.: Cox response trace plot of Bursting strength of unwashed fabrics.

According to Figure-2.11.2, it could be stated that recycled polyester & polyester have higher bursting strength compared to cotton & recycled cotton, as expected, yet recycled cotton has slightly higher bursting strength than conventional cotton, which is an interesting result. According to previous studies, it could be understood that ring spun 100% recycled polyester could have lower bursting strength than 100% recycled polyester fabric having filament yarns and fabrics with coarser recycled polyester ring spun yarns have higher bursting strength results compared to fabrics with thinner recycled polyester yarns (Uyanık (2021)). Also, according to Sari et. al (2024)'s study, it could be claimed that increasing recycled cotton amount does not affect bursting strength adversely, yet both MCRC, RC, 20C1 & 30C1 have higher bursting strength than their recycled cotton fabrics, so maybe the difference could result from yarn properties.

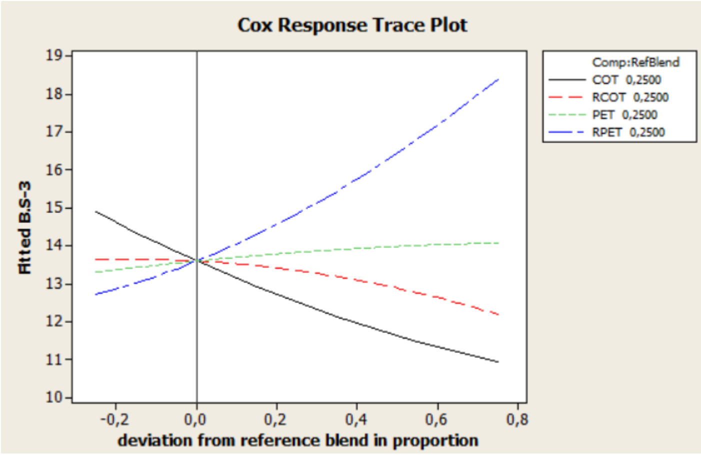

Figure 2.11.3.: Cox response trace plot of bursting strength of 3rd cycle t-shirts.

According to 3rd cycle results of bursting strength, it could be claimed that bursting strength of cotton, recycled cotton & recycled polyester almost did not change with 3 cycles of washing & tumble drying, yet polyester's bursting strength decreased approximately 10%. Yılmaz & Keleş (2024) stated that repeated laundering & tumble drying of recycled cotton and their blends did not affect bursting strength adversely in single jersey fabrics, and also authors claimed that Ne 20 50% recycled cotton/50% recycled PES single jersey fabric has higher bursting strength at all cycles compared to line dried one, so it could be thought that tumble drying does not have an adverse effect on bursting strength of recycled fabrics.

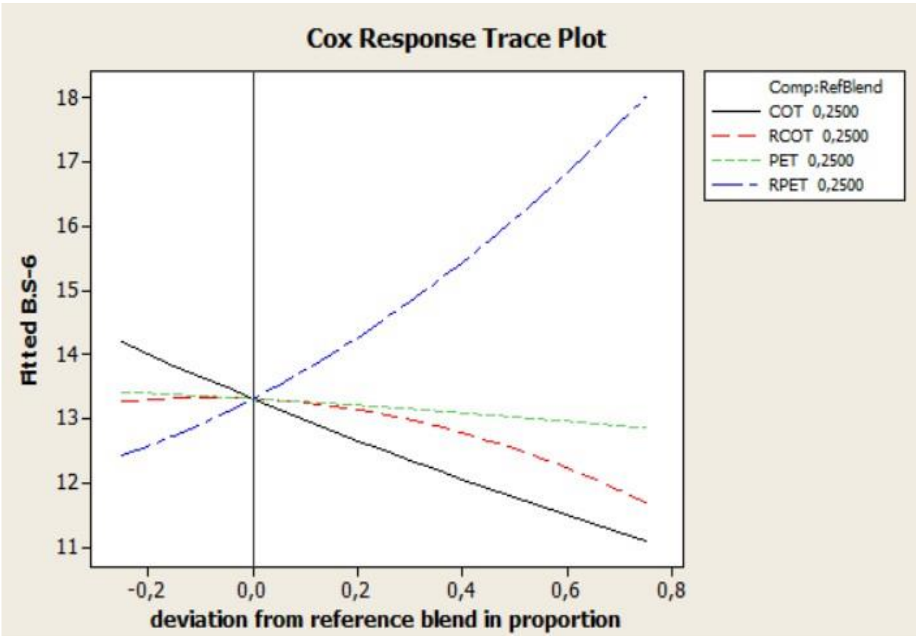

Figure 2.11.4: Cox response trace plot of Bursting strength of 6th cycle t-shirts.

According to 6th cycle results of bursting strength, it could be stated that recycled polyester, recycled cotton and conventional cotton's bursting strength almost did not change throughout the 6 washing & tumble-drying cycles, use of recycled polyester should be advised if there is a need for highest bursting strength. Polyester's bursting strength seems 10% decreased after 3rd cycle, and became more closer to cotton & recycled cotton. Even there is harsh washing & tumble-drying conditions, according to last cycle it could be claimed that decrease in bursting strength of all t-shirts could be ignorable.

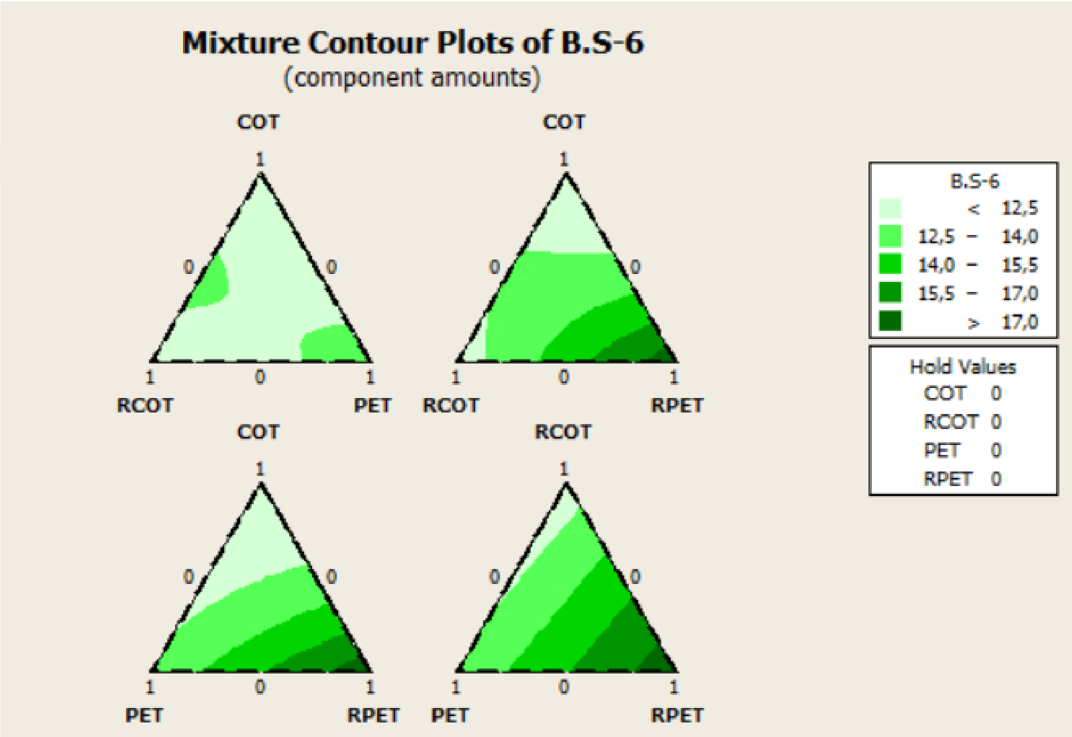

Figure 2.11.5: Mixture contour plots of Bursting strength of 6th cycle t-shirts.

Based on the Figure 2.11.5, it could be understood that if there is a fabric with equal blend of cotton-recycled cotton-polyester with Nm 30 yarn count, this fabric would probably have bursting strength lower than 12,5 at the end of 6 washing & tumble-drying cycles. Also, Nm 30 50% recycled cotton-50% recycled polyester blend would probably have bursting strength between 14-15,5 at the end of 6 washing and tumble-drying cycles while 90%polyester 10% recycled polyester and 90% polyester 10% recycled cotton fabrics were having bursting strength between 12,5 to 14. Nm 30 20% cotton 80% recycled polyester would probably one of the highest bursting strengths after multiple washing & tumble-drying cycles, approximately 16.

2.12 Seam Strength

For seam strength test, TS EN ISO 13935-2 standard had been followed.

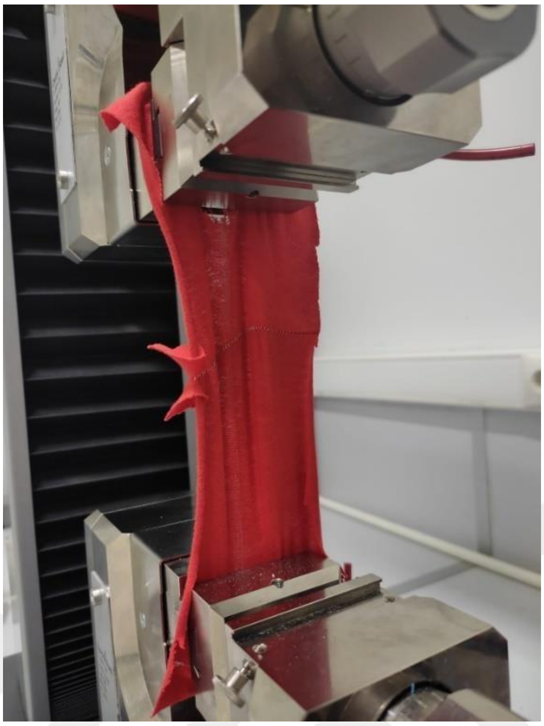

Figure 2.12.1: Seam strength test of unwashed cotton-rec cot. blend fabric.

Figure 2.12.2 : 6th cycle MCP, after Seam Strength test. Seam is maintained while fabric is broken.

Figure 2.12.3 : 6th cycle MCRP, after seam strength test. Fabric stitch is durable while fabric is broken.

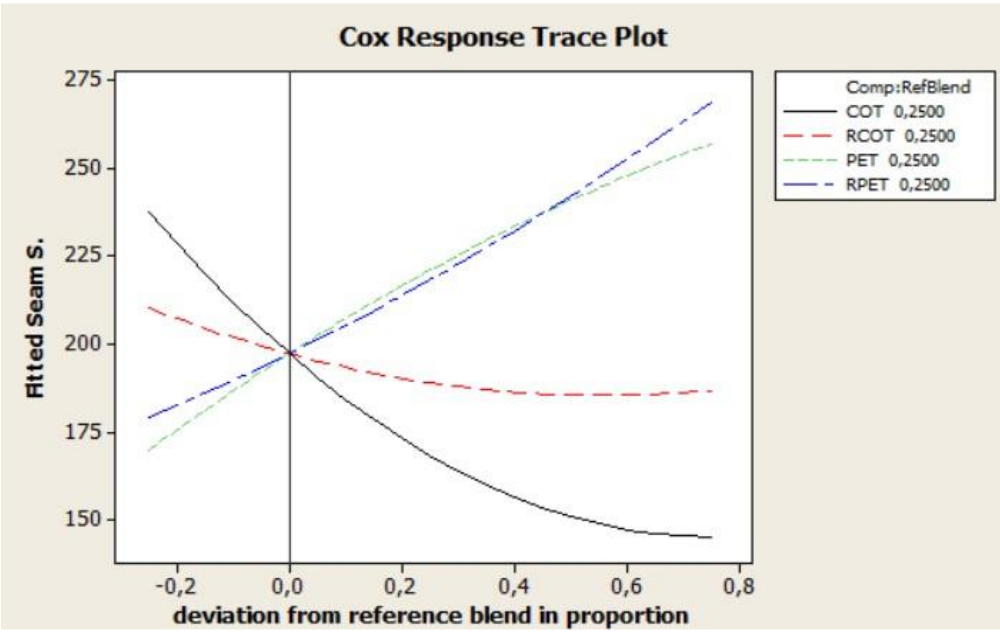

Figure 2.12.4.: Cox response trace plot of Seam Strength of unwashed fabrics.

According to seam strength of unwashed fabrics, it could be said that recycled cotton's seam strength is 25% higher than cotton, the reason could be high level of twist in recycled cotton yarns. Also, smooth & flexible fabrics could have higher seam strength, so this is the reason why normal polyester & recycled polyester exhibits greater seam strength compared to conventional cotton & recycled cotton.

