JULY 2019 M.Sc. In Textile Engineering ŞEBNEM SÖZCÜ

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

THE PRODUCTION OF BCF YARN AND MACHINE CARPET FROM RECYCLED POLYPROPYLENE PELLETS

M.Sc. THESIS

IN

TEXTILE ENGINEERING

BY

ŞEBNEM SÖZCÜ

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Prof. Dr. Cem GÜNEŞOĞLU

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July 2019

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REPUBLIC OF TURKEY
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
TEXTILE ENGINEERING DEPARTMENT

Name of the Thesis : The Production Of BCF Yarn And Machine Carpet From Recycled Polypropylene Pellets

Name of the Student : Şebnem SÖZCÜ

Exam Date : 10.07.2019

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I declare that the thesis is written in accordance with academic and ethical rules and that all the literature information used is included in the thesis with reference.

Şebnem SÖZCÜ

ABSTRACT

THE PRODUCTION OF BCF YARN AND MACHINE CARPET FROM RECYCLED POLYPROPYLENE PELLETS

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M. Sc. in Textile Engineering

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July 2019

46 pages

Polypropylene (PP) is a polyolefin class fiber known as its low density, low thermal conductivity, very low moisture absorption, good abrasion resistance, power contamination and wool-like properties. The most common use of Polypropylene fiber is production of BCF (Bulk Continuous Filament) yarns for use as loop yarn in machine carpets. Despite its various advantages, PP raw material is imported from abroad. PP yarn coils used as pile yarn in carpet weaving are separated from waste by leaving a certain amount of yarn on loom and BCF carpet yarn is collected together with wastes produced during production. Decomposed wastes are recycled using different sectors subject to recycling operations. Our main aim with this study is to re-evaluate PP yarn wastes obtained from commercially imported PP raw materials, to prevent economic loss and to reduce environmental impacts of production process. With the thesis, reuse of wastes in carpet sector has emerged and mechanical recycling process is applied on waste PP yarns and PP yarns containing recycling additive have been produced. Yarn production was made by changing spin shape (cross-sectional area of yarn) and number of filaments; thus, it was observed whether machine parameters were effective alongside recycling additive ratios. Yarns obtained from recycled polypropylene waste were subjected to mechanical yarn tests and compared with standard polypropylene yarn properties. At the end of study, carpet production was made in order to observe the effect of recycled PP yarns on carpet and compared with standard polypropylene carpet test values.

Keywords: BCF Carpet Yarn, Machine Carpet, Polypropylene, Recycling Technology, Polypropylene Waste.

ÖZET

GERİ DÖNÜŞTÜRÜLMÜŞ POLİPROPİLEN CİPSLERİNDEN BCF İPLİK VE MAKİNE HALISI ÜRETİMİ

SÖZCÜ, Şebnem

Yüksek Lisans Tezi, Tekstil Mühendisliği Bölümü

Tez Danışmanı: Prof. Dr. Cem GÜNEŞOĞLU

Temmuz 2019

46 sayfa

Polipropilen (PP), düşük yoğunluk, düşük termal iletkenlik, çok düşük nem emilimi, iyi aşınma dayanımı, güç kirlenme ve yün benzeri tutum özellikleriyle bilinen poliolefin sınıfı bir liftir. PP lifinin en yaygın kullanım alanı, makine halılarında ilmek ipliği olarak kullanmak üzere BCF (Bulk Continuous Filament (Hacimli Sürekli Filament)) iplik üretimidir. Çeşitli avantajlarına karşın PP ham maddesi yurt dışından ithal edilmektedir. Halı dokumasında hav ipliği olarak kullanılan PP iplik bobinleri tezgâh üzerinden belirli metrajda iplik bırakılarak telefe ayrılarak, BCF halı ipliği üretim esnasında ortaya çıkan telefler ile birlikte toplanmaktadır. Ayrıştırılan telefler geri dönüşüm işlemlerine tabi olarak farklı sektörlerde kullanılarak yeniden değerlendirilmektedir. Bu çalışma ile ana hedefimiz ticari olarak ithal edilen PP ham maddesinden elde edilen PP iplik teleflerini yeniden değerlendirmek, ekonomik kaybın önüne geçmek, üretim sürecinin çevresel etkilerini azaltmaktır. Tez çalışması ile halı sektöründe teleflerin yeniden kullanımı ortaya çıkmış ve telef PP iplikler üzerine mekanik geri dönüşüm işlemi uygulanarak geri dönüşüm katkı maddesi içeren PP iplik üretimleri gerçekleştirilmiştir. İplik üretimleri, düze şekli (ipliğin kesit alanı) ve filament sayısı değiştirilerek yapılmış; böylece geri dönüşüm katkı maddesi oranlarının yanında, makine parametrelerinin de etkili olup olmadığı gözlenmiştir. Geri dönüştürülmüş polipropilen teleflerinden elde edilen ipliklere mekanik iplik testleri yapılarak, standart polipropilen iplik özellikleri ile karşılaştırılmıştır. Çalışma sonunda, geri dönüştürülmüş PP ipliklerin halı üzerindeki etkisini de gözlemlemek için halı üretimleri yapılarak, standart polipropilen halı test değerleri ile karşılaştırılmıştır.

Anahtar Kelimeler: BCF Halı İpliği, Makine Halısı, Polipropilen, Geri Dönüşüm Teknolojisi, Polipropilen Telef.

To my mother and sister…

ACKNOWLEDGEMENTS

The sample production of this thesis was made by Gaziantep Kartal Halı Tekstil BCF Yarn Production and Carpet Weaving Enterprises. Carpet and yarn tests were performed at Gaziantep University and Kartal Halı Tekstil BCF Yarn Laboratory, respectively.

I would like to endless thank my dear supervisor Professor Dr. Cem Güneşoğlu, who showed me the greatest support from the beginning to the end of the thesis, who guided and did not hesitate to share his knowledge.

I would like to thank to my research assistant Serap Gamze Serdar and Hatice İbili as well who helped me in the laboratory studies and evaluation of test results at Gaziantep University.

Also I would like to thank Volkan Balcı, the manager of Research and Development Center in Kartal Halı Tekstil, for his interest and assistance during my thesis. I would like to thank Hacı Binici, BCF Yarn Production Chief, Mustafa Yılmaz, and BCF Yarn Production Quality Control Officers Hayri Öfkeli and Harun Deniz for their technical support and knowledge during the production of my thesis. I would like to thank my friends Azin Rakhtshah, Emine Çot, Deniz Akgün, Azize İnce, Mehmet Şakir Erboz, Fatma Yalçınkaya and Ayşegül Gündüz who have always been with me in the preparation of my thesis.

I would like to thank my family, my precious mother Nilgün Sözcü and my sister Esra Sezişli, who have always trusted, and supported me from the moment I started my thesis until the end.

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LIST OF ABBREVIATIONS

PP	Polypropylene
BCF	Bulk Continuous Filament
PVC	Polyvinyl Chloride
V-PP	Virgin Polypropylene
R-PP	Recycled Polypropylene
PE	Polyethylene
POY	Partially Oriented Yarns
FOY	Fully Oriented Yarns
ISO	International Organization For Standardization
UNEP	United Nations Environment Program
LDPE	Low Density Polyethylene
Tg	Glass Transition Temperature
HDPE	High Density Polyethylene
PC	Polycarbonat
PBT	Polybutylene Terephthalate
PAI	Polyamide-Imide
PET	Polyethylene Terephthalate
PA	Polyamide
RCS	Recycled Claim Standard
MFI	Melt Flow Index
DIN	Deutsches Institut Für Normung
ASTM	American Society For Testing And Materials
EN	European Norm
TS	Turkish Standard

AATCC	American Association Of Textile Chemists And Colorists
CIE	Commission Internationale de l'Eclairage
CIE Lab	Formula defined by CIE
L*	Lightness/Darkness
a*	Red/Green
b*	Yellow/Blue
DL*	(Delta) Difference in lightness/darkness value
Da*	Difference on red/green axis
Db*	Difference on yellow/blue axis
DE	Total difference in color value
BS	British Standard
TSE	Turkish Standard Institute
MD	Machine direction
CD	Cross direction
CRI	Carpet Rug Instutition
%R	Reflectance

CHAPTER 1

INTRODUCTION

1.1 Introduction

Consumption and environmental problems continue to increase with population growth in the world. Due to the increasing environmental problems and resulting in wastes, different industrial and societal studies have been carried out recently to reduce the harmful effects emitted by many types of products and materials, and to sustainability (or recycling) [1]. The studies focused on recycling and sustainability as seen in demand in all areas; also in the textile industry is of considerable importance. Textile recycling industry is one of the oldest industries in the world; however, very few people have understood the recycling industry, its numerous players and generally recycled textile products worldwide have used recycled textile and garment products as recycled and introduced them to new uses [2]. In addition to clothing, the textile industry has evolved into a global $ 1 trillion sector of home textiles (furniture, bedding, linens, curtains, cleaning materials), entertainment materials, electronics, automotive - aerospace components and many other materials such as polymers (especially plastics) [3, 4]. Improving the environmental performance of the textile industry is very important as the production of textiles and garments worldwide is over 80 million tons per year [5].

The textile industry has a long history of being dissatisfied with its resources and a significant amount of waste is produced each year. Commercially, the generation of textile waste is affected by the amount of production of textile products which results in amount of waste. This situation, which is economically affected, it is also faced by consumer demand [6].