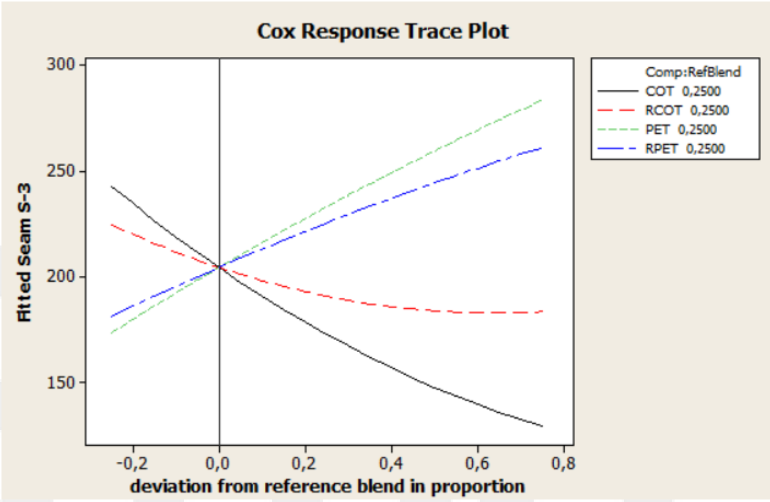

Figure 2.12.5.: Cox response trace plot of Seam Strength of 3rd cycle t-shirts.

According to 3rd cycle of seam strength results, it could be stated that recycled polyester's seam strength decreased approximately 7% after 3 cycles of washing & drying.

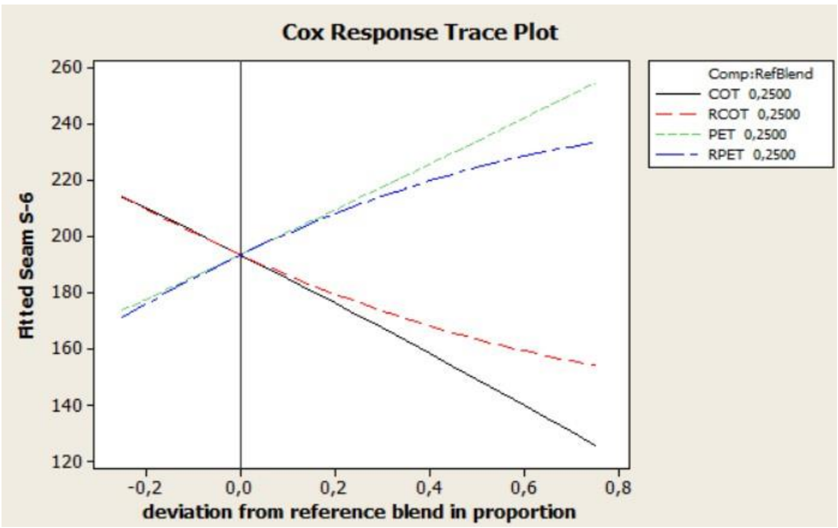

Figure 2.12.6.: Cox response trace plot of Seam Strength of 6th cycle t-shirts.

According to 6th cycle of seam strength results, it could be stated that RP has 50% higher seam strength than RC. Based on Koçak et.al (2024)'s study, it could be said that RP has higher seam strength at all cycles, comparing to their 100% recycled polyester fabric, difference between them could result from fabric construction or yarn count.

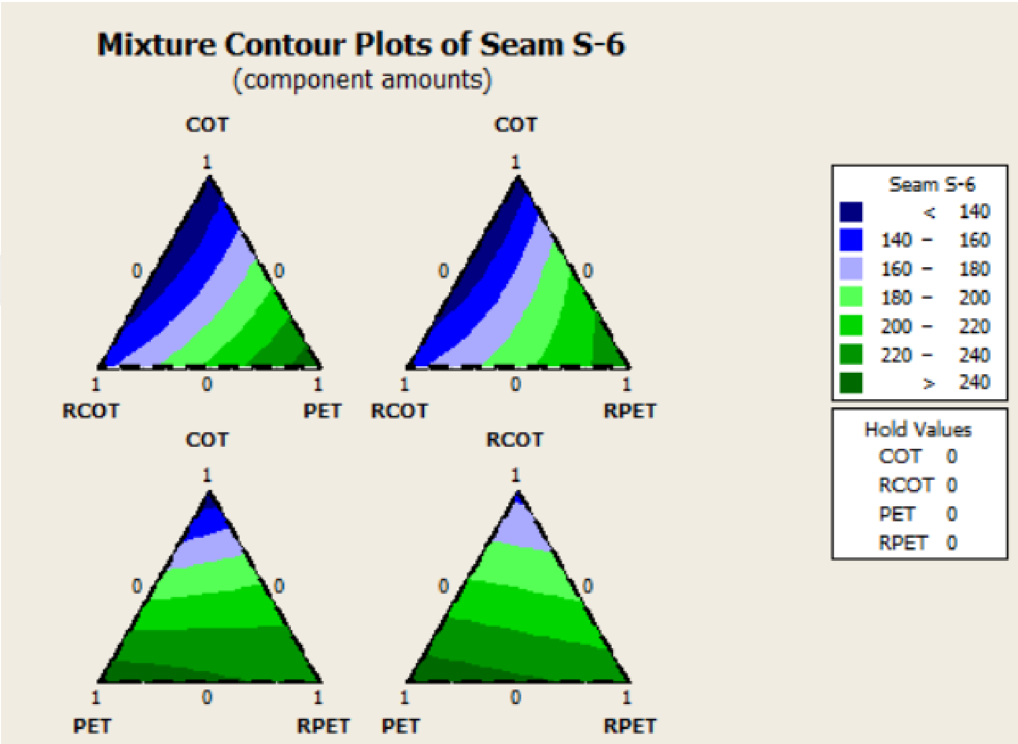

Figure 2.12.7: Mixture contour plots of Seam strength of 6th cycle t-shirts.

Based on Figure 2.12.7, it could be stated that a fabric with Nm 30 yarns & equal blend of recycled cotton-polyester-recycled polyester would probably have 200-220 N seam strength after 6 cycles of washing& tumble-drying. Nm 30 50% recycled cotton-50% recycled polyester would probably have 180-200 N seam strength at the end of 6th cycle. Nm 30 75% rcot 25& pet would probably have 160-180 N seam strength at the end of 6th cycle.

2.13 Air Permeability Test

For air permeability test, ASTM D737 standard had been followed.

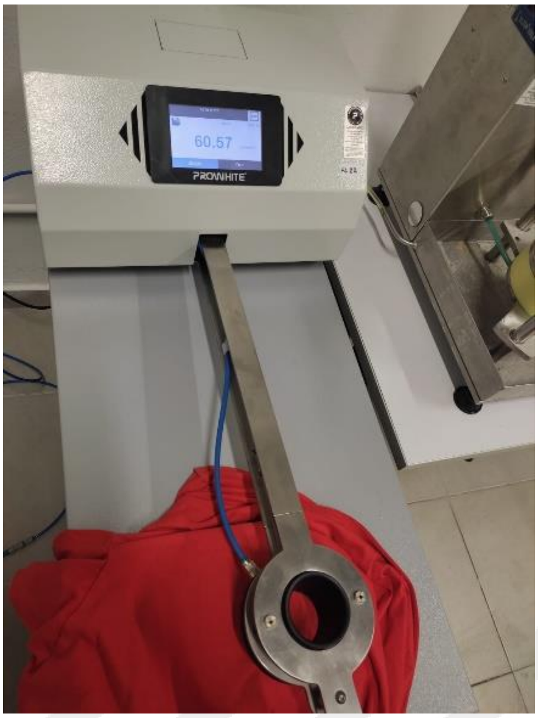

Figure 2.13.1.: Air Permeability Testing.

Regression for Mixtures: A.P versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.P (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	58,66	0,2400	*	*	1,540
RCOT	44,41	0,3394	*	*	1,160
PET	37,26	0,9217	*	*	1,180
RPET	135,80	0,3394	*	*	1,160
COT*RCOT	13,92	1,6371	8,50	0,075	1,340
COT*RPET	-82,57	1,6371	-50,44	0,013	1,340

S = 0,339411 PRESS = *
R-Sq = 100,00% R-Sq(pred) = *% R-Sq(adj) = 99,99%

Analysis of Variance for A.P (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	5787,19	5787,19	1157,44	10047,20	0,008
Linear	3	5466,77	5636,57	1878,86	16309,51	0,006
Quadratic	2	320,42	320,42	160,21	1390,70	0,019
COT*RCOT	1	27,38	8,33	8,33	72,27	0,075
COT*RPET	1	293,04	293,04	293,04	2543,75	0,013
Residual Error	1	0,12	0,12	0,12		
Total	6	5787,30				

Figure 2.13.2.: Regression analysis of air permeability of unwashed fabrics, from Minitab.

The regression analysis results indicate that the model of air permeability of unwashed fabrics is statistically significant, as evidenced by an F-value greater than 1 and a p-value below 0.05. Additionally, the R-squared and adjusted R-squared values exceeding almost 100% suggest that the model explains a substantial proportion of the variance in the dependent variable. These findings imply a strong explanatory power of the independent variables.

Regression for Mixtures: A.P-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.P-3 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	63,50	4,000	*	*	1,540
RCOT	39,70	5,657	*	*	1,160
PET	7,75	15,362	*	*	1,180
RPET	118,40	5,657	*	*	1,160
COT*RCOT	-18,67	27,285	-0,68	0,618	1,340
COT*RPET	-91,08	27,285	-3,34	0,185	1,340

S = 5,65685 PRESS = *
R-Sq = 99,26% R-Sq(pred) = *% R-Sq(adj) = 95,54%

Analysis of Variance for A.P-3 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	4270,03	4270,03	854,01	26,69	0,146
Linear	3	3911,61	4062,25	1354,08	42,32	0,112
Quadratic	2	358,42	358,42	179,21	5,60	0,286
COT*RCOT	1	1,81	14,98	14,98	0,47	0,618
COT*RPET	1	356,61	356,61	356,61	11,14	0,185
Residual Error	1	32,00	32,00	32,00		
Total	6	4302,03				

Figure 2.13.3.: Regression analysis of air permeability of 3rd cycle t-shirts, from Minitab.

The regression analysis of 3rd cycle of air permeability indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: A.P-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for A.P-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	67,0	2,000	*	*	1,540
RCOT	55,1	2,828	*	*	1,160
PET	66,5	7,681	*	*	1,180
RPET	107,2	2,828	*	*	1,160
COT*RCOT	-27,7	13,642	-2,03	0,292	1,340
COT*RPET	-109,6	13,642	-8,03	0,079	1,340

S = 2,82843 PRESS = *
R-Sq = 99,60% R-Sq(pred) = *% R-Sq(adj) = 97,60%

Analysis of Variance for A.P-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1988,01	1988,01	397,602	49,70	0,107
Linear	3	1464,80	1601,84	533,948	66,74	0,090
Quadratic	2	523,21	523,21	261,607	32,70	0,123
COT*RCOT	1	7,34	32,90	32,903	4,11	0,292
COT*RPET	1	515,87	515,87	515,873	64,48	0,079
Residual Error	1	8,00	8,00	8,000		
Total	6	1996,01				

Figure 2.13.4.: Regression analysis of air permeability of 6th cycle t-shirts, from Minitab.

The regression analysis of 6th cycle of air permeability indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

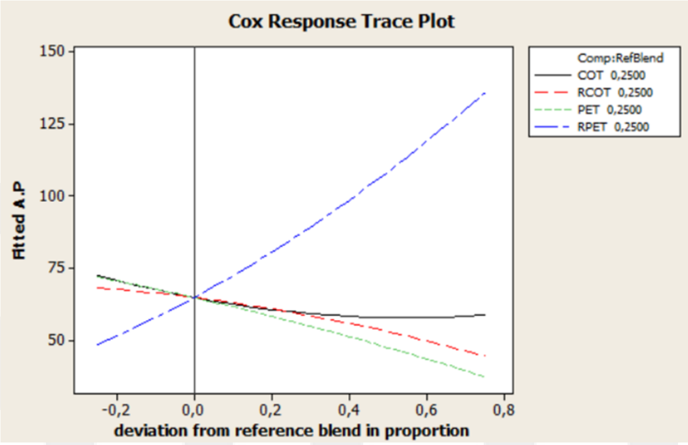

Figure 2.13.5.: Cox response trace plot of air permeability of unwashed fabrics.

According to cox response plot of air permeability of unwashed fabrics, it could be stated that increasing recycled polyester increases air permeability, and increasing other fibers decreases air permeability. This could be as a result of recycled fibers' looser structure and increased porosity, which facilitate easier airflow (Koçak ED et.al (2024)). In this chart, recycled cotton, natural cotton and polyester behave very similar, in order to have an optimum air permeability, fibers should be chosen wisely. B. Utebay et. al (2024) stated that amount of recycled cotton could have important effect on Nm 30 fabrics, and their 80% recycled cotton 20 % recycled cotton fabric has almost 20 % higher air permeability than 30C1 and 30% higher air permeability than RC, since these fabrics have same yarn count & they are both knitted fabrics, it could be stated that difference between them result from finishing & dyeing treatments. For unwashed fabrics, when amount of recycle cotton increases, air permeability decreases, but for 60% and 100% conventional cotton, air permeability remains same. Also, air permeability increases with increasing amount of recycle polyester. When yarn becomes thicker, air permeability decreases.

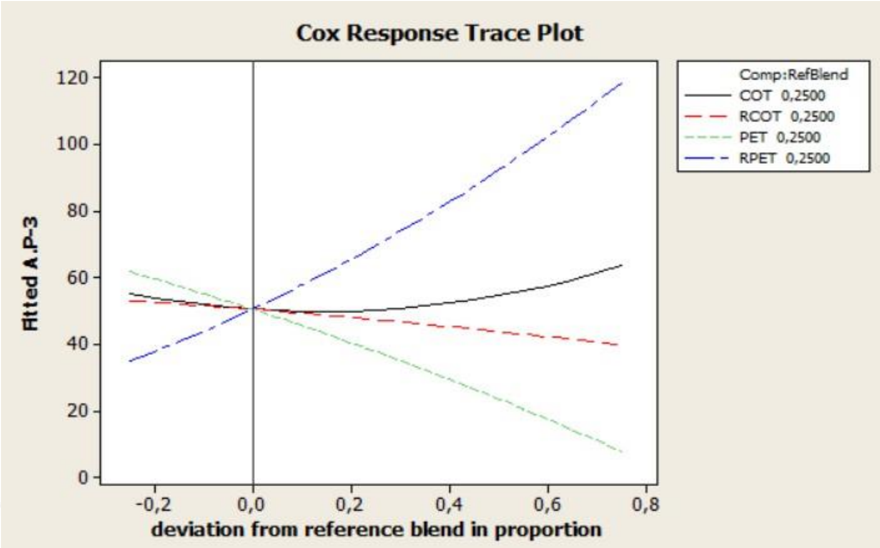

Figure 2.13.6.: Cox response trace plot of air permeability of 3rd cycle t-shirts.

According to cox response plot of 3rd cycle air permeability, it could be stated that air permeability increases with increasing recycled polyester, and decreases with decreasing polyester and recycled cotton. It could be understood that while amount of cotton does not make a significant change at 3rd cycle of air permeability, recycled cotton acts like polyester than a natural cotton. Moreover, washed polyester's air permeability is lower than unwashed polyester fabric, but washed cotton & recycled cotton's air permeability is almost same with unwashed cotton & recycled cotton fabrics.

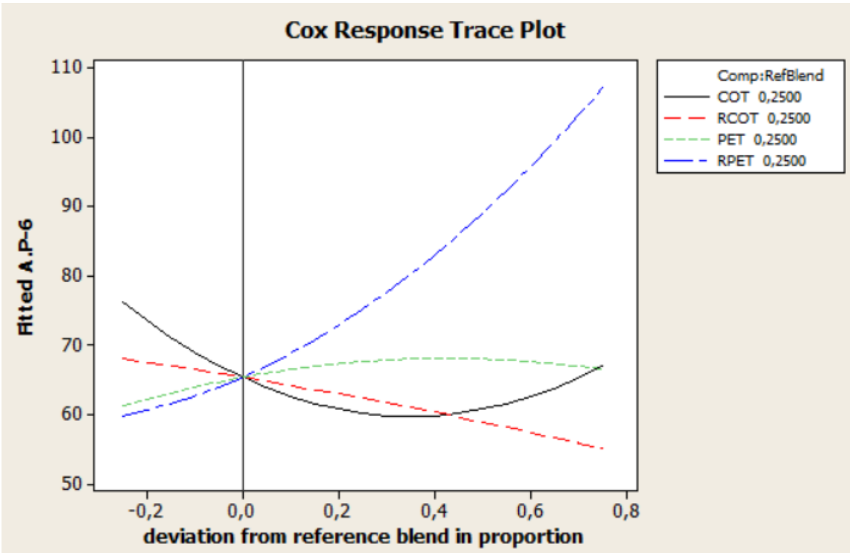

Figure 2.13.7.: Cox response trace plot of air permeability of 6th cycle t-shirts.

According to 6th cycle of air permeability test, it could be stated that while natural cotton shows a nonlinear trend, first decreasing and then increasing, suggesting a more complex interaction, recycled cotton has a slight negative effect, indicating that increasing its proportion reduces the fitted response. Also, polyester remains relatively stable, and it does not have a significant effect on model as recycled polyester. Also, Yılmaz & Keleş (2024) stated that multiple washing & tumble-drying cycles could decrease air permeability approximately 50%, yet in this research, such a significant change between unwashed fabrics & 6th cycle t-shirts in terms of air permeability has not been observed.

2.14 Water Vapour Permeability Test

For water vapour permeability test, TS EN ISO 15496 standard had been followed.

Figure 2.14.1.: Water vapour permeability testing.

Regression for Mixtures: W.V.P versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for W.V.P (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	4750	138,9	*	*	1,540
RCOT	5667	196,4	*	*	1,160
PET	6139	533,5	*	*	1,180
RPET	4917	196,4	*	*	1,160
COT*RCOT	-2801	947,5	-2,96	0,208	1,340
COT*RPET	2500	947,5	2,64	0,231	1,340

S = 196,434 PRESS = *
R-Sq = 96,73% R-Sq(pred) = *% R-Sq(adj) = 80,41%

Analysis of Variance for W.V.P (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1143214	1143214	228643	5,93	0,302
Linear	3	443760	639555	213185	5,52	0,301
Quadratic	2	699454	699454	349727	9,06	0,229
COT*RCOT	1	430779	337284	337284	8,74	0,208
COT*RPET	1	268675	268675	268675	6,96	0,231
Residual Error	1	38586	38586	38586		
Total	6	1181800				

Figure 2.14.2.: Regression analysis of Water Vapour Permeability of unwashed fabrics, from Minitab.

The regression analysis of water vapour permeability of unwashed fabrics indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values are between 80-95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: W.V.P-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for W.V.P-3 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	5243,8	82,65	*	*	1,540
RCOT	6124,5	116,88	*	*	1,160
PET	7998,6	317,42	*	*	1,180
RPET	5283,3	116,88	*	*	1,160
COT*RCOT	757,3	563,77	1,34	0,407	1,340
COT*RPET	2506,4	563,77	4,45	0,141	1,340

S = 116,885 PRESS = *
R-Sq = 98,89% R-Sq(pred) = *% R-Sq(adj) = 93,35%

Analysis of Variance for W.V.P-3 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1219044	1219044	243809	17,85	0,178
Linear	3	941271	1173680	391227	28,64	0,136
Quadratic	2	277773	277773	138887	10,17	0,217
COT*RCOT	1	7745	24652	24652	1,80	0,407
COT*RPET	1	270029	270029	270029	19,76	0,141
Residual Error	1	13662	13662	13662		
Total	6	1232706				

Figure 2.14.3.: Regression analysis of Water Vapour Permeability of 3rd cycle t- shirts, from Minitab.

The regression analysis of 3rd cycle of water vapor permeability indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: W.V.P-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for W.V.P-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	5506	33,35	*	*	1,540
RCOT	3272	47,16	*	*	1,160
PET	8177	128,08	*	*	1,180
RPET	5736	47,16	*	*	1,160
COT*RCOT	5320	227,48	23,38	0,027	1,340
COT*RPET	5121	227,48	22,51	0,028	1,340

S = 47,1640   PRESS = *
R-Sq = 99,97%   R-Sq(pred) = *%   R-Sq(adj) = 99,83%

Analysis of Variance for W.V.P-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	7990223	7990223	1598045	718,40	0,028
Linear	3	5924065	6008325	2002775	900,35	0,024
Quadratic	2	2066158	2066158	1033079	464,42	0,033
COT*RCOT	1	939092	1216371	1216371	546,82	0,027
COT*RPET	1	1127066	1127066	1127066	506,67	0,028
Residual Error	1	2224	2224	2224		
Total	6	7992447				

Figure 2.14.4.: Regression analysis of Water Vapour permeability of 6th cycle t-shirts, from Minitab.

The regression analysis of 6th cycle of water vapour permeability results indicate that the model is statistically significant, as evidenced by an F-value greater than 1 and a p-value below 0.05. Additionally, the R-squared and adjusted R-squared values exceeding almost 100% suggest that the model explains a substantial proportion of the variance in the dependent variable. These findings imply a strong explanatory power of the independent variables.

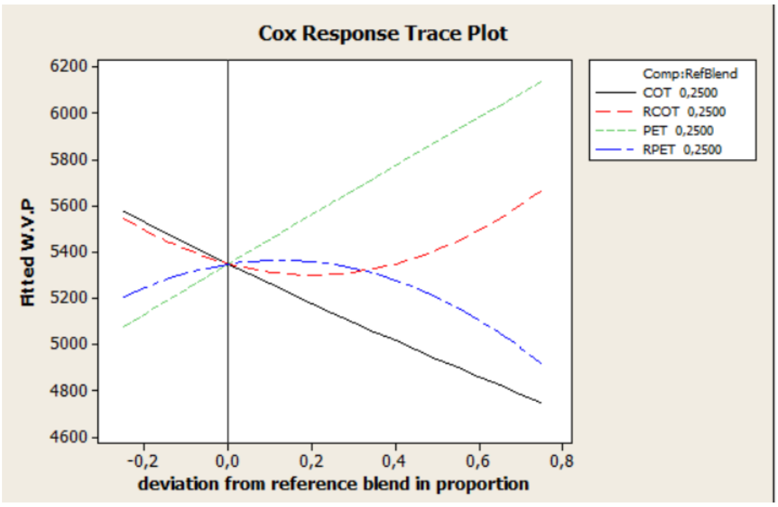

Figure-2.14.5.: Cox response trace plot of water vapour permeability of unwashed fabrics.

According to water vapour permeability of unwashed fabrics, it could be claimed that water vapour permeability increases with increasing recycled cotton and polyester, and decreases with increasing natural cotton and recycled polyester. Moreover, it could be said that increasing air permeability could cause decrease in water vapour permeability. Badr et al. (2016) indicated that the greatest water vapor permeability may arise from the fineness of fibers and the smoothness of the fabric, yet 100% recycled cotton exhibits the highest water vapor permeability overall, despite lacking a smoother surface. Fabrics produced from recycled cotton consist of shorter and thicker fibers compared to standard cotton, leading to a denser structure with decreased air permeability (Alp et al., 2023).

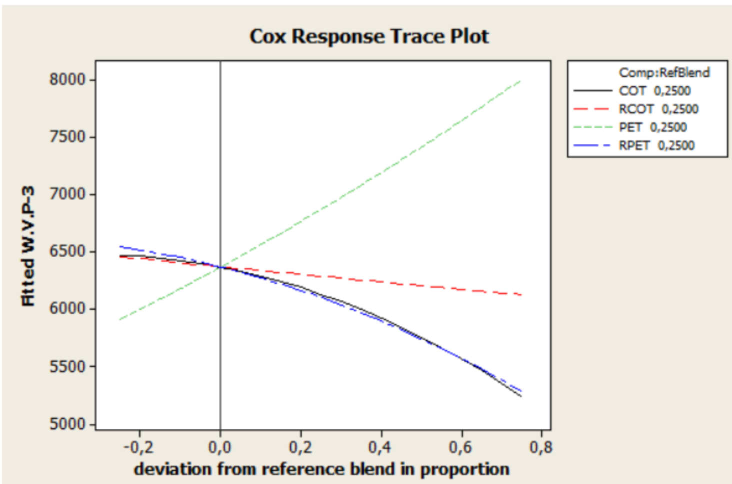

Figure 2.14.6.: Cox response trace plot of W.V.P. of 3rd cycle t-shirts.

According to water vapour permeability of 3rd cycle, it could be stated that 3 cycles of washing increases water vapour permeability for all fabrics. Also, recycled polyester behaves more similar to natural cotton after 3 cycles of washing on water vapour permeability. At 3rd cycle, it could be stated that water vapour permeability increases with increasing polyester, and decreases with increasing cotton, recycled cotton, and recycled polyester. Demiryurek et al. (2019) noted that enhanced water vapor permeability in multiple washes results from the mechanical impact of laundering, which leads to fiber loss in the fabric, and this could be the explanation for increased water vapour permeability of 3rd cycle MCRC and 20C1 t-shirts.