Today, the consumption of synthetic polymers has also increased rapidly. The reason is that, these materials have many advantageous properties than other materials, including glass, metals, ceramics and wood, such as being light in weight, resistant to various chemicals and the surrounding atmosphere. Furthermore, they can be easily processed with the desired products by many methods [2]. However, polymer production has always been combined with the next stage, revealing the need for further use of waste generated after consumption. The slow development in the field of recycling creates a serious problem; tens of millions of tons of polymeric material that are discarded each year. These wastes cause ecological problems as well as social problems. Recycling has been the center of attention due to the accumulation of waste in landfills, low sustainability, increased cost and reduced space. Furthermore, the unsustainable methods lead to the exclusion of a significant amount of material from the economic cycle. Therefore, recycling can not only solve the existing warehouse problem but also the first two ecologically occurring problems, but on the other hand, recycling can also be very useful economically affecting the market price of waste plastics due to its low starting materials currently [7].

Currently, the added value created by recycling is also quite low; as a result, the large quantities of used plastic and synthetic textiles can only partially be recycled to the economic cycle. In addition, unlike metals and ceramics, the recycling of polymers is now largely impossible to avoid loss of some of its properties. On the other hand, this means in no way can the quality of products be made from recycled polymers and also increased to the desired level [8].

In the future, the bulk viscosities of used polymers may be an important source of raw materials for the production of plastics and textile products, monomer for the synthesis of other polymers, as well as fuel and energy production.

Although polyester is more popular in polymer recycling, polypropylene is used extensively by carpet manufacturers. A province with the highest production capacity in Turkey carpets with annual production of about 450.447.680 m^2 of carpet made in Gaziantep [9], and also in the production of polypropylene annually consumes 366.100 tonnes [10].

With the increasing usage of polymers, the need for imports increases. In order to reduce the importation and to allow the re-evaluation of the polymers, to decrease the environmental impacts of the production process and to prevent economic loss, a thesis was initiated to recycle polypropylene yarns.

1.2 Objective of the Study

In this thesis, polypropylene yarns separated from BCF carpet yarn production and carpet looms are recycled, mixed with virgin polypropylene (V-PP) and recycled polypropylene (R-PP) granules and re-used as pile yarn in carpet. Waste polypropylene yarns were converted into granular form by mechanical recycling method. Following the recycling process, V-PP and R-PP were mixed with 5% recycled polypropylene in different proportions, fiber sections and filament counts were produced. Different cross-sectional shapes and filament numbers were tested in order to determine the changes in the opacity of the yarns containing the recycling additive and to observe the effective parameter.

After the yarn production, carpet production was also realized and the effects of recycled PP yarns and changed parameters on the carpet were examined.

Finally, by determining the appropriate parameters, it was possible to produce standard carpet from R-PP yarns.

1.3 Structure of Thesis

Chapter 2 contains literature surveys for the study. In this chapter, polypropylene production, polypropylene yarns production, overview of recycling methods, recycling methods in textile, applications and information about the importance is given. Chapter 3 discusses the classification and recycling of polypropylene yarns separated from weaving and BCF production units in Kartal Halı Tekstil, the production of polypropylene yarns containing recycle granules and the production of recycled polypropylene yarns. Chapter 4 consists of mechanical yarn tests applied to yarns produced with recycling additives, and the results and evaluation of mechanical carpet tests were applied to carpets produced from recycled yarns. The thesis is concluded in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Production of Polypropylene

Polypropylene, consisting of hydrogen and carbon atoms, was discovered in 1954 by the experimental studies of propylene and ethylene, collaboration between Italian chemist Guilio Natta and his assistant Paulo Chini's Italian company Montecatini. The catalyst type was discovered by German chemist Karl Ziegler and used for the production of polyethylene (PE) at ambient pressure. Polypropylene started commercial production in 1957 with Hercules Incorporated, Montecatini and Farbwerke Hoechst. In 1963, Ziegler and Natta received the Nobel Prize in Chemistry. Accepted as 'Ziegler and Natta' catalyst, Ziegler and Natta studies were awarded the Nobel Prize in Chemistry in 1963 [11]. After 2001, Polypropylene became the sole thermoplastic material by replacing PVC (polyvinyl chloride).

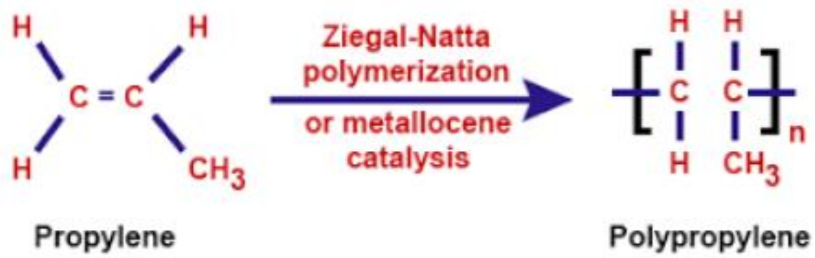

Figure 2. 1 Monomer to polymer scheme of polypropylene [12].

2.2 Production of Polypropylene Fibers

Polypropylene fibers are produced by melt extrusion from PP granules. The granular PP polymers melted in the extruder at temperatures of about 200-240 ^{o}C are conveyed to the draft zone by means of a screw pump system. The polymer transmitted by melting through the draft zone is drawn from the nozzles of desired thickness and cross- section. Filaments that crystallize through the cooling unit are given strength at this stage and filaments drawn from each pore of the spinning nozzle processed together by means of drafting rollers. In the last stage, stretching – drawing process is applied to give flexibility and strength to PP filaments [13]. The extrusion step of the PP yarn is separated according to the desired yarn type and the application area of the yarn. There are different processes for multifilament yarn, monofilament yarn, staple yarn, strip and nonwoven production. These are briefly mentioned as follows:

Multifilament PP yarn: produced in a variety of shapes, such as partially oriented yarns (POY), fully oriented yarns (FOY) and BCF yarns.

The cost of the POY process is low. In addition, higher flexibility is provided in subsequent stages such as drafting (stretching of filaments), twist and texturing. POY yarns are usually produced at a linear density of 40-200 dtex and 0.5-4.0 dtex for each filament linear density. The most important feature of the POY stage is the length of the cooling unit through which the filaments pass after melt spinning from the spinning nozzle. Before winding the multifilaments into coils, the cooling unit length can be up to 10 m to ensure adequate cooling of each filament at the high production speeds used. The average winding speed is 2000-3000 m / min. POY yarns are then processed by spinning and possibly subjected to spinning and texturing.

With the production of FOY yarn, the spinning and drafting patterns are an integral part of the ongoing process. The FOY process is very versatile, depending on the control settings used and the PP grade, a wide range of different mechanical yarns can be produced. Final winding speed is over 5000 m / min. Both the linear density of each filament of high tenacity yarns is 5-10 dtex for technical fabrics, and the linear density of standard yarns is 1-2 dtex per filament and is produced by FOY process for more conventional applications. Compared to the yarns produced by the POY process, FOY yarns are more durable. POY yarns can be drawn even after production.

BCF process combines spinning, drawing and texturing in a single method. Filament production speeds at about 1500-4000 m / min. Except for the filaments textured after drafting; BCF is similar to FOY production [14].

2.3 Properties of Polypropylene Fibers

In common with other synthetic fibers, the properties of PP fibers are influenced by a number of factors:

- PP grade used in fiber formation
- Fiber processing conditions
- Available additives.

PP fibers are highly resistant to chemical attack by acids, alkalis and most organic liquids. The fibers are swollen at high temperatures by some organic liquids and can be dissolved even if the temperature is high enough. The fibers are also sensitive to the effect of strong oxidants, such as hydrogen peroxide, which reduces hydrogen power and causes discoloration. In addition, PP fibers are attenuated by ultraviolet radiation, so that the commercial PP fibers contain light stabilizers. Fibers are not degraded by microorganisms [14].

2.4 Recycling and Its Importance

Recycling, with advocates recorded up to Plato in 400 B.C., has been a common practice for most of human history. In times of scarce resources, archaeological studies of old waste dumps show less household waste (such as ash, broken tools and pottery); in the absence of new material, the studies shows that more waste is recycled.

The depletion of natural resources and the associated waste production are associated with unsustainable human attitudes and behaviors. However, understanding the thought processes and activities behind waste generation can provide new insights into how to prevent waste, including resource conservation efforts, without dramatic changes in human behavior and lifestyles. Waste generation is a complex issue for confronting local, national and international governments. While management may require the integration of interdisciplinary worldviews, its understanding can be further improved by various socio-cultural perspectives. As a result, many studies have been conducted in the field of waste management, most of which focused on the socio-demographic and psychological aspects of waste generation and management. The findings of these studies have inspired different environmental policies, including the legal frameworks that initiated the design of many waste management strategies in the world [15]. Accordingly, there are several ISO (International Organization for Standardization) standards for recycling, such as ISO 15270: 2008 for plastic waste and ISO 14001: 2004 for environmental management control of recycling practices [16].

2.4.1 Textile Recycling

Textile recycling processes have been available for a long time but have been greatly influenced by factors limiting the ability to integrate into economically viable processes, such as high prices and the availability of raw materials. Processes such as re-spinning of post-production and post-consumer materials, pulping of cotton and linen into paper pulp, and production of nonwoven materials have been associated with the diversification of these types of processes - variations. Recently, due to an increasing awareness of the impacts of the textile industry's existing linear supply chain, great attention has been paid to increasing the reuse and recycling of textile products, especially to further improve textile recycling processes. Re-use refers to the use of the product in its original form; recycling is expressed as the conversion of waste into product [17].