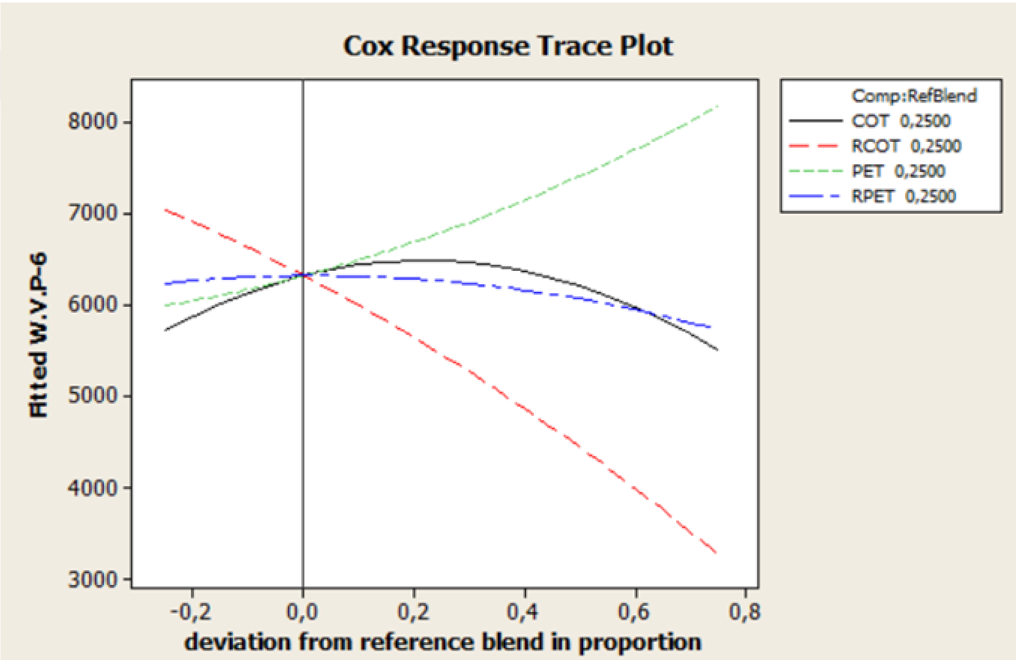

Figure 2.14.7.: Cox response trace plot of W.V.P of 6th cycle t-shirts.

According to cox response plot of 6th cycle of water vapour permeability, it could be stated that amount of recycled cotton significantly changes the results. During washing and drying, cotton fibers can swell and rearrange, leading to a denser structure with reduced porosity. Repeated exposure to heat and water causes fabric shrinkage, decreasing air and moisture permeability. Additionally, washing can result in microfibril loss, making the fabric surface smoother and less breathable. In recycled cotton, mechanical processing weakens fibers, increasing cross-linking during washing and further reducing breathability, so these are the possible reasons for reducing water vapour permeability of recycled cotton.

To minimize these effects, low-temperature washing and drying, limited use of harsh detergents, and air drying or low-heat tumble drying are recommended. Moreover, since recycled pet's dimensional stability does not change significantly during multiple washings, water vapour permeability of pet at 6^{th} cycle is almost stable even the amount of polyester increases.

2.15 Drying Rate Test

Figure 2.15.1: For drying rate test, Fabrics stay in distilled water for 30 min.

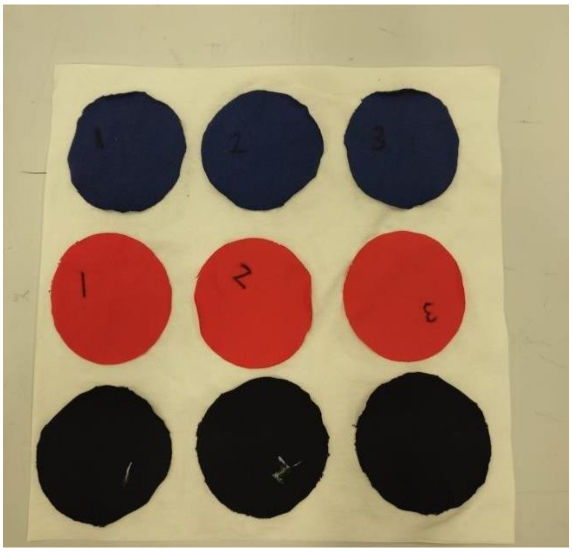

Figure 2.15.2: Drying rate of 30C1, MCP, and MCRP before washing and drying cycles, 1 hour after getting wet.

```
Regression for Mixtures: D.R versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for D.R (component proportions)

Term        Coef  SE Coef       T      P    VIF
COT         7048    174,6       *      *  1,540
RCOT        7809    246,9       *      *  1,160
PET         4598    670,4       *      *  1,180
RPET       24140    246,9       *      *  1,160
COT*RCOT    2712   1190,6    2,28  0,263  1,340
COT*RPET  -31293   1190,6  -26,28  0,024  1,340


S = 246,851     PRESS = *
R-Sq = 99,98%   R-Sq(pred) = *%   R-Sq(adj) = 99,86%


Analysis of Variance for D.R (component proportions)

Source          DF     Seq SS     Adj SS    Adj MS        F      P
Regression       5  253003206  253003206  50600641   830,40  0,026
   Linear        3  208815355  236737339  78912446  1295,02  0,020
   Quadratic     2   44187851   44187851  22093926   362,58  0,037
     COT*RCOT    1    2093628     316182    316182     5,19  0,263
     COT*RPET    1   42094223   42094223  42094223   690,80  0,024
Residual Error   1      60935      60935     60935
Total            6  253064142
```

Figure 2.15.3 : Regression analysis of drying rate of unwashed fabrics, from Minitab.

The regression analysis of drying rate results indicate that the model is statistically significant, as evidenced by an F-value greater than 1 and a p-value below 0.05. Additionally, the R-squared and adjusted R-squared values exceeding almost 100% suggest that the model explains a substantial proportion of the variance in the dependent variable. These findings imply a strong explanatory power of the independent variables.

```
Regression for Mixtures: D.R-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for D.R-3 (component proportions)

Term        Coef  SE Coef      T      P    VIF
COT         9591    360,7      *      *  1,540
RCOT        8638    510,1      *      *  1,160
PET         4901   1385,3      *      *  1,180
RPET       16698    510,1      *      *  1,160
COT*RCOT   -5248   2460,4  -2,13  0,279  1,340
COT*RPET   -5694   2460,4  -2,31  0,260  1,340


S = 510,107     PRESS = *
R-Sq = 99,55%   R-Sq(pred) = *%   R-Sq(adj) = 97,29%


Analysis of Variance for D.R-3 (component proportions)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       5  57386802  57386802  11477360  44,11  0,114
   Linear        3  55113337  51273250  17091083  65,68  0,090
   Quadratic     2   2273464   2273464   1136732   4,37  0,320
     COT*RCOT    1    879736   1183798   1183798   4,55  0,279
     COT*RPET    1   1393728   1393728   1393728   5,36  0,260
Residual Error   1    260209    260209    260209
Total            6  57647011
```

Figure 2.15.4 : Regression analysis of drying rate of 3^{rd} cycle t-shirts, from Minitab.

The regression analysis of 3rd cycle of drying rate indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: D.R-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for D.R-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	9008	488,0	*	*	1,540
RCOT	10442	690,2	*	*	1,160
PET	12074	1874,4	*	*	1,180
RPET	18678	690,2	*	*	1,160
COT*RCOT	-1903	3329,1	-0,57	0,669	1,340
COT*RPET	-7502	3329,1	-2,25	0,266	1,340

S = 690,207   PRESS = *
R-Sq = 99,34%   R-Sq(pred) = *%   R-Sq(adj) = 96,02%

Analysis of Variance for D.R-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	71266837	71266837	14253367	29,92	0,138
Linear	3	68812686	66667610	22222537	46,65	0,107
Quadratic	2	2454151	2454151	1227075	2,58	0,403
COT*RCOT	1	35085	155660	155660	0,33	0,669
COT*RPET	1	2419066	2419066	2419066	5,08	0,266
Residual Error	1	476386	476386	476386		
Total	6	71743222				

Figure 2.15.5 : Regression analysis of drying rate of 6th cycle t-shirts, from Minitab.

The regression analysis of 6th cycle of drying rate indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

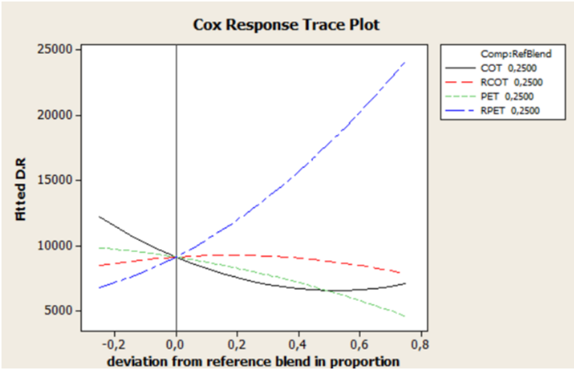

Figure 2.15.6 : Cox response trace plot of drying rate of unwashed fabrics.

Based on cox response trace plot of drying rate of unwashed fabrics, it could be stated that when amount of recycled polyester increases, drying rate increases. The faster drying rate of recycled polyester compared to conventional polyester can be attributed to its filament yarn structure. Unlike ring-spun yarns, which consist of twisted staple fibers that create micro-gaps capable of retaining moisture, filament yarns are continuous and smoother, minimizing water absorption. This smoother surface allows moisture to spread and evaporate more efficiently. Additionally, filament-based fabrics often exhibit greater air permeability, further accelerating the drying process. As a result, the structural differences between filament and ring-spun yarns play a crucial role in the moisture management properties of these fabrics. Also, Duru & Candan (2013) claimed that tight cotton-polyamide-elastane blend fabrics could have lower drying rate compared to slack version of same fabric, also their highest drying rate in cotton quite closer to unwashed MCP & MCRP, and unwashed RC has 2 times higher drying rate than their unwashed cotton drying rate, so if higher drying rate is preferred in fabric, use of recycled cotton should be advised.

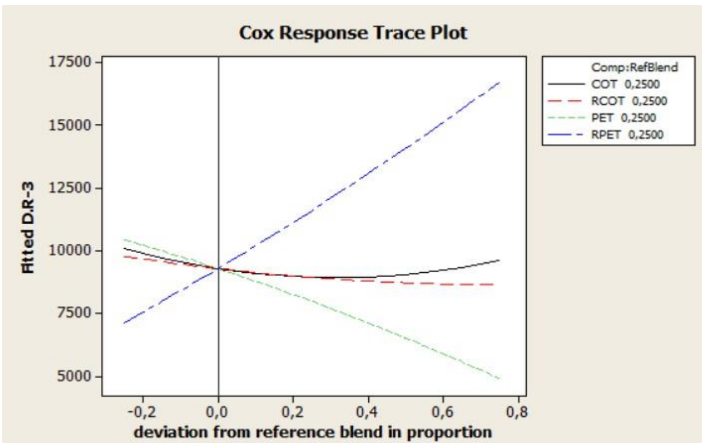

Figure 2.15.7 : Cox response trace plot of Drying Rate of 3rd cycle t-shirts.

According to cox response trace of 3rd cycle of drying rate, it could be said that multiple washing cycles could decrease drying rate of recycled polyester, but drying rate of cotton & recycled cotton does not change significantly after 3 washing cycles and even their results become closer. Polyester again has the lowest drying rate, and it's drying rate is same with unwashed polyester.

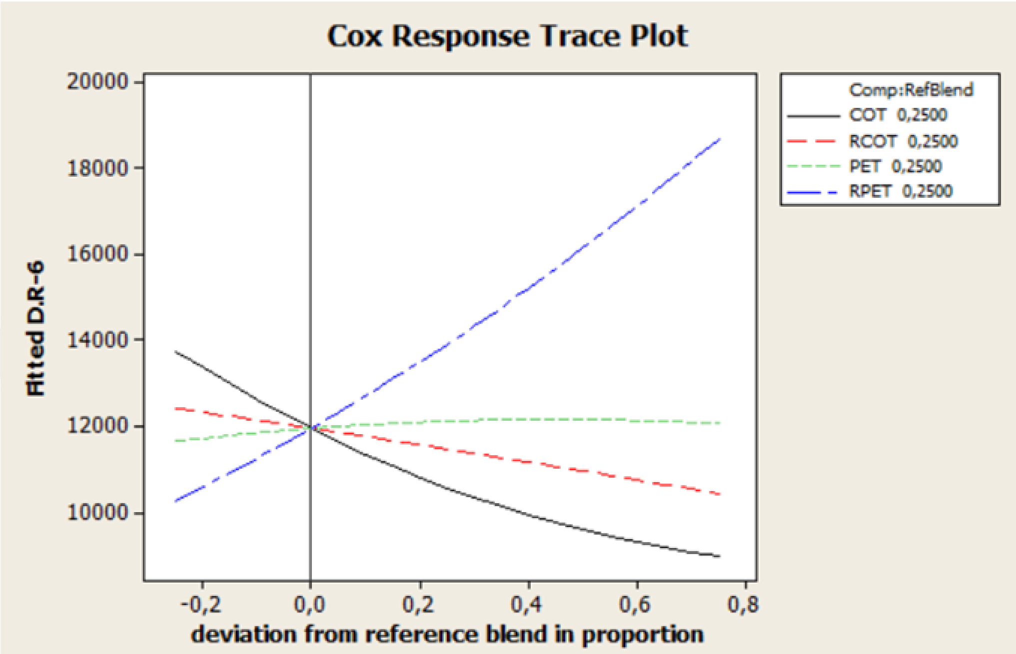

Figure 2.15.8 : Cox response trace plot of Drying Rate of 6th cycle t-shirts.