Textile re-use refers to various means to extend the practical service life of textile products by extending them to new owners (Fortuna and Diyamandoglu, 2017), without prior making change or modification (eg, repair). This can be done, for example, by renting, exchanging, borrowing and taking over, facilitated by second hand stores, flea markets, garage sales, online markets, charities and clothing libraries. In the academic literature, various forms of re-use such as cooperative consumption, product-service systems, commercial sharing systems and access-based consumption have been conceptualized (Belk, 2014).

On the other hand, textile recycling most often refers to the reprocessing of pre- or post-consumer textile waste for use in new textiles or non-textile products [18]. It is important to use sustainable materials and production methods in order to solve the problem of increasing consumption rate of natural resources in textile and garment sector which is one of the most polluting industries in the world. For this purpose, instead of the conventional linear material flow, the cyclic material flow should be adopted and the use of recycled fibers should be directed [5].

Figure 2.2 shows the change in total fiber production in the world over the years and the trend for the future. In the estimation made until 2025, total fiber production is projected to increase by 3.7% every year [19].

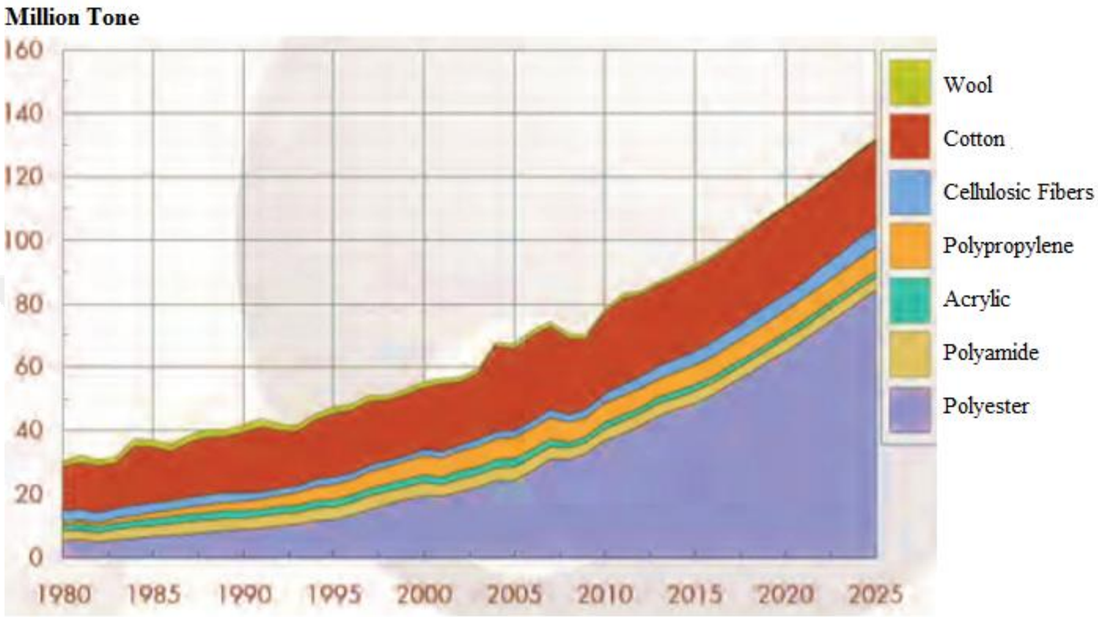

Figure 2. 2 Total fiber production changes over the years **[**19]

In 2014, fiber consumption in the world amounted to 89.4 million tons, a large part of which consists of synthetic fibers. The proportional distribution of fibers in the global fiber market in 2014 is given in Figure 2.3.

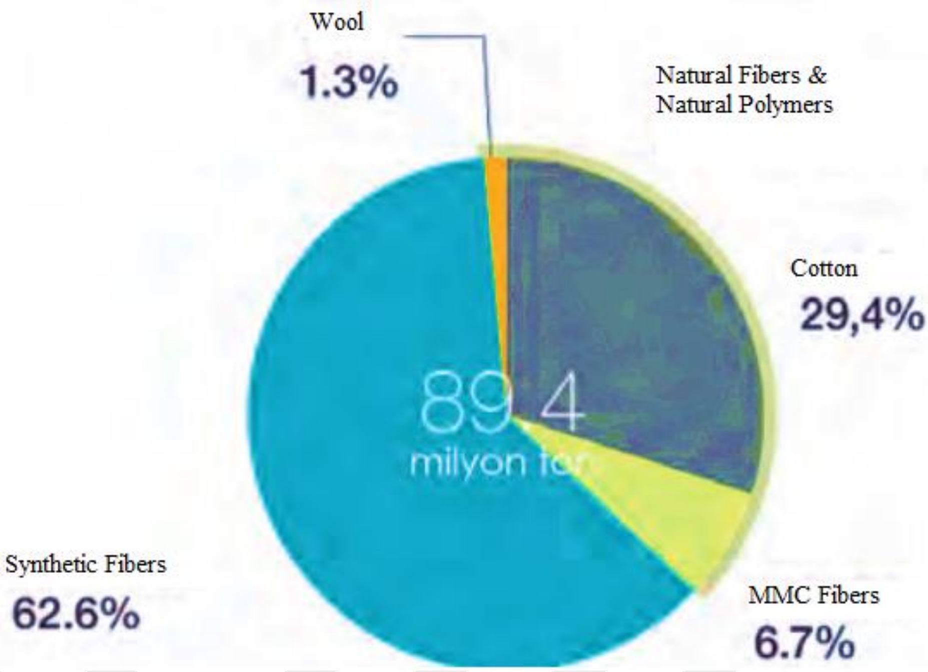

Figure 2. 3 Global fiber market 2014

When we look at the world market, we can see that polyester is a synthetic fiber and cotton is a natural fiber. As of 2014, 63% of the world fiber production is synthetic fibers, 82% of which is polyester fibers. Cotton is the second most important fiber and has a ratio of 29% among all fibers. The demand for polyester has doubled in recent years and has replaced cotton, the most widely used fiber for many years. By 2025, while the production of cotton fibers remained constant, it was predicted that polyester fiber production would increase and would be 3 times more than cotton production in order to meet the increasing fiber demand.

The main raw material source for synthetic polymers is petroleum. In the production of renewable natural fibers such as cotton, energy and chemicals based on non-renewable resources are also needed. It is very difficult to say which type of fiber is more environmentally friendly because each fiber has its own environmental burden. Some fibers cause high consumption of natural resources during fiber production and others during textile production processes. Although some fibers are obtained from edible sources, they cannot be recovered; some fibers are produced from non-renewable sources but can easily be recycled into high quality products [20].

Adequate use of natural resources is of great importance for sustainable living, and the rate of natural resource formation and consumption needs to be consistent with sustainability. In its 2011 report, the United Nations Environment Program (UNEP) foresees that by 2050, the natural resource consumption rate will be three times faster than the current consumption rate [21]. It is important to use sustainable materials and production methods in order to solve this problem which is one of the most polluting industries in the world. For this purpose, instead of the conventional linear material flow, the cyclical material flow should be adopted and the use of recycled fibers should be directed.

2.4.2 Recycling of Plastic Based Materials

Due to the ideal properties of thermoplastic polymers such as corrosion resistance, low density, high strength and user-friendly design, the use of plastics rather than the use of aluminum or other metals has become much higher. For example, density is a very important parameter because when PP and LDPE (low density polyethylene) are the best choices (due to their low density), for a material whose purpose is to produce a composite as light as possible, it provides information about the internal strength of the structure to be created. The glass transition temperature (Tg) is another important feature in the study of polymer mechanical properties, since the flexibility of the amorphous polymers is greatly reduced when cooled below Tg. At these temperatures, there is no dimensional change or segmental movement in the polymer. In addition, thermoplastic polymers are often very important in tensile strength (important for their performance under stress) and in the case of tensile modulus (resistance to elastic deformation of polymers) [22]. The main thermoplastic polymers and their properties are presented in Table 2.1 [23].

Table 2. 1 The properties of various polymers [23].

Properties	Limits	Type of Polymers					
		PP	**LDPE**	**HDPE**	**PC**	**PBT**	**PAI**
ρ (g/cm^3)	Upper	0,92	0,925	1	1,24	1,35	1,45
	Lower	0,899	0,91	0,941	1,19	1,23	1,38
Tg	Upper	-10	-125	-100	150	45	290
	Lower	-23	-	-133	140,5	20	244
σ_{max} (MPa)	Upper	41,4	78,6	38	72	55,9	192
	Lower	26	4	14,5	53	51,8	90
E (GPa)	Upper	1,776	0,38	1,49	3	2,37	4,4
	Lower	0,95	0,055	0,413	2,3	-	2,8

Furthermore, the cost of plastic production is low due to simple mass production. The main reasons for the use of thermoplastic polymers in various applications are;

- Thermoplastic polymers can be processed in a number of ways, leading to various plastic products;

- Several compounds, working conditions, additives, fillers and reinforcing are used for a particular application;

- Various production systems are used to produce plastic products in the lowest cost range [23].

2.4.3 Recycling Methods

Recycling and incineration are the usual aspects of recovery methods in thermoplastic polymers. Incineration presents some problems such as the production of toxic gases and residual ash containing lead and cadmium. Recycling offers advantages such as reducing environmental problems and saving both material and energy [23].

Collection → Separation → Manufacturing → Marketing

Figure 2. 4 Basic recycling stages [23].

Although many different methods are applied for the recycling of thermoplastic wastes such as PET, PE (polyethylene), PP, PA (polyamide) (generally all textile synthetic fibers in this group), there are basically four main approaches [24].

a. Primary recycling
b. Secondary (mechanical) recycling
c. Tertiary (chemical) recycling
d. Quaternary recycling /energy recovery

2.4.3.1 Primary Recycling

It is represented as the most popular process because of its simplicity and low cost. This process refers to the re-use of poor quality and scrap materials directly by recycling facilities, such as in their original structures. The disadvantage of the process is that it is represented by the presence of a limit on the number of cycles for each material [25-26].

2.4.3.2 Secondary (Mechanical) Recycling

Only thermoplastic polymers can be used in this process because the polymers are remelted and retreated to convert them to the final product [23]. The separating products, cleaning it and then re-using it as separate polymers or as a mixture. In polymer recycling, mechanical recycling means retreating the waste by conventional melt extrusion into granules. There are two processes in textile mechanical recycling: melt extrusion and defibrillation of textile products by carding. The main disadvantage of these processes is the deterioration of product properties in each cycle [24].

2.4.3.3 Tertiary (Chemical) Recycling

It is also known as chemical recycling. The main purpose is to produce the monomer, the original polymer (or lower molecular weight polymer) of the polymer from which the waste plastic is produced, and a variety of chemicals to be used for other purposes. In this process, plastic wastes are evaluated to produce monomers for the production of their own polymer, which can be converted to various chemicals for use as intermediates or raw materials [25].

2.4.3.4 Quaternary Recycling / Energy Recovery

Burning, which is an energy recovery method, can also be classified as a recycling method. Incineration or quaternary recycling remains a popular method for energy recovery and reduction of waste volume. It is the most common method of using waste plastic especially in Europe. The method is used as easily and economically as other methods, especially in the treatment of mixed and heavily contaminated wastes which are not recyclable.

Incineration of energy intensive wastes can create heat, electricity or other forms of energy that can be used directly in technological processes or in the heating of buildings. Quaternary recycling reduces waste volume to about 1% of the initial volume and decomposes toxic and infectious waste. It is therefore ideal for the recycling of medical applications and packaging of hazardous materials. The inorganic components are converted to inert slag by incineration and can be used for road construction. Various installations and methods are used to perform the combustion process. Plastic wastes are used as an energy intensive fuel for high temperature processes: the calorific value of synthetic polymers is generally higher than that of coal. For example, calorific is suitable for cement kilns, chemical waste incineration plants and metal melting furnaces [26].

This method is a good solution because it generates a significant amount of energy from the polymers, but is not ecologically acceptable due to the health risk from airborne toxicants such as dioxins (heavy metals, chlorine-containing polymers, toxic carbon and oxygen-based free radicals) [23].

Among the above recycling techniques, chemical recycling is the only thing acceptable according to the principles of sustainable development, since it leads to the formation of raw materials (monomers) from which the polymers are made. In this way additional resources are not needed [24].

In addition, the advantages and disadvantages of recycling methods are listed in Table 2.2 [23].

Table 2.2 Advantages and disadvantages of recycling methods

Type of Recycling Method	**Advantages**	**Disadvantages**
Mechanical recycling	Cost-effective, efficiency, well known	Deterioration of product of properties, pre-treatment
Chemical recycling	Operational for PET, simple technology	Mainly limited to condensation polymers
Energy recycling	Generates considerable energy from polymers	Not ecologically acceptable

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 Preparation of Waste PP Yarns

During the production of carpet, the decrease in the amount of yarn on the polypropylene coils used causes tension (stretch) mismatch in the yarn, and causes a fault on the carpet surface. In order to prevent this fault on the carpet surface, a certain amount of yarn is left on the bobbin and separated into waste and classified according to colors.

On the other hand, polypropylene yarn waste in BCF yarn production consists of breaks due to production parameters (temperature, winding speed, pressure etc.) during filament drafting stage. Polypropylene yarn wastes formed in both production areas are separated for use in different sectors. However, in this study, PP yarn waste obtained in both production (polypropylene yarns used in carpet looms and filament drawing of BCF yarn production) were recycled, later BCF yarn and carpet were produced.

3.2 Methods

3.2.1 Recycling of Polypropylene Yarn Waste

PP ecru wastes were converted to granules at MTM Plastic Recycling Company / Gaziantep. The process flow is as following:

a) Collection: Classification of the wastes according to fiber type and color.

b) Breaking: Converting the wastes into small particles by mechanical means.

c) Agglomeration: This step is used for the drying and densification of broken wastes via heat created by the high speed rotating blades; also drying and compacting as well as size reduction are also achieved.

d) Extrusion: Dense particles are converted into pellets by high temperature and shearing forces applied by the extruder screw and granulator.

3.2.2 BCF Polypropylene Carpet Yarn Production From Recycled PP Granules

R-PP pellets were mixed with V-PP to produce R-PP BCF yarns with required R-PP content. The minimum R-PP content was defined as 5% due to the RCS (Recycled Claim Standard) applications; the R-PP portion was varied to 10%, 20% and 50%. The BCF yarn production was completed by using trilobal spinnerets to produce fibers with trilobal cross section as widely used in machine carpet and BCF industry. The effect of fiber cross section was also observed by using delta and delta / trilobal mix spinnerets. The using spinneret types were given in Figure 3.1. The variation of fiber cross section was applied only at BCF yarns with 20% R-PP content. All the yarns were 2000 dtex and filament numbers were 144 (for trilobal), 200 (for delta / trilobal mix) and 240 (for delta). And in the Table 3.1 BCF carpet yarn sample classification was given. Except for BCF carpet yarn productions containing 50% recycling additive, all yarn samples were produced with the same parameters.

Figure 3. 1 The Using spinneret cross sections a)144 filaments/trilobal, b)200 filaments/trilobal/delta mixing

Table 3. 1 The classification of BCF samples

Sample Code	R-PP / V-PP content (%)	Fiber cross-section	Yarn fineness (dtex)
T1-144	0 / 100	Trilobal	2000 / 144
T2-144	5 / 95	Trilobal	2000 / 144
T3-144	10 / 90	Trilobal	2000 / 144
T4-144	20 / 80	Trilobal	2000 / 144
T5-144	50 / 50	Trilobal	2000 / 144
T/D1-200	0 / 100	Trilobal / Delta	2000 / 200
T/D2-200	20 / 80	Trilobal / Delta	2000 / 200
D1-240	0 / 100	Delta	2000 / 240
D2-240	20 / 80	Delta	2000 / 240

The BCF yarn production were run at Rieter KXC 20 melt spinning machine in Kartal Halı and production parameters were detailed under followings Table 3.2 and Table 3.3.

Table 3. 2 Rotational Speed and Temperatures of Godets

Godets	Rotational Speed (mt/min)	Temperature Values (^{O}C)
Godet 1	1200	10
Godet 2	1260	90
Godet 3	3290	138
Godet 4	3310	145
Godet 5	3320	145
Cabin	850	-
Drum	800	145
Drawing	**2,61**	

Table 3. 3 Temperature and pressure values of extruder

Extruder Zones	Temperature (°C)	Pressure (Bar)
Zone 1	244	135
Zone 2	246	
Zone 3	248	
Zone 4	250	

3.2.3 BCF PP Carpet Yarn Production with containing 50% R-PP Granules

Productions of BCF carpet yarn containing 50% R-PP were made by changing drawing ratio of BCF carpet yarn production parameters. The increase in the recycling rate was also increased the melt flow index (MFI) in the material (MFI was measured as 30 gr/10 min for R-PP), caused breakage during drafting. Accordingly, extruder temperature values and yarn draft in the machine were reduced. Production was taken efficiently according to the drawing and extruder temperatures given in Table 3.4 and Table 3.5.

Table 3.4 Rotational speed and temperatures of godets for containing 50% R-PP

Godets	Rotational Speed (mt/min)	Temperature Values (^{O}C)
Godet 1	1200	10
Godet 2	1260	90
Godet 3	3250	138
Godet 4	3300	145
Godet 5	3310	145
Cabin	850	-
Drum	800	145
Drawing	**2,58**	

Table 3.5 Temperature and pressure values of extruder for containing 50% R-PP

Extruder Zones	Temperature (°C)	Pressure (Bar)
Zone 1	241	135
Zone 2	243	
Zone 3	245	
Zone 4	247	

3.2.4 Twisting and Fixing Process

Twisting and fixing processes were applied to the yarns produced with the use of R-PP and V-PP in order to provide strength and stability with heat treatment. Twisting was carried out on the Volkman 05-0-C-F twisting machine using the same machine parameters for R-PP and V-PP yarns. Twist parameter values were given in Table 3.6.

Table 3.6 Twist machine production parameters

Twist number	Twist type	Tension Setting	Working Speed(rpm)	Min/mt
110	S	18	4500	81,81

After the twisting process, BCF Polypropylene carpet yarns are subjected to two different heat treatments as fixed or frieze. With these processes, the yarns change the appearance of the carpet and determine whether the yarns in the carpet are flat (fixed) or crimped (frieze). And the produced all yarn samples were processed as flat (fixed). Superba TVP 3 fixing machine was used for heat treatment of sample yarns. The fixed parameters were given in Table 3.7.

Table 3.7 Superba fixing production parameters

Working Speed (mt/min)	**Tunnel Heat (^{o}C)**	**Engine Power (kw)**	**Conveyor Belt Speed (mt/min)**
450	135	35*2	16,5

3.2.5 Structural Evaluation of Polypropylene Granules

3.2.5.1 MFI Test

MFI measurements of recycled and virgin PP granules were performed on ATS FAAR STRUMENTI tester. The heating system is in the range of 0-400 ^{o}C and measurements was made according to ASTM D1238 (American Society for Testing and Materials) standard. MFI measurement results were obtained in gr / 1 min with an apparatus weighing 2.16 kg [28].