According to cox response trace plot of 6th cycle of drying rate, it could be stated that recycled polyester's drying rate does not change significantly after 3 more cycles. Increasing amount of polyester does not change drying rate at this cycle, yet drying rate of 6th cycle polyester is 2 times higher than 3rd cycle polyester, so polyester could become more hydrophobic at the end of washing& tumble-drying cycles. Moreover, drying rate of recycled cotton slightly increases between 3-6th cycles, so repeated washing gives a more hydrophobic behavior to recycled cotton.

Cotton & recycled cotton's drying rate is almost same with unwashed ones, so repeated washing & drying cycles did not affect drying rate of cotton, recycled cotton and their blends. Duru & Candan (2013) stated that their cotton-elastane-polyamide blend fabric's drying rate approximately 10% increased after 5 cycles of washing & drying, yet in this master's thesis there is approximately 30-35% increase after 6 cycles of washing & drying, in drying rate of cotton, recycled cotton and their blends.

2.16 Wicking Test

For wicking test, BS 3424-18 standard had been followed.

2.16.1 Horizontal wicking test

Figure 2.16.1.1 : After 6th cycle, horizontal wicking test of Nm 30/1 60% cot 40% pet fabric.

Regression for Mixtures: H.W versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for H.W (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	12,66	0,9405	*	*	1,540
RCOT	15,50	1,3301	*	*	1,160
PET	-10,87	3,6121	*	*	1,180
RPET	4,50	1,3301	*	*	1,160
COT*RCOT	-47,67	6,4153	-7,43	0,085	1,340
COT*RPET	-23,53	6,4153	-3,67	0,169	1,340

S = 1,33008 PRESS = *
R-Sq = 99,05% R-Sq(pred) = *% R-Sq(adj) = 94,29%

Analysis of Variance for H.W (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	184,176	184,176	36,8352	20,82	0,165
Linear	3	73,644	119,803	39,9344	22,57	0,153
Quadratic	2	110,532	110,532	55,2660	31,24	0,126
COT*RCOT	1	86,731	97,691	97,6911	55,22	0,085
COT*RPET	1	23,801	23,801	23,8010	13,45	0,169
Residual Error	1	1,769	1,769	1,7691		
Total	6	185,945				

Figure 2.16.1.2 : The regression analysis of horizontal wicking of unwashed fabrics, from Minitab.

The regression analysis of horizontal wicking of unwashed fabrics indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R- squared values exceed 95% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: H.W-3 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for H.W-3 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	7,40	0,7815	*	*	1,540
RCOT	10,21	1,1052	*	*	1,160
PET	8,92	3,0013	*	*	1,180
RPET	12,15	1,1052	*	*	1,160
COT*RCOT	-33,12	5,3305	-6,21	0,102	1,340
COT*RPET	-2,91	5,3305	-0,55	0,682	1,340

S = 1,10517 PRESS = *
R-Sq = 98,46% R-Sq(pred) = *% R-Sq(adj) = 90,73%

Analysis of Variance for H.W-3 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	77,8513	77,8513	15,5703	12,75	0,209
Linear	3	30,6000	17,4309	5,8103	4,76	0,322
Quadratic	2	47,2513	47,2513	23,6257	19,34	0,159
COT*RCOT	1	46,8864	47,1481	47,1481	38,60	0,102
COT*RPET	1	0,3649	0,3649	0,3649	0,30	0,682
Residual Error	1	1,2214	1,2214	1,2214		
Total	6	79,0727				

Figure 2.16.1.3.: The regression analysis of 3rd cycle of horizontal wicking, from Minitab.

The regression analysis of 3rd cycle of horizontal wicking indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 90% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: H.W-6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for H.W-6 (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	12,72	1,170	*	*	1,540
RCOT	10,84	1,655	*	*	1,160
PET	-0,22	4,494	*	*	1,180
RPET	11,71	1,655	*	*	1,160
COT*RCOT	-41,90	7,982	-5,25	0,120	1,340
COT*RPET	-17,93	7,982	-2,25	0,267	1,340

S = 1,65497 PRESS = *
R-Sq = 97,07% R-Sq(pred) = *% R-Sq(adj) = 82,45%

Analysis of Variance for H.W-6 (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	90,8862	90,8862	18,1772	6,64	0,286
Linear	3	8,7968	18,3359	6,1120	2,23	0,449
Quadratic	2	82,0894	82,0894	41,0447	14,99	0,180
COT*RCOT	1	68,2754	75,4686	75,4686	27,55	0,120
COT*RPET	1	13,8140	13,8140	13,8140	5,04	0,267
Residual Error	1	2,7389	2,7389	2,7389		
Total	6	93,6251				

Figure 2.16.1.4.: The regression analysis of 6th cycle of horizontal wicking, from Minitab.

The regression analysis of 6^{th} cycle of horizontal wicking indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 90% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

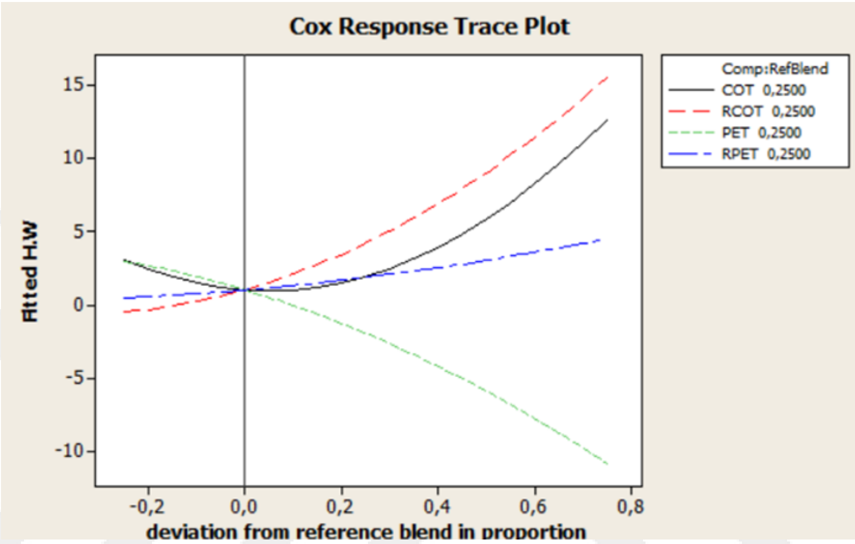

Figure 2.16.1.5.: Cox response trace plot of horizontal wicking of unwashed fabrics.

According to cox response trace plot of horizontal wicking of unwashed fabrics, it could be said that increasing amount of all fibers except conventional polyester, increases horizontal wicking. Cotton fibers naturally absorb and retain moisture through capillary action, allowing water to spread more efficiently across the fabric. In contrast, polyester fibers are hydrophobic, meaning they repel water and do not facilitate the same level of moisture distribution. Additionally, the porous and irregular structure of cotton fibers enhances capillary action, further increasing horizontal wicking efficiency compared to the smoother, less absorbent surface of polyester fibers. According to Chowdhary et al. (2019), the horizontal wicking ability of fabrics may decrease as a result of shrinkage following washing, and this master's thesis had recorded high shrinkage rates for both cotton, recycled cotton and their blends. Furthermore, it can be suggested that utilizing hydrophilic treatments on recycled fibers might enhance their capability to absorb moisture and improve transport efficiency.

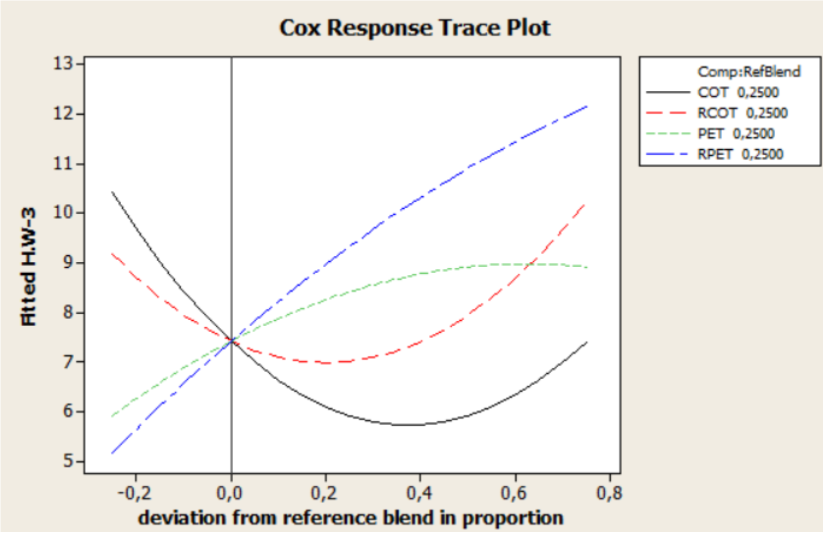

Figure-2.16.1.6.: Cox response trace plot of 3rd cycle of horizontal wicking test.

According to cox response trace plot of 3rd cycle of horizontal wicking test, it could be said that 3 cycles of washing & drying increases horizontal wicking of recycled polyester and conventional polyester, and decreases horizontal wicking of cotton & recycled cotton, so washing makes polyester & recycled polyester more hydrophilic, and also repeated exposure to water causes cotton fibers to expand, which can disrupt capillary pathways and reduce moisture transport efficiency. However, recycled cotton typically retains higher horizontal wicking values than virgin cotton due to its shorter, more fragmented fibers and increased porosity, so that's why recycled cotton's horizontal wicking is higher than natural cotton at 3rd cycle.

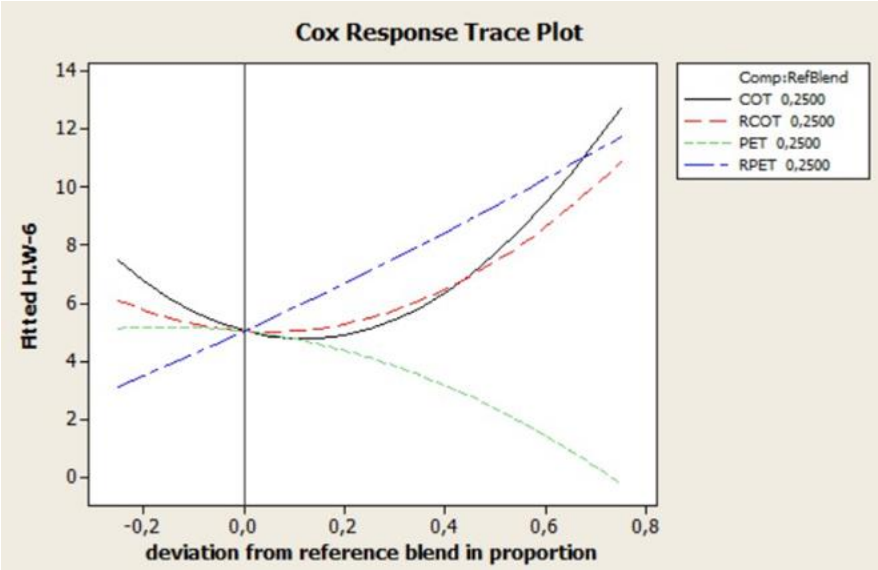

Figure-2.16.1.7.: Cox response trace plot of 6th cycle of horizontal wicking test.

According to cox response trace plot of 6th cycle of horizontal wicking test, it could be stated that cotton &recycled cotton's horizontal wicking become more similar after 6 cycles, also their horizontal wicking values are almost same with unwashed ones. Recycled polyester's horizontal wicking does not change significantly after 3 cycles, and polyester's horizontal wicking lower than 3rd cycle, so it could be stated that after repeated washing & drying cycles, filament yarns could be more prone to permeable than ring spun yarns.