3.2.6 Evaluation of BCF Carpet Yarns

3.2.6.1 Crimp Contraction -Shrinkage Test

After the production of sample yarns, automatic crimp contraction and shrinkage device TEXTECHNO-TEXTURMAT ME + was used to measure crimp and tensile values and compare with V-PP. Crimp contraction test procedure was carried out according to German standard DIN 53 840 (Deutsches Institut für Normung) and European standard EN ISO 14 621 (European Norm). Thermal treatment was applied to observe optimum yarn crimp and crimp parameters were determined according to ASTM D 4031 standard.

ASTM D 2259, EN 14 621 or DIN 53 866 test methods are used to determine the yarn shrinkage due to hydrothermic (water thermal) or heat treatments. Bulk properties of textured yarns were determined according to ASTM D 4031 standard.

The test was usually carried out by determining the initial length of the yarns and the second lengths after heat treatment, and the percentage of differences give the shrinkage [29].

3.2.6.2 Tensile Strength Test

TS EN ISO 2062 (Turkish Standard) standard and Tinius Olsen H5KS test device were used to measure the strength values. The yarns were subjected to a constant tensile load by holding the clamp from the top and bottom and the strength value at the point of breaking was recorded. Although it is possible to adjust the tensile loads between 1 kN and 100 N, the test results are evaluated with ± 10% tolerance according to the standard [30].

3.2.6.3 Color Measurement Test

To observe the effect of R-PP content and fiber cross-section, color difference between BCF samples and 100% V-PP BCF yarn as standard were measured with 600™ model DATACOLOR Reflectance Spectrophotometer according to AATCC 173 (American Association Of Textile Chemists and Colorists). The measurements depend on determining CIElab (Commission Internatiole de I'Eclairage *L*(lightness), a*(red/green)* and *b*(yellow/blue)* values of color coordinates of sample and standard BCF yarns; calculating DL (Delta Lightness), Da (Delta red/green) and Db (Delta yellow/blue) values by simply subtraction of obtained values then DE (total difference in color value) color difference was calculated with the Equation (3.1)

$$\mathrm{DE} = \sqrt{DL^2 + Da^2 + Db^2} \tag{3.1}$$

3.2.7 Evaluation of Carpet Use and Performance Characteristics

Carpet samples were woven according to the quality parameters given in Table 3.8 and then some of the mechanical and static effects that may be encountered during the use of carpets were tested and carpet performance was determined before used. In order to determine the carpet quality, the strength of the textile flooring was determined by using tuft withdrawal force determination, appearance retention (by hexapod), thickness loss under dynamic load, thickness loss under long-term static loading and abrasion tester were used as well.

Table 3.8 The properties of carpet samples

Warp x Weft density	Number of Point (loops/m^2)	Knitted structure	Pile Height (Lancet (mm))	Number of Weft Yarn and Type	Number of Stuffer Yarn	Number of Chain Yarn	Latex Type
32 x 60	192000	½	26	20/1 LBS jute	Ne 12/4 Cotton	300x2 Denier PES	SBR (Stryene Butadiene Rubber)

3.2.7.1 Static Loading Test

The test was applied to calculate the thickness loss under long-term static loading of heavy objects on the carpets and the WIRA Instrumentation tester was used. Sample tests were performed according to BS 4939: 1987 test standard and the results were evaluated. The cutting samples as 10 cm x10 cm were placed on the plate with double-sided adhesive; thickness measurements were taken before the test and 10 kg weight was put to test. Each sample was stored under a 10 kg load for 24 hours and then removed after 24 hours. Thickness loss of the extracted samples was calculated between 2 minutes and an hour then 24 hours.

Carpet thicknesses were measured with WIRA Digital Carpet Thickness Gauge before and after the tests [32].

3.2.7.2 Dynamic Loading Test

In the test applied to determine the thickness decrease in the carpet as a result of walking traffic; the dynamic loading tester was used to observe the effect of carpet pile on bedding-down by synchronizing walking on the carpet with 2 main walking movements forward. The test was performed and evaluated using BS 4052 (British Standard) and ISO 2094 standards [33].

Two weighted rectangular metal legs can be dropped on carpet samples in a controlled manner with free fall movement every 4 seconds and the carpet is subjected to a certain number of standard impacts; the differences between the thicknesses determined under 2 kPa pressure before and after impact were measured. Carpet thicknesses were measured with WIRA Digital Carpet Thickness Gauge before and after the tests.

3.2.7.3 Carpet Abrasion Test

WIRA Carpet Abrasion Machine was used to measure the abrasion resistance of carpet samples. For the use of the test device, it is considered appropriate to measure carpets containing at least 80% wool. However, as a result of our research, 100% synthetic carpets for abrasion resistance can not be found one-to-one accepted standard, this test for 100% polypropylene yarn carpet samples with reference to BS EN 1813: 1998 Textile Floor Coverings standard was applied and evaluated.

The test pieces were prepared with a 38 mm diameter cutting circle to be evaluated by taking 4 measurements from each carpet sample. Carpet samples placed in the device were subjected to abrasion by rotating the machine carpet piece and abrasive surface in the same direction with the pressure adjusted to 0.56 kg / cm^2 and 5000 cycle applied by abrasive. The weights of each of the four samples prepared before and after the test were calculated using the following formula, Equation (3.2):

$$\text{Mass loss} = \text{Initial mass} - \text{Final mass} \qquad (3.2)$$

3.2.7.4 Determination of Appearance Retention with Hexapod Test

WIRA Hexapod Tumbler Carpet Tester, which is applied to predetermine the resistance of rugs woven from R-PP yarns against mechanical effects and to evaluate the changes in appearance, is prepared on the basis of ISO 10361 (2000) standard accepted by ISO and approved by TSE (Turkish Standard Institute) standards and finalized.

The carpet sample is placed into the rotating drum of the hexapod machine with the pile loop face inward along the machine direction (MD) and cross direction (CD). After a certain number of rotations (12000 revolutions) of the drum of the hexapod, which will rotate freely, the appearance of the surface change is determined [35]. While checking the test sample; crush, bark, pilling, pilling, yarn and loop loss, shading (change in total light reflection), color change, change in pattern clarity and the appearance of carpet back to be seen in terms of CRI 4 (Carpet Rug Index) Scale 1 to 5 according to the scale visually rated.

3.2.7.5 Determination of Tuft Withdrawal Force

According to TS 5145 test standard, stitch removal force was made to determine the strength of stitch in carpet and Prowhite GH-1 Tuft Withdrawal Tensometer tester was used. The loop pulling force is based on determining the greatest force exerted during the extraction and removal by holding at one end of the carpet loop. One end of the loop ring is clamped and the clamp is gripped in a direction perpendicular to the device and the measurement is taken from the sample fixed by the presser foot. A minimum of 15 measurements were taken from each sample. The largest readings were recorded and the mean loop strength was calculated in kgf (N) [36].

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Test Results of BCF Carpet Yarns

Yarn production was carried out by changing the parameters to examine whether the number of filaments and cross sections had a significant effect.

Yarn test results were classified according to the number and cross-section of the filaments. The test values of the yarns produced accordingly was given in following Figures 4.1, Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5, Figure 4.6, Figure 4.7, respectively.

4.1.1 Results of Elongation Values of BCF Carpet Yarn

The tolerance of elongation values of V-PP was determined in the range of % 40-50 according to TS EN ISO 2062 standard. If we examine the elongation graph in Figure 4.1, no serious fluctuation is observed. When the elongation values of 100% V-PP yarns according to the number of filaments were compared, it was seen that the highest elongation value was obtained in 240 filaments and the lowest elongation value was obtained in 144 filaments. According to these results, as the number of filaments were increased, there was a partial decrease in elongation values. However, when the V-PP yarn results are examined by filament number, it was seen that Delta filament cross section gived better results.

This parameter, which was important for processability, was expected to increase the elongation values in the yarn with the increase of the recycled ratio, because the addition of recycled results in the formation of the amorphous region in the structure of the yarn.

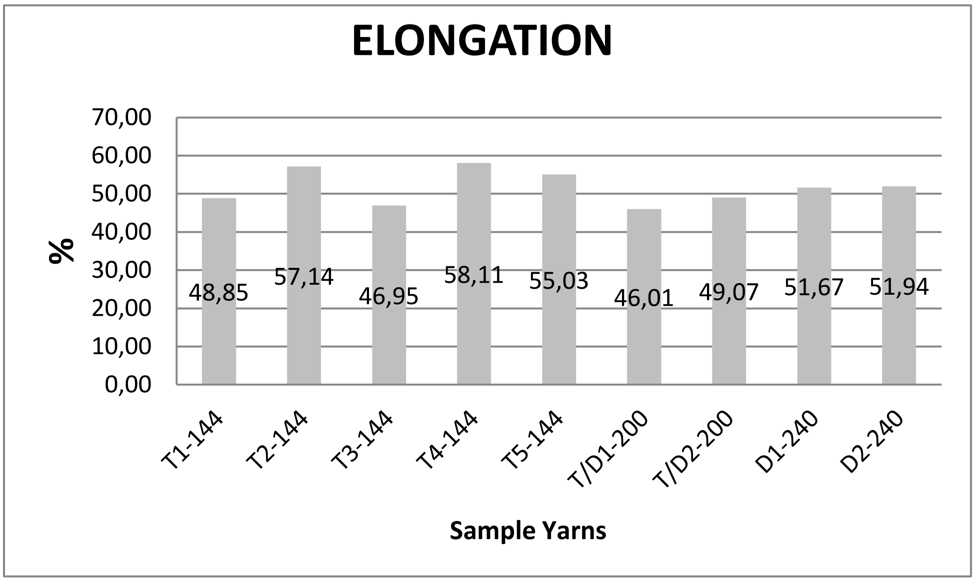

Figure 4.1 Elongation test results

4.1.2 Results of Tensile Strength of BCF Carpet Yarn Values

The friction between the filaments increases with the increase in the number of filaments, and with this increase the theoretical specific strength values are expected to increase. Tolerance of tensile strength values was determined as ± 10% according to TS EN ISO 2062 standard. Among the yarns, the highest breaking strength values were generally obtained in all V-PP yarns. Figure 4.2 shows an increase in strength due to the number of filaments and these results confirmed that the strength was increased with increasing number of filaments. When the values of the yarns of different cross-sections were compared, it was observed that the addition of 20% recycled had no significant effect on the strength.

Accordingly, as the ratio of the recycle additive increased, a relatively decrease in the strength value occured. And this reduction was thought to result from the weakening of the bond between the polymers by the addition of recycling.

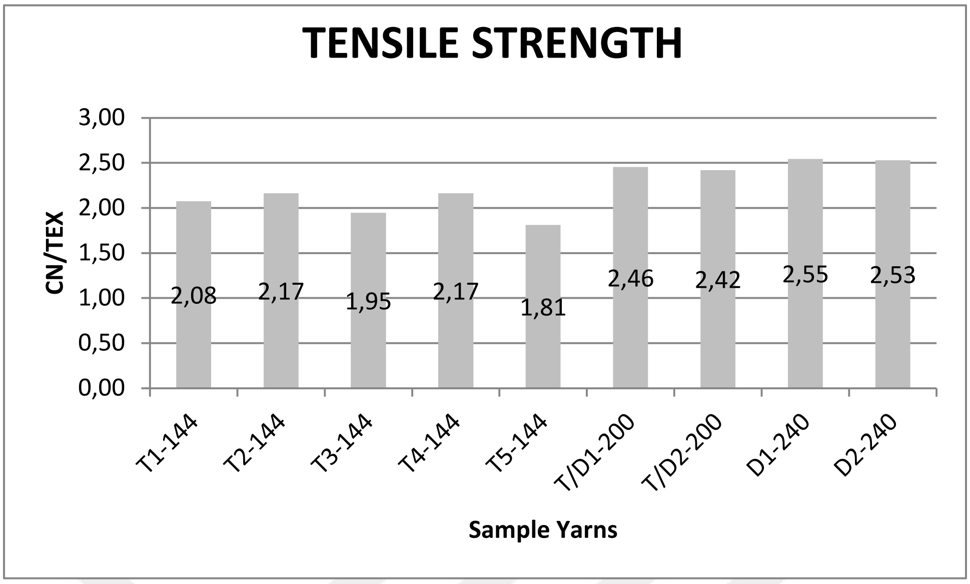

Figure 4.2 Results of tensile strength of BCF carpet yarn

4.1.3 Results of Shrinkage Values of BCF Carpet Yarns

The shrinkage in the yarns depends entirely on the amount of crystal and amorphous regions in the yarn structure. The addition of different structures into the polymers also affects the polymer morphology. The MFI value of the recycled raw material used here was determined to be 30 gr by measuring 2 minute at 235 ^{o}C. The standard homopolymer polypropylene MFI is 25 gr. Therefore, it was thought that adding the recycled raw material to the filament structure would increased the amount of amorphous region due to its fluidity. This would result in more shrinkage in the yarn. Figure 4.3 was showed the Shrinkage graph. According to the graph, it was observed that there was no significant increased with the addition of recycled up to 20%. However, with the recycled ratio of up to 50%, the yarn had a lot of shrinkage and achieved the expected shrinkage.

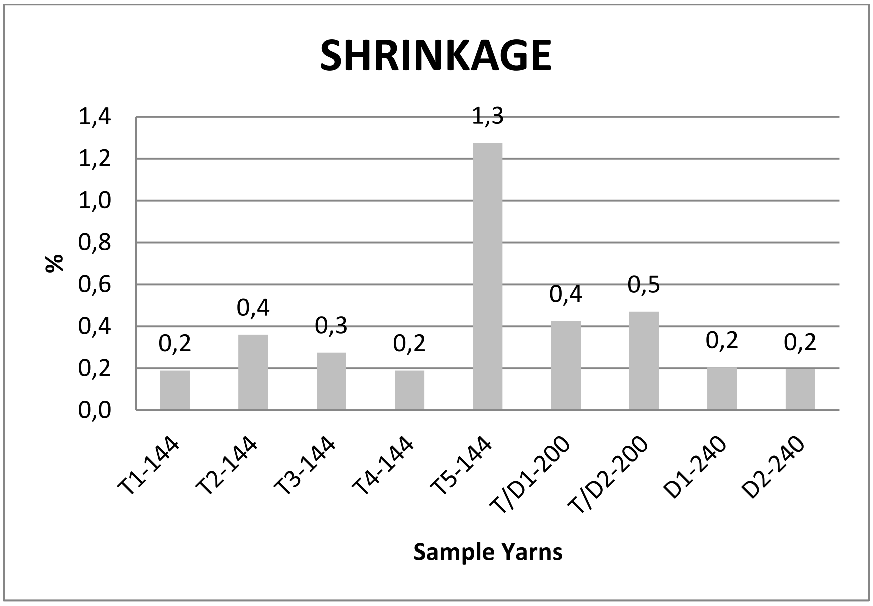

Figure 4.3 Shrinkage values of BCF carpet yarns

4.1.4 Results of Crimp Values of BCF Carpet Yarns

It is an important parameter that affects the appearance and toughness of the crimp carpet due to the increase in the area covered by the yarn in the carpet (bulkiness) and the mechanical performance of the yarn. Therefore, it is desirable that the crimp value be at an optimum degree. Therefore, it is desirable that the crimp value be at an optimum degree. When we look at the graph, there was no trend, especially with the increase in recycled rate, especially between samples T1-144, T2-144, T3-144, T4-144 and T5-144 samples.

However, when compared to the filament cross-section, a reduction in the crimp value of samples containing 20% recycled was observed. In this case, although no significant effect of the recycled ratio was observed, the crimp value decreased when the filament cross-section was changed.

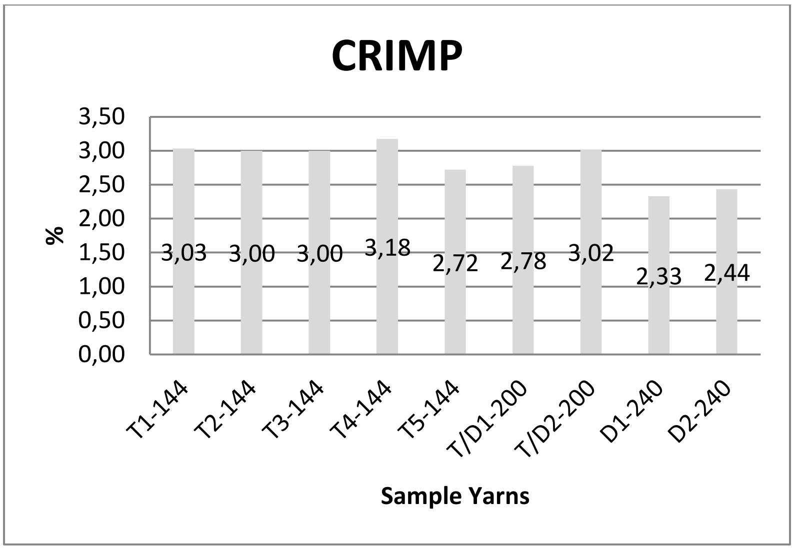

Figure 4. 4 Consequence of crimp value of BCF carpet yarns

4.1.5 Color Mesurements Test Results (Spectrophotometer)

Reflectance (%R) Spectrophotometer measurement results of the BCF samples were given in Table 4.1; Figure 4.5, 4.6 and Figure 4.7 shows %R vs wavelength diagrams. The results showed that as the content of R-PP increases, the yarns had lower lightness values and yellowish hue. Increased R-PP content, yellowness and L * values were observed to decrease. On the other hand, the fiber cross section showed great effect on color difference since at the same R-PP content ratio (%20), delta and delta / trilobal cross section yarns gave lower color differences. It was concluded that delta cross section worked well for recycled pellet spinning in terms of color difference. The yellow hues at the yarns were attributed to the yellow cast of R-PP pellets and delta cross section lowered light scattering which hindered the yellowish hue.