2.16.2 Vertical wicking test

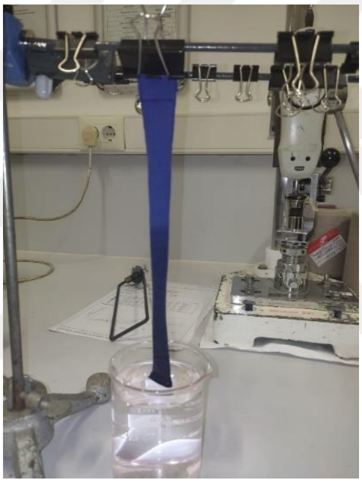

Figure 2.16.2.1: After 6th cycle, vertical wicking test of Nm 20/1 100% rec. cot. fabric.

Regression for Mixtures: V.W - LT versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for V.W - LT (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	0,0736	0,006944	*	*	1,540
RCOT	0,0667	0,009821	*	*	1,160
PET	0,0076	0,026671	*	*	1,180
RPET	0,0567	0,009821	*	*	1,160
COT*RCOT	-0,2535	0,047369	-5,35	0,118	1,340
COT*RPET	0,0063	0,047369	0,13	0,916	1,340

S = 0,00982093 PRESS = *
R-Sq = 96,96% R-Sq(pred) = *% R-Sq(adj) = 81,77%

Analysis of Variance for V.W - LT (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0,003077	0,003077	0,000615	6,38	0,291
Linear	3	0,000244	0,000526	0,000175	1,82	0,488
Quadratic	2	0,002833	0,002833	0,001416	14,69	0,181
COT*RCOT	1	0,002831	0,002762	0,002762	28,63	0,118
COT*RPET	1	0,000002	0,000002	0,000002	0,02	0,916
Residual Error	1	0,000096	0,000096	0,000096		
Total	6	0,003174				

Figure-2.16.2.2.: The regression analysis of long-time vertical wicking, from Minitab.

The regression analysis of long-time vertical wicking indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 90% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

Regression for Mixtures: V.W - LT versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for V.W - LT (component proportions)

Term	Coef	SE Coef	T	P	VIF
COT	0,0736	0,006944	*	*	1,540
RCOT	0,0667	0,009821	*	*	1,160
PET	0,0076	0,026671	*	*	1,180
RPET	0,0567	0,009821	*	*	1,160
COT*RCOT	-0,2535	0,047369	-5,35	0,118	1,340
COT*RPET	0,0063	0,047369	0,13	0,916	1,340

S = 0,00982093   PRESS = *
R-Sq = 96,96%   R-Sq(pred) = *%   R-Sq(adj) = 81,77%

Analysis of Variance for V.W - LT (component proportions)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	0,003077	0,003077	0,000615	6,38	0,291
Linear	3	0,000244	0,000526	0,000175	1,82	0,488
Quadratic	2	0,002833	0,002833	0,001416	14,69	0,181
COT*RCOT	1	0,002831	0,002762	0,002762	28,63	0,118
COT*RPET	1	0,000002	0,000002	0,000002	0,02	0,916
Residual Error	1	0,000096	0,000096	0,000096		
Total	6	0,003174				

Figure 2.16.2.3.: The regression analysis of 3rd cycle of long-time vertical wicking, from Minitab.

The regression analysis of 3rd cycle of long-time vertical wicking indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 90% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

```
Regression for Mixtures: V.W - LT6 versus COT; RCOT; PET; RPET

Estimated Regression Coefficients for V.W - LT6 (component proportions)

Term          Coef   SE Coef       T       P    VIF
COT         0,0849  0,008819       *       *  1,540
RCOT        0,0800  0,012473       *       *  1,160
PET         0,0115  0,033872       *       *  1,180
RPET        0,0233  0,012473       *       *  1,160
COT*RCOT   -0,3433  0,060159   -5,71   0,110  1,340
COT*RPET    0,0636  0,060159    1,06   0,482  1,340


S = 0,0124726    PRESS = *
R-Sq = 97,75%    R-Sq(pred) = *%    R-Sq(adj) = 86,48%


Analysis of Variance for V.W - LT6 (component proportions)

Source           DF    Seq SS    Adj SS    Adj MS      F      P
Regression        5  0,006750  0,006750  0,001350   8,68  0,252
   Linear         3  0,001156  0,002842  0,000947   6,09  0,288
   Quadratic      2  0,005594  0,005594  0,002797  17,98  0,164
     COT*RCOT     1  0,005420  0,005067  0,005067  32,57  0,110
     COT*RPET     1  0,000174  0,000174  0,000174   1,12  0,482
Residual Error    1  0,000156  0,000156  0,000156
Total             6  0,006906
```

Figure 2.16.2.4.: The regression analysis of 6th cycle of long-time vertical wicking, from Minitab.

The regression analysis of 6th cycle of long-time vertical wicking indicates that if the F-value is greater than 1 but the p-value exceeds 0.05, the model is not statistically significant overall. However, given that the R-squared and adjusted R-squared values exceed 90% and the confidence interval is 95%, the model appears to explain a substantial portion of the variance in the dependent variable. The discrepancy between high explanatory power and low statistical significance may indicate issues such as overfitting, multicollinearity, or insufficient sample size.

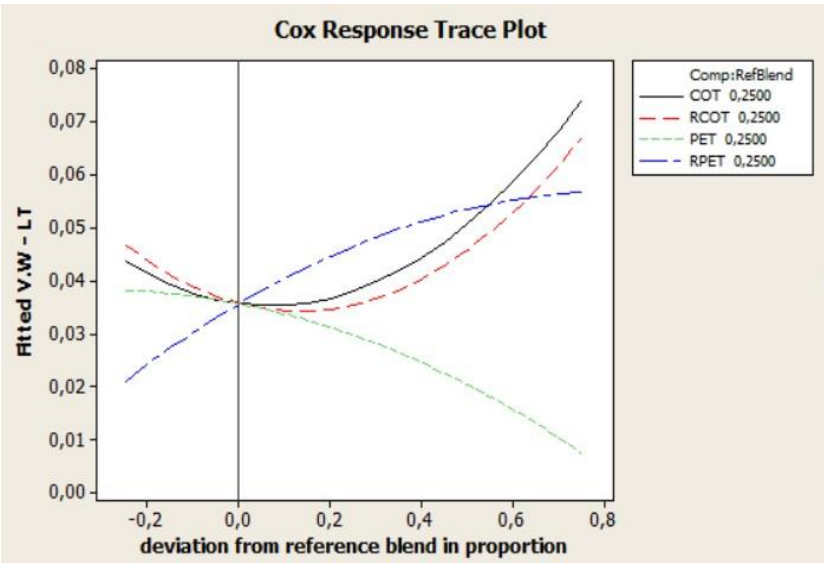

Figure-2.16.2.5.: Cox response plot of vertical wicking of unwashed fabrics.

According to cox response plot of vertical wicking of unwashed fabrics, it could be stated that increasing cotton & recycled cotton increases vertical wicking, and according to results, MCRP, 20C1 and RC have same vertical wicking values, so using recycled cotton or using cotton-recycled polyester blend did not change the vertical vicking enormously. Also, RP's vertical wicking is almost same with cotton & their blends, this could be result from smooth filament yarns in fabric. Lowest vertical wicking belongs to MCRC interestingly, so it is not advised to use MCRC, because it behaves like a polyester fabric. Based on Duru & Candan (2013)'s study, it could be understood that unwashed 20C1, RC, MCRP's vertical wicking value is almost same with their C-D-M fabric, and MCP's vertical wicking is quite similar with their C-D-T fabric, and their fabrics include cotton blends with polyamide and elastane threads. Kumar and Das (2013) indicated that increased vertical wicking in cotton may be due to a reduced machine gauge; therefore, it can be inferred that if cotton and recycled cotton fabrics possess an equal number of loops in the course direction, their vertical wicking results could be similar.

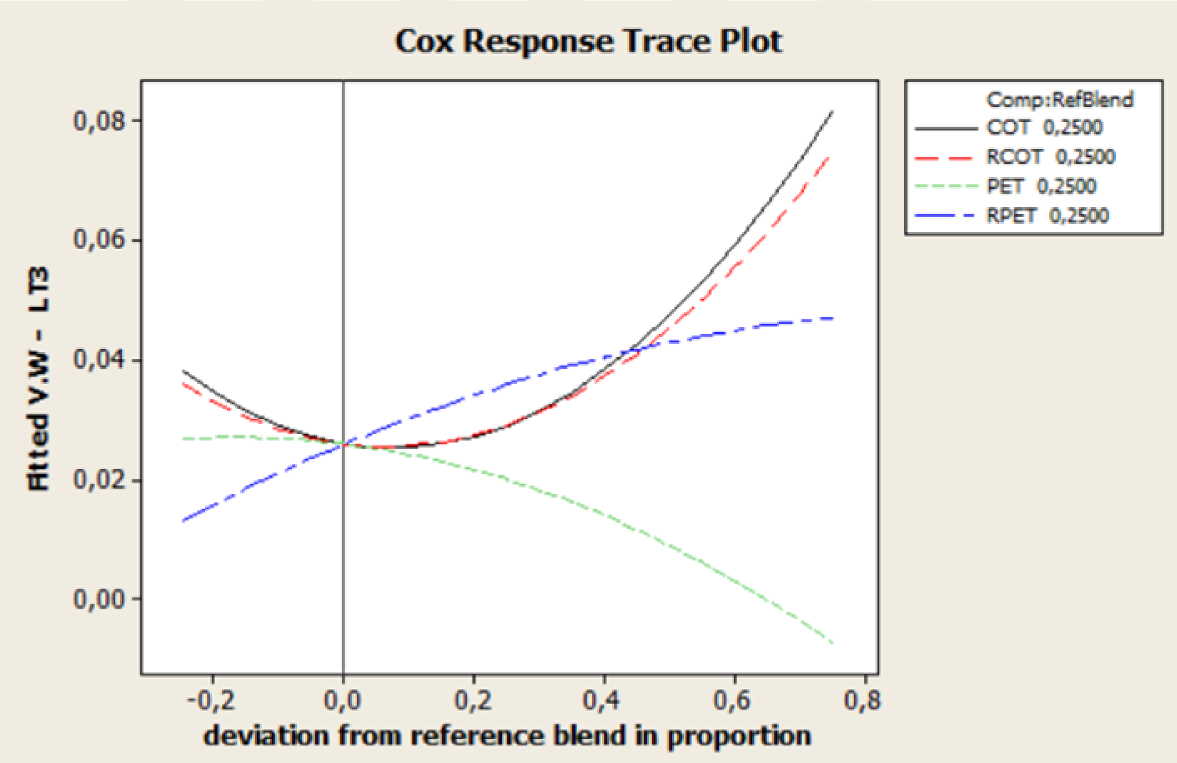

Figure 2.16.2.6.: Cox response trace plot of vertical wicking of 3rd cycle t-shirts.

According to 3rd cycle results of vertical wicking, it could be stated that recycled polyester's vertical wicking is 20% lower than unwashed one and polyester also became more hydrophobic during these 3 cycles, so washing & tumble drying could affect wicking properties of synthetic fibers more adversely. While cotton's vertical wicking increases 14% comparing to unwashed one, recycled cotton's vertical wicking stays almost same with unwashed recycled cotton.

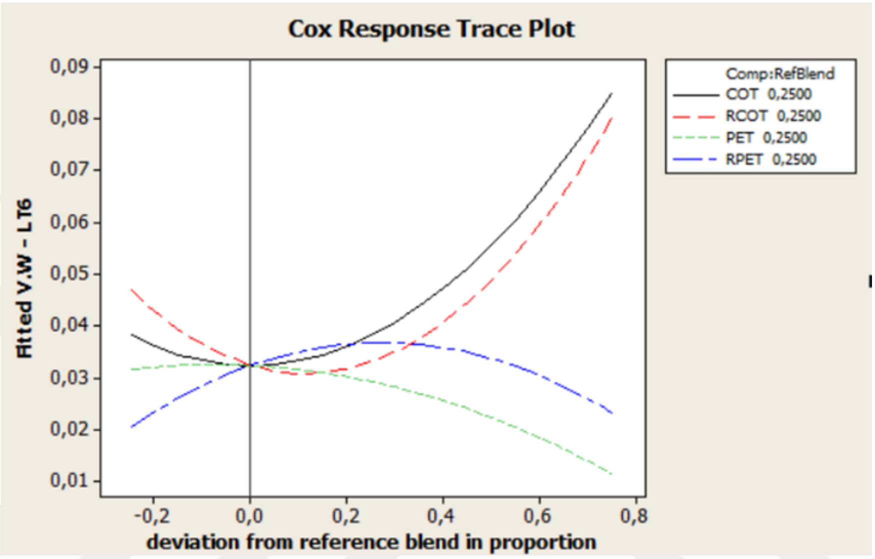

Figure 2.16.2.7.: Cox response trace plot of vertical wicking of 6th cycle t-shirts.