Table 4.1 Conclusion of reflentance spectrophotometer measurement of BCF yarns

Sample Code	DL*	Da*	Db*	DE
T2-144	-2,29	0,27	2,05	3,09
T3-144	-3,21	0,40	3,11	4,49
T4-144	-5,99	0,79	5,20	7,97
T5-144	-13,65	2,04	8,61	16,27
T/D2-200	-2,58	0,49	2,27	3,58
D2-240	-0,44	0,02	0,42	0,61

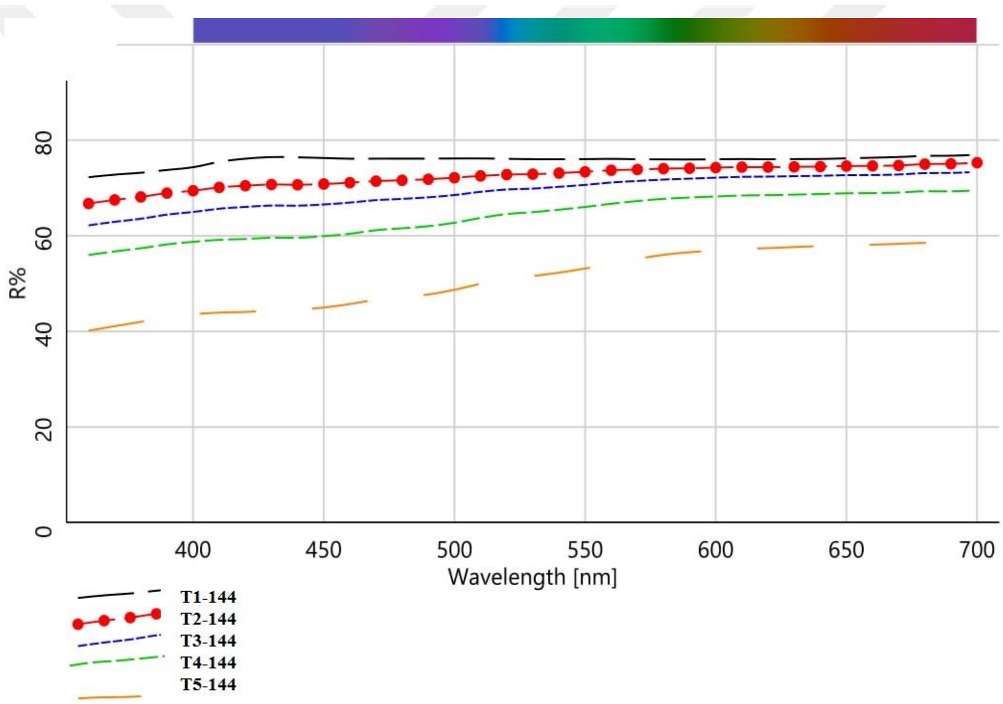

Figure 4.5 %R vs wavelength diagrams for 144 filaments BCF samples

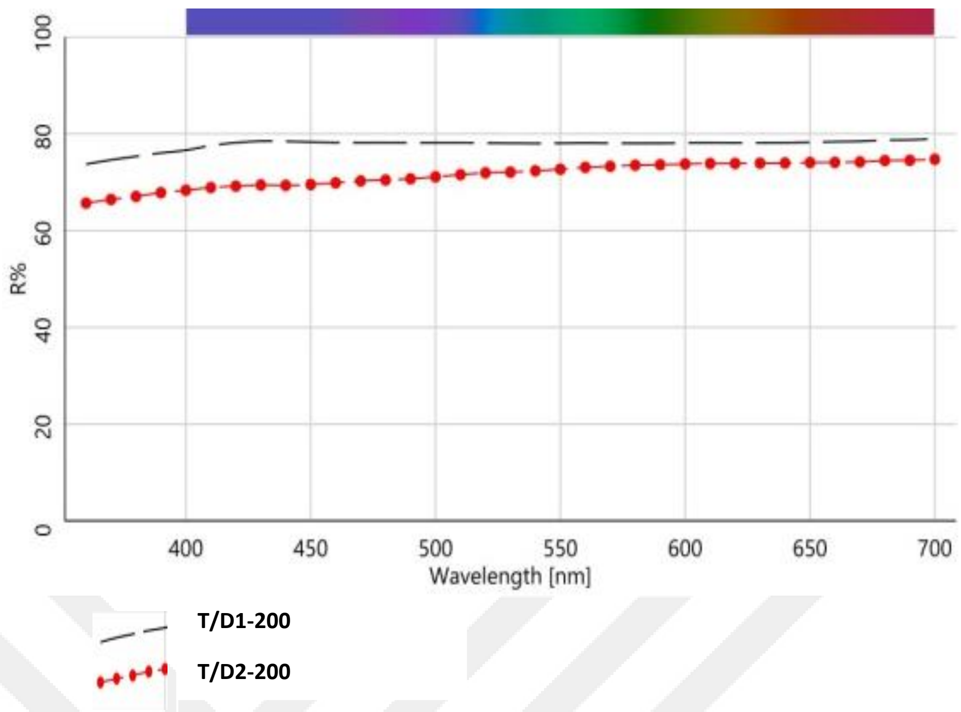

Figure 4. 6 %R vs wavelength diagrams for 200 filaments BCF samples

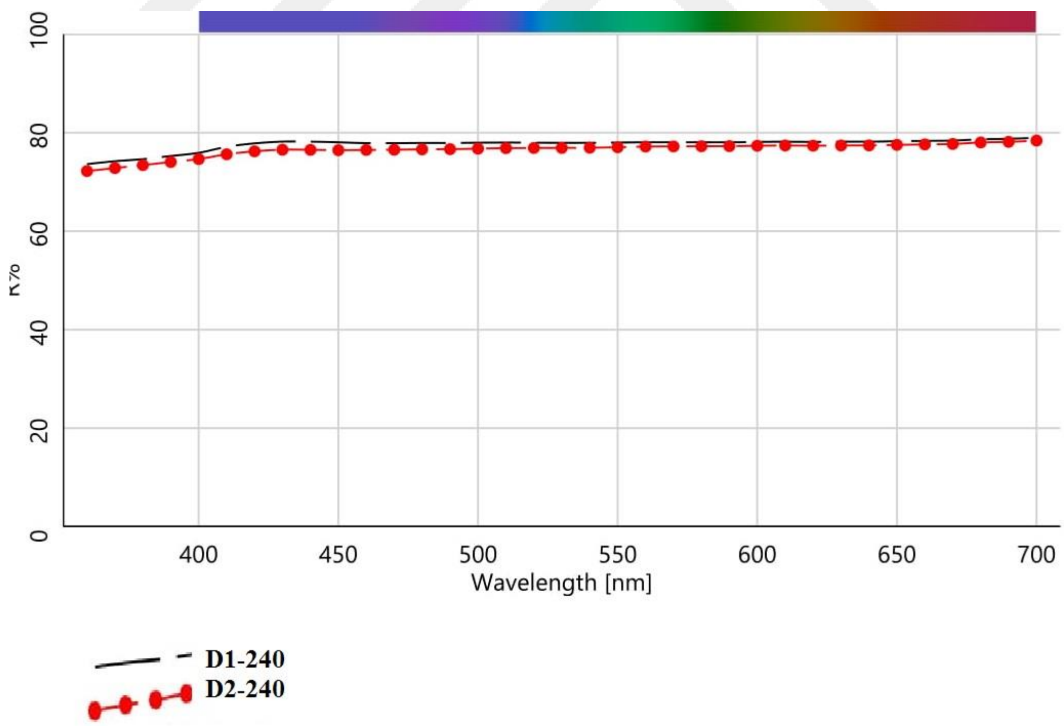

Figure 4.7 %R vs wavelength diagrams for 240 filaments BCF samples

4.2 Carpet Test Results

4.2.1 Appearance Retention of Carpet (Hexapod)

According to the CRI 4 Scale, the evaluation between 1 and 5 is expressed as follow Table 4.2:

Table 4.2 Description of CRI -4 Scales

Number of Degree	Description of Grading
1	Major change in appearance
2	There is a lot of change in appearance
3	Moderate appearance
4	Minor change in appearance
5	No change in appearance
Notes: Intermediate values can be given when necessary.	

The results of the test according to the machine direction and cross direction according to CRI-4 Scale are as in Table 4.3.

Table 4.3 Results of appearance retention of BCF carpet with hexapod

Sample Code	**MD**	**CD**
T1-144	1-2 (1,25)	1-2 (1,75)
T2-144	1-2 (1,5)	2-3 (2,5)
T3-144	1-2 (1,5)	1-2 (1,5)
T4-144	1-2 (1,5)	1-2 (1,5)
T5-144	(2)	1-2 (1,5)
T/D1-200	1-2 (1,25)	1-2 (1,25)
T/D2-200	1-2 (1,75)	(2)
D1-240	1-2 (1,25)	1-2 (1,5)
D2-240	1-2 (1,5)	1-2 (1,33)

There was no significant difference in hexapod test results with recycled increase in machine direction. However, with the change of the filament cross-section, an increase in grading was observed and a positive effect on the change in appearance is observed.

In terms of machine width direction and filament cross-section, no trend is seen.

However, in both machine direction and machine width evaluation, it was interpreted that T/D1-200 and T/D2-200 samples with 200 filament cross-sections provide greater resistance to change of appearance.

As a result of hexapod test of 100% polypropylene carpet samples in general, it was determined that there was a visible flattening in the pile layer and regional flares occurred as a result of impact. It was also found that regional flares and crushes were found in the samples with recycle added carpet as a result of impact.

4.2.2 Result of Tuft Withdrawal Force

The tuft withdrawal force measurement results of carpet samples according to TS 5145 test standard was given in the following Table 4.4

Table 4.4 Consequence of tuft witdhdrawal force measurements

Sample Code	Tuft Withdrawal Force (gr/F)
T1-144	1537,66
T2-144	1521
T3-144	1561,3
T4-144	1474,33
T5-144	1494
T/D1-200	1604
T/D2-200	1578
D1-240	1634
D2-240	1667,33

Figure 4.8 showed that with the increase in the number of filaments, the increase in tuft withdrawal force was the expected result.
However, no correlation was found between the increase in the recycled ratio and the tuft withdrawal force between the samples.