According to 6th cycle results of vertical wicking, it could be said that while cotton's vertical wicking stays same with 3rd cycle results, while recycled cotton's vertical wicking increases approximately 14 % after 3rd cycle, so maybe recycle cotton's water permeability tend to increase more after 3rd cycle, compared to cotton. Recycled polyester's vertical wicking decreases 50% comparing to 3rd cycle, and decreases 60% comparing to unwashed recycled polyester fabric while polyester's vertical wicking remains same with unwashed one, so multiple washing & drying cycles could affect vertical wicking properties of recycled polyester more adversely than virgin polyester. Duru & Candan (2013) made 5 cycles of washing & flat drying, and their vertical wicking results of washed fabrics indicate that RC, 30C1, 20C1 and MCRC fabrics have almost 2 times higher vertical wicking than their cotton-polyamide-elastane blend fabrics, and washed & flat dried C-DW-T has closer vertical wicking with 6th cycle RP, so using elastane and polyamide threads during production of cotton fabrics made the fabric as hydrophobic as recycled polyester.

2.17 DSC Test

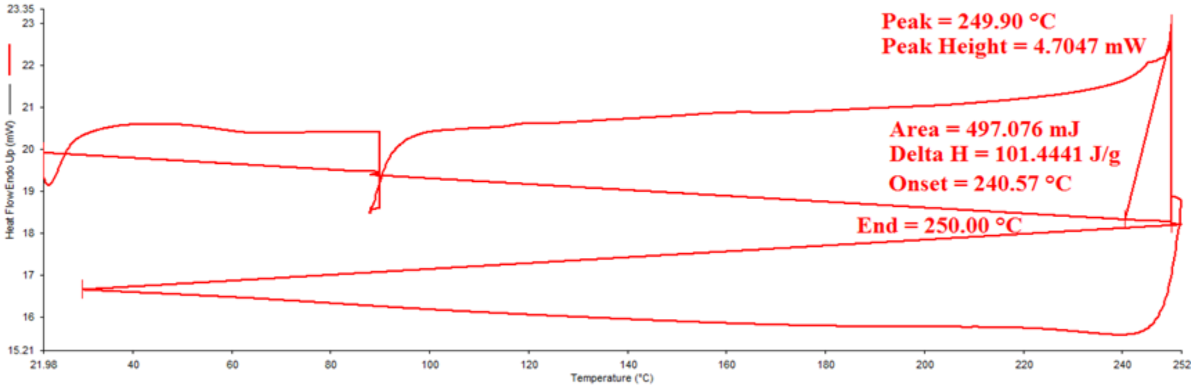

Figure 2.17.1.: DSC test of non-washed 100% recycle polyester fabric.

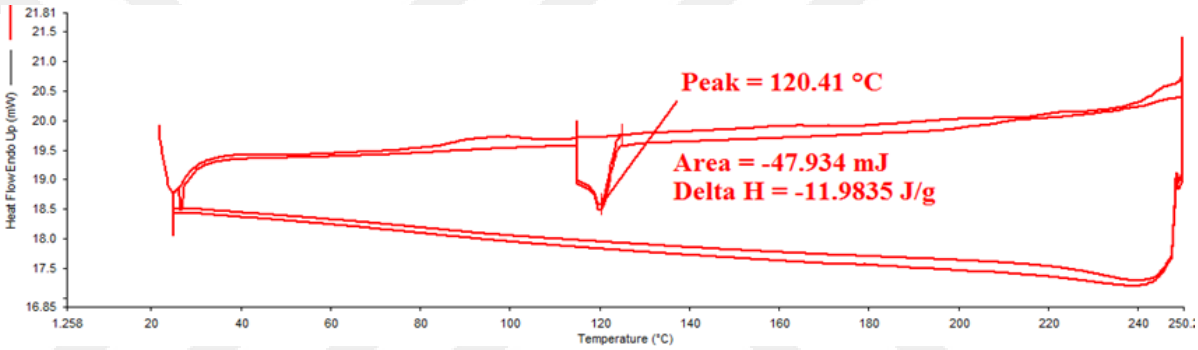

Figure 2.17.2.: DSC test of 100% recycle polyester at 3rd cycle.

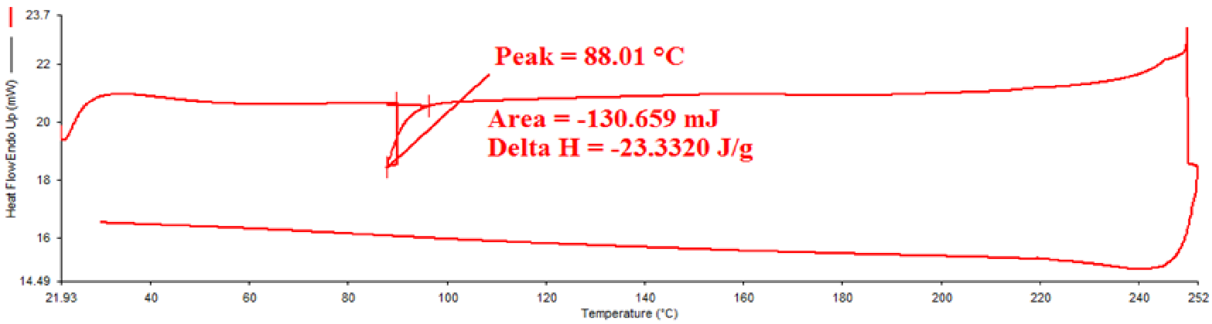

Figure 2.17.3.: DSC test of 100% recycle polyester at 6th cycle.

Based on the relationship between thermophysical properties, L. Šudomová et. al (2023) showed that DSC may be used to differentiate PET materials with varying origins and recycling levels, so in this thesis, DSC Test was used in order to understand thermophysical properties of recycled polyester ideally. According to above figures, it could be said that peak degree in DSC test is becoming lower and lower with multiple washing & drying cycles.

According to Mirjalili & Karimi (2013)'s research, it could be understood that after washing& tumble-drying, RP's Delta H (Enthalpy, J/g) becomes closer to untreated 100 % normal polyester, yet still 2 times higher than normal polyester, which seems an interesting result. Also, 6^{th} cycle RP's enthalpy is almost same with 6^{th} cycle MCP. L. Šudomová et. al (2023) also claimed that products from recycled polyester could have higher peak temperature and enthalphy (J/g) than normal polyester.

2.18 Thermal Comfort (Alambeta) Test Results

Figure 2.18.1: Thermal Conductivity Test from 3^{rd} cycle t-shirts.

For thermal comfort test, ISO 11092 standard had been followed.

2.18.1 Thermal resistance

Based on test results, it could be said that MCP's thermal resistance increases 16% between 0-6^{th} cycles while MCRP's thermal resistance increases 4,5%, so thermal resistance of polyester affected by multiple washing& drying more than recycled polyester.

2.18.2 Thermal conductivity

Based on test results, RP's thermal conductivity 20% increased between unwashed fabric to 6^{th} cycle t-shirt. MCRC's thermal conductivity increased 33% between 0-6^{th} cycles. Thermal conductivity of 20C1 increases 25% between 0-6^{th} cycles while 30C1's thermal conductivity increases 5,5%, so maybe thermal conductivity of cotton fabrics having coarser yarns affected by multiple washing & drying more than fabrics with thinner yarns.

Quality	W.V.P (g/m^2/day)		Seam Strength (N)		Air Permeability (cm^2/s)		Thermal Conductivity (mW/m.K)	
	0^{th} cycle	6th cycle	0^{th} cycle	6^{th} cycle	0^{th} cycle	6^{th} cycle	0^{th} cycle	6th cycle
MCRC	4444,4	5888,9	124,4	121,89	56,30	55,60	36,7	48,3
RC	5666,7	3272,2	186,7	154,27	44,41	55,10	47,9	43,8
MCP	5305,6	6574,3	189,7	177,26	50,10	66,80	44,1	46,1
MCRP	5416,7	6826,5	165,5	189,72	69,70	56,80	37,2	45,8
30C1	4888,9	5472,2	129,7	116,77	58,42	65	47,2	49,8
20C1	4611,1	5538,9	160,1	134,70	58,90	69	43,1	54
RP	4916,7	5735,6	268,8	233,37	135,80	107,23	34	43,4

Table 2.18.1 : Numeric test results of W.V.P, Seam strength, Air Permeability, and Thermal Conductivity, from 0th & 6th cycle.

2.19 Amount of Fiber Release

Figure 2.19.1 : Amount of fiber release of MCRC, at the end of 1^{st} & 6^{th} cycle.

Figure 2.19.2 : Amount of fiber release of RC, at the end of 1^{st} & 6^{th} cycle.

In this test, TS EN 12127 standard had been used to determine fiber weight. Almost all fabrics' fiber release decreased 4 times from 1^{st} cycle to 6^{th} cycle. Nm 20/1 40% preconsumer cot. 60% conv. Cot fabric has the highest fiber release in all cycles while 100% rec. cot has the lowest fiber release. According to the results, it could be said that if recycle cotton did not blend with another fiber, it has better performance compared to other fibers. For blended fabrics with same yarn number, amount of fiber release was quite same, but rec. pes- cot blend fabric has slightly higher fiber release than cot-pes blend fabric in all cycles. Also, even Nm 20/1 100%cot has higher fiber release than Nm 30/1 in all cycles, they have same fiber release on 6^{th} cycle.

3. COMPARISON OF ALL TEST RESULTS

3.1 Best Results of Unwashed Fabrics

Based on best results of unwashed fabrics, it could be pointed out that RC has the highest water comfort and fastness properties while RP has the highest mechanical strength properties. It could be stated that RC has better results than both 100% cotton fabrics and MCRP, so use of RC should be advised.

Figure 3.1.1 : Color of RC at 0^{th}, 3^{rd} and 6^{th} cycle.

3.2 Best Results of 3rd Cycle T-shirts

For 3rd cycle results, it could be concluded that MCRP’s fastness results seem outstanding yet RP has better strength amongst all qualities. Since MCRP had been dried in mixed programme, it could be said that mixed programme could protect fastness properties of cotton-recycled polyester fabrics up to 3 cycles.

3.3 Best Results of 6^{th} Cycle T-shirts

100% recycled polyester has higher better results compared to all qualities, yet if fabric needs better fastness & water comfort properties, than Nm 30 100 % cotton could be advised, but if fabric needs higher strength, than RP could be advised. Since 30C1 dried in cotton-cupboard programme, it could be said that cotton cupboard program in drying machines could protect fastness & water comfort properties of cotton fabrics. Also, if cotton cupboard program uses less time and energy, mechanical strength properties of RP could also protect even after multiple cycles of washing & drying.

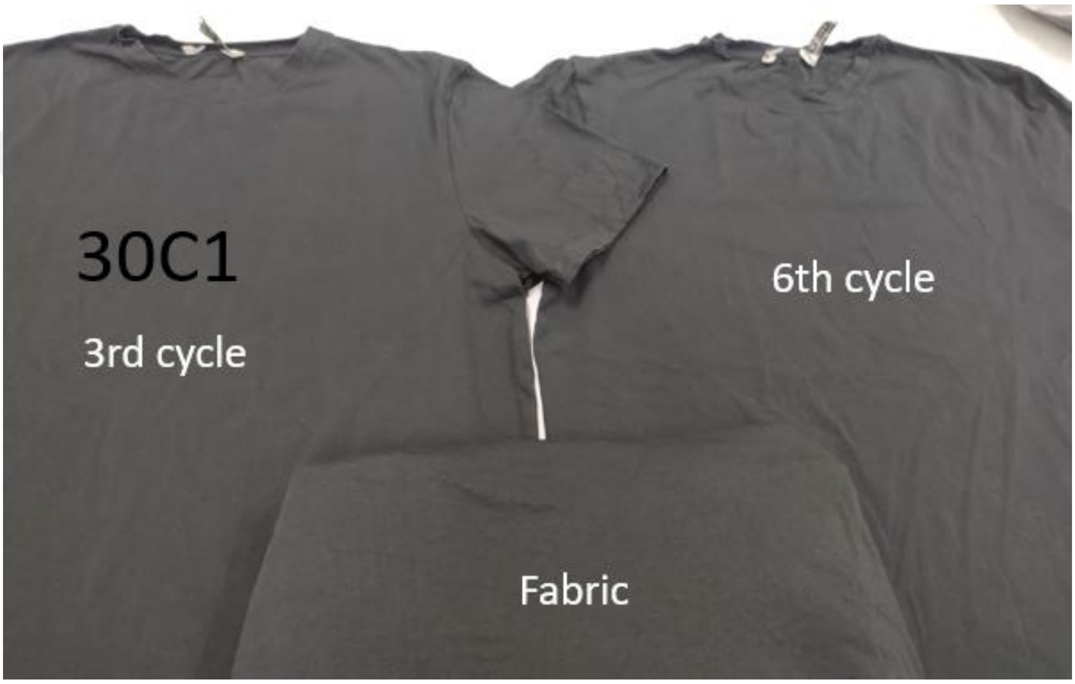

Figure 3.3.1 : Color of 30C1 at 0^{th} , 3^{rd} and 6^{th} cycle.

4. DETERMINATION OF A NEW DRYING ALGORITHM

Quality	Drying time (Minute, cot eco)	Energy amount (WH, cot eco)	Drying time (Minute, Mixed)	Energy amount (WH, Mixed)	Drying time (Minute, cotton cupboard)	Energy amount (WH, cotton cupboard)
MCRC	90	656	-	-	130	967
30C1	90	648	-	-	130	981
RC	90	677	-	-	130	976
20C1	100	693			120	919
MCP	75	566	90	591	-	-
RP	90	771	-	-	70	495
MCRP	70	529	100	592	-	-

Table-4.1.1 : Drying time & energy for all qualities and programs.

In this research, MCP & MCRP dried in karma program, MCRC, 30C1, RC, 20C1, and RP dried in cotton cupboard program during tests. RP actually would be dried in synthetics program but this program was only 30 min, did not dry recycled polyester & it's standards made for cotton-polyester blend fabrics, so a new algorithm made for RP. According to this new algorithm, 60-70 minutes of cotton cupboard or approximately 450-500 WH energy in cotton cupboard will be enough for drying of recycled polyester. After all the textile quality tests were made, drying in cot eco program was also investigated, so all t-shirts were dried in cot eco as well, yet cot-eco dried t-shirts did not tested in lab. According to results, it could be stated that cotton cupboard uses too much time and energy for drying, and excessive drying of cotton, recycled cotton, and their blends could cause decrease in strength and increase in dimensional stability (%), so using this program for recycled cotton probably decreases life span of cloth. Moreover, significant moisture retention was seen in t-shirts processed by the Cot Eco programme, especially on the vicinity of the collar. The weight of the clothes after washing and drying was similar to that of the clothes before washing, but the resulting level of dryness was not high enough to wear directly.

Because the Cot Eco program could not attain full cupboard dryness, it cannot be recommended for drying any type of fabric, even if it uses less energy than the Cotton Cupboard program. On the other hand, the Mixed program effectively reached the required level of dryness while exhibiting better advantages in cycle duration and energy usage when compared to the Cotton Cupboard program. As a result, it is advised that all fabric types could be dried using the Mixed program. Approximately 450–500 Wh of energy is needed to obtain ideal dryness for RP, 550–600 Wh for MCP and MCRP fabrics, and 700–750 Wh for cotton and recycled cotton blends, according to this master's thesis' findings. Therefore, it is expected that drying durations for cotton fabrics can be further decreased without sacrificing fabric quality by altering the settings of the Mixed and Cotton Cupboard programs.

5. CONCLUSIONS AND RECOMMENDATIONS

To conclude, it could be stated that RC could have better fastness results than normal cotton and their blends, and RP could have better fabric strength properties than normal polyester and their blends. Both recycled cotton and recycled polyester perform better in a fabric with single fiber type, their blends could have undesirable fabric properties in terms of textile quality. RC was too thick for a summer cloth, so maybe it could be blend with viscose or tencel to obtain a thinner t-shirt fabric. Also, only RP's stitches opened during seam strength test, in order to get rid of this problem, stitch type, sewing thread type etc. could be modified, also RP could be produced from ring spun yarns instead of filament yarn, and then it could be tested and change in strength could be evaluated & compared. It could be stated that almost all qualities have same test results at 0^{th} & 6^{th} cycle, so even the tumble drying took a lot time, recycled fabrics are not tend to damage adversely. It is also predicted that, with this new drying programme, recycled fabrics could protect their quality properties up to 15 cycles.

In next project, 50% viscose 50% recycled cotton, 50% viscose 50% recycled polyester, 50% tencel 50% recycled polyester, 50% tencel 50% recycled cotton fabrics' quality properties could be tested before & after washing & tumble drying, maybe effect of changing washing temperature could be evaluated or effect of line drying & tumble drying could be compared with above fabrics. Moreover, this new drying algorithm could be also tested with these fabrics, then it could be answered that if this new drying programme dries other fabrics properly, or if this new drying programme protects quality properties of recycled fiber blends with viscose or tencel.

REFERENCES

[1] **Acar Eda, Tama Birkoçak Derya & Ünal Zümrüt** (2023). Evaluation of the performance properties of fabrics containing recycled cotton fibre, ANNALS OF THE UNIVERSITY OF ORADEA, FASCICLE OF TEXTILES, LEATHERWORK.

[2] **Alam, Shafayet & Khan, G. M. & Razzaque, S & Hossain, M. & Haque, Md & Zebsyn, S.** (2008). Dyeing of cotton fabrics with reactive dyes and their physico- chemical properties.

[3] **A. A. Badr et. al.,** (2016). Influence of Tencel/cotton blends on knitted fabric performance, Alexandria Eng. J. (2016), http://dx.doi.org/10.1016/j.aej.2016.02.031

[4] **A.A. Chekdid et al.,** (2021). Mixture design applied for formulation and characterization of vegetal-based fermented products. LWT 146 (2021) 111336. https://doi.org/10.1016/j.lwt.2021.111336

[5] **Sena Cimilli Duru and Cevza Candan** (2013). Effect of repeated laundering on wicking and drying properties of fabrics of seamless garments, Textile Research Journal 83(6) 591–605, DOI: 10.1177/0040517512456754

[6] **Usha Chowdhary, Mohammed Maruf Adnan, Ching I Cheng**. (2019). Pre-Post Washing Comparison for Horizontal Wicking Behaviour of Three Types of Knits in Different Fiber-Contents. J Textile Sci & Fashion Tech. 2(5): 2019. DOI:10.33552/JTSFT.2019.02.000548.

[7] **de Araujo, M. D., and Smith, G. W.,** (1989). Spirality of Knitted Fabrics, Part II: The Effect of Yarn Spinning Technology on Spirality. Textile Research Journal.

[8] **Mazari A, Havelka A, Naeem J, Adamek K.** (2021). Comparative Study on the Water Vapour Permeability of Textile by a Standard and Novel device. FIBRES&TEXTILES in Eastern Europe 2021; 29, 6(150): 59-64.DOI:10.5604/01.3001.0015.2724

[9] **Necef et. al** (2023). INVESTIGATING THE EFFECT OF RECYCLED COTTON INCLUDED FABRICS ON THE THERMAL BEHAVIOUR BY USING A FEMALE THERMAL MANIKIN. AUTEX Research Journal, Vol. 23, No 3, September 2023, DOI 10.2478/aut-2022-0020

[10] **Jamshaid H** (2018). Spirality in Knitted Fabric. J Textile Sci Eng 8: 350. Doi: 10.4172/2165-8064.1000350

[11] **Marmaralı and Sevgi** (2023). Study on the Comfort Properties of Knitted Fabrics Produced from Conventional and Sustainable Cotton and Polyester Fibres. Tekstilec, 2023, Vol. 66(4), 339–350

[12] **Uyanık, S., and Kaya Nacarkahya, T.** (2024). "Evaluation of the Bursting Strength and Pilling Properties of Knitted Fabrics Produced from Recycled Yarns with Cotton Hard Waste." ASTM International. J. Test. Eval. September 2024; 52(5): 2936–2948. https://doi.org/10.1520/JTE20230376

[13] **Uttam & Sethi** (2016), IMPACT OF REPEATED WASHINGS ON DIMENSIONAL STABILITY AND FABRIC PHYSICAL FACTORS OF WOVEN COTTON FABRIC. International Journal of Research in Engineering &Applied Sciences.

[14] **P Ramasubramaniam and Chezliyan N L,** (2019). A study on the impact of spirality on various knitted fabrics. IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 6 Issue 11, November 2019.

[15] **Grosberg & Swani,** (1966). The Mechanical Properties of Woven Fabrics, Part III:The Buckling of Woven Fabrics, Textile Research Journal. Doi:10.1177/004051756603600405.

[16] **Hu. J.** (2008). Fabric Testing, Woodhead Publishing, England, ISBN: 9781845692971.

[17] **Sari et. al.** (2024). Analysing the effect of mechanically recycled cotton fibres from pre- consumer wastes on mechanical and fastness properties of knitted fabrics. International Journal of Clothing Science and Technology © Emerald Publishing Limited 0955-6222. DOI 10.1108/IJCST-03-2024-0059

[18] **Koçak ED, Aksaman MS, Ateş M, et al.** (2024). The effect of recycled fiber content on performance/quality properties of swimwear fabrics. DOI: 10.15406/jteft.2024.10.00368

[19] **Uyanık Seval,** (2021). The bursting strength properties of knitted fabrics containing recycledpolyester fiber, THE JOURNAL OF THE TEXTILE INSTITUTE 2021, VOL. 112, NO. 12, 1998–2003. https://doi.org/10.1080/00405000.2020.1862490

[20] **B. Kumar* and A. Das,** (2014). Vertical Wicking Behaviour of Knitted Fabrics, Fibers and Polymers 2014, Vol.15, No.3, 625-631, DOI: 10.1007/s12221-014-0625-x

[21] **Alp, G., Yıldırım, N., Kertmen, M., Türksoy, H.G.** (2023). Investigation of Performance Properties of Denim Fabrics Produced from Recycled Cotton Blended Yarns, DEUFMD, 25(74), 275-285. DOI:10.21205/deufmd.2023257402

[22] **Oğuz Demiryürek*, İnci Güleyüpoğlu** and Eda Turhan*** (2019). Effects of Repeated Laundering on Thermal Comfort Properties of Cellulosic Knitted Fabrics, Cellulose Chem. Technol., 53 (7-8), 795-803(2019).

[23] **L. Šudomová et al.** (2023), A differential scanning calorimetry (DSC) approach for assessing the quality of polyethylene terephthalate (PET) waste for physical recycling: a proof-of-concept study, Journal of Thermal Analysis and Calorimetry (2023) 148:10843–10855.

[24] **Mohammad Mirjalili & Loghman Karimi** (2013): The impact of nitrogen low temperature plasma treatment upon the physical–chemical properties of polyester fabric, Journal of The Textile Institute, 104:1, 98-107.

[25] **Xinchen Yu & Xuemei Ding,** (2023). Investigation on polyester woven fabric damage by tumble drying, Drying Technology, 41:14, 2258-2268, DOI:10.1080/07373937.2023.2232442.

[26] **Yılmaz & Keleş,** (2024). A Comparative Study of Cotton/PES Knitted Fabrics Produced from Recycled Fiber-Based and Virgin Yarns, Fibers and Polymers (2024) 25:4951– 4963. https://doi.org/10.1007/s12221-024-00780-5

[27] **Yılmaz & Keleş,** (2023). Effects of Recycled Fiber Usage and Laundering Processes on the Performance Properties of Knitted Fabrics. Fibers and Polymers (2023) 24:1503– 1516. https://doi.org/10.1007/s12221-023-00128-5

[28] **Yilmaz, Fulya & Tetik, Gamze & Celep, Gizem.** (2022). Abrasion resistance of Denim Fabrics from Virgin and Recycled Cotton Yarns.

[29] **B. Utebay et al.,** (2024). Effects of finishing processes on physical properties of knitted fabrics produced by recycled cotton fibers. Journal of Cleaner Production 476. https://doi.org/10.1016/j.jclepro.2024.143800

CURRICULUM VITAE

Name Surname : **Bilge Melikoğlu**

EDUCATION :

- **B.Sc.** : 2022, Istanbul Technical University, Faculty of Textile Technologies and Design, Department of Textile Engineering
- **M.Sc.** : 2025, Istanbul Technical University, Faculty of Textile Technologies and Design, Department of Textile Engineering

PUBLICATIONS, PRESENTATIONS AND PATENTS ON THE THESIS:

Bilge Melikoğlu, Umut Kıvanç Şahin, Onur Ercan and Tayfun Güven (2025). ‘The Effect of Washing on the Water Comfort Properties of Cotton and Recycled Cotton Knitted Fabrics’ (2025), 7th INTERNATIONAL CONFERENCE ON NATURAL FIBERS (ICNF-2025).