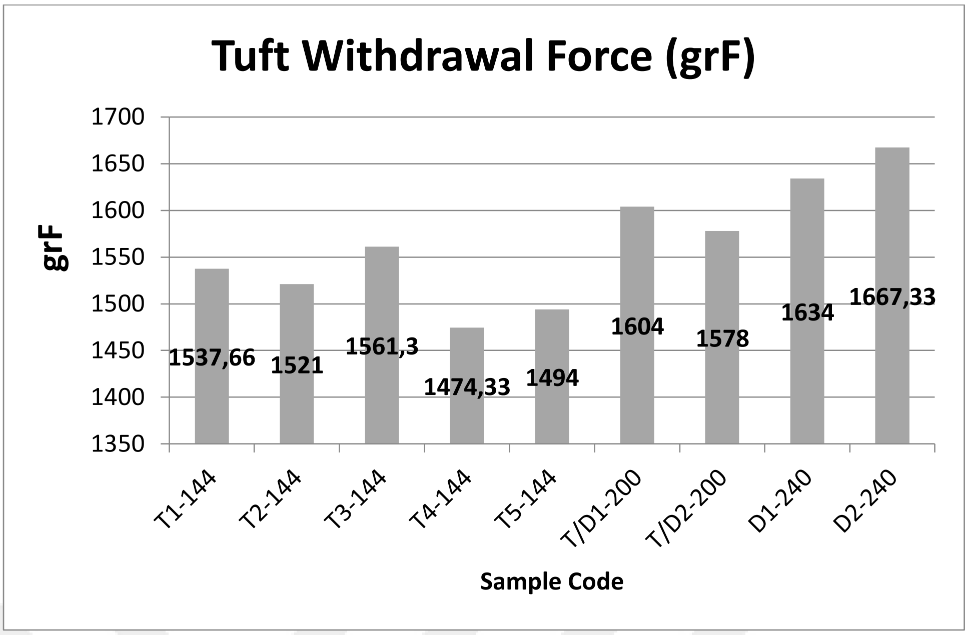

Figure 4.8 Graphical expression of pile withdrawal force measurements

4.2.3 Thickness Loss Under The Dynamic Loading

As a result of the dynamic loading test, the differences in thickness loss of each sample were taken and the difference values were given in Table 4.5.

Table 4.5 Thickness Loss of R-PP and V-PP Carpets Under Dynamic Loading

Carpet Type	T1-144	T2-144	T3-144	T4-144	T5-144	T/D1-200	T/D2-200	D1-240	D2-240
Before Test (mm)	11,76	13,72	12,14	13,56	13,64	13,105	14,015	8,985	10
After Cycle 50 (mm)	1,375	3,165	1,14	3,3	3,455	2,56	3,985	0,465	1,41
After Cycle 100 (mm)	2,195	4,07	2,275	4,64	4,81	3,545	4,96	0,815	2,27
After Cycle 200 (mm)	2,895	4,595	3,055	5,51	5,81	4,25	5,68	1,135	2,69
After Cycle 1000 (mm)	3,82	5,33	4,025	6,67	6,705	5,115	6,415	1,625	3,34

As shown in Table 4.5 and Figure 4.9, with the increase in the number of revolutions was increased the difference and percentage of thickness loss. However, no correlation was observed between thickness losses due to increased recycled ratio and filament numbers. However, it was observed that the samples with delta filament section caused less thickness loss compared to the samples in the other cross section.

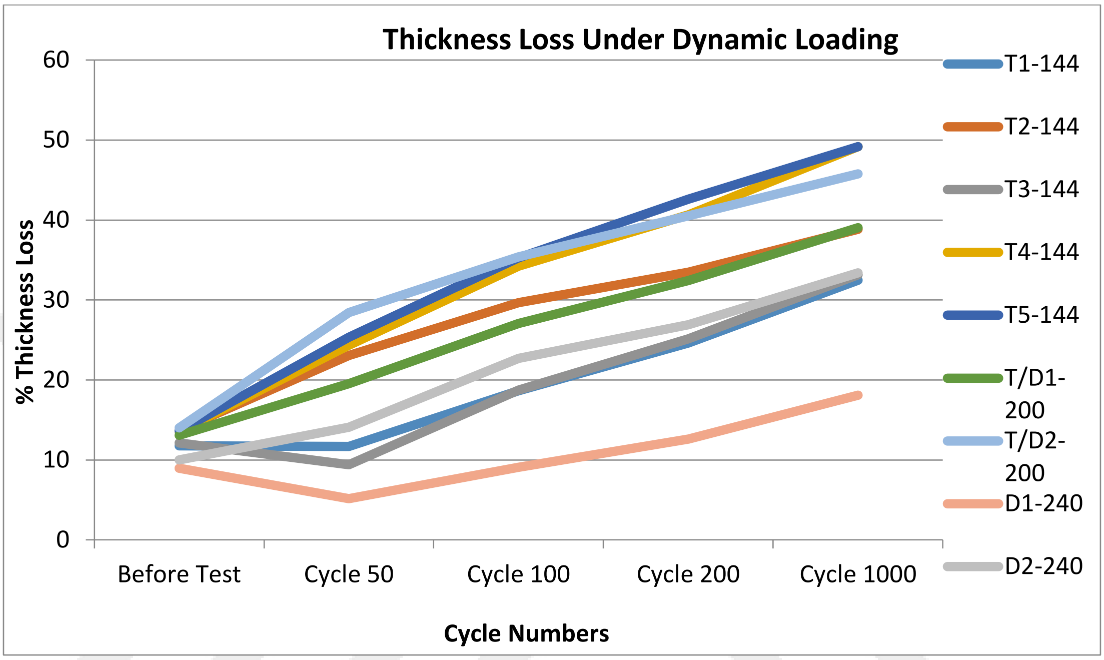

Figure 4.9 Graphical expression of dynamic loading test results

4.2.4 Thickness Loss Under Long-Term Static Loading

By applying static loading to carpet samples for a long time, the pressure created by objects such as chairs or table legs was simulated and the result was given in Table 4.6 and Figure 4.10.

Although a trend cannot be said among the filament numbers, it was observed that the thickness loss of the samples with delta cross-section was less than that of the other samples according to Figure 4.10.

Table 4.6 Consequence of before and under long term static loading

Sample Codes	T1-144	T2-144	T3-144	T4-144	T5-144	T/D1-200	T/D2-200	D1-240	D2-240
1st thickness (B.T) (mm)	12,07	12,09	11,67	13,72	13,16	11,83	11,67	8,88	10,08
AFTER 2 MIN.(mm)	6,57	6,95	7,43	6,68	6,43	6,71	6,45	5,82	5,41
AFTER 1 H(mm)	8,09	8,46	8,92	8,05	7,9	7,93	7,92	6,35	6,61
AFTER 24 H (mm)	9,75	10,07	10,11	9,8	9,52	9,9	9,51	7,37	7,97

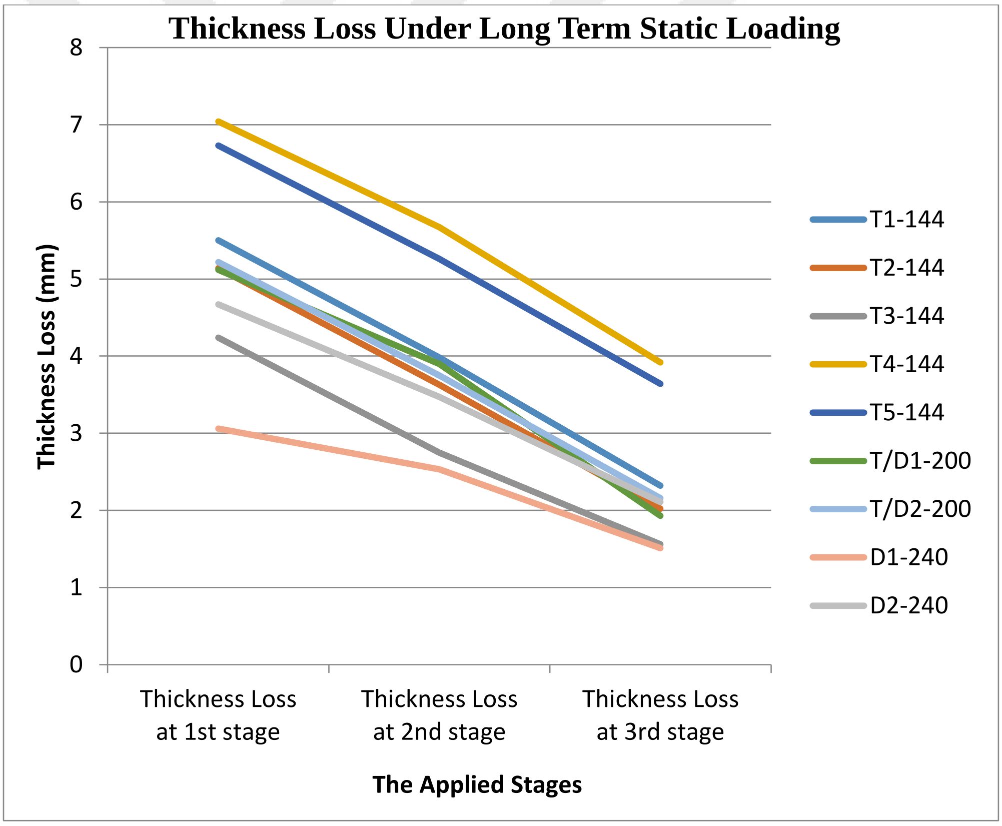

Figure 4.10 Graphical analyses of thickness loss of under long term static loading

4.2.5 Abrasion Resistance Results of BCF PP Carpets

Weight loss resulting from abrasion resistance tests performed at 5000 cycles was evaluated as a percentage in Table 4.7.

Table 4.7 Results of abrasion resistance of BCF carpet sample

Sample Codes	T1-144	T2-144	T3-144	T4-144	T5-144	T/D1-200	T/D2-200	D1-240	D2-240
Before Test (gr)	2,70	2,92	2,99	2,79	2,85	3,06	3,01	2,90	2,80
After 5000 Cycle (gr)	2,64	2,86	2,94	2,74	2,79	3,00	2,96	2,86	2,73
Weight Loss (%)	2,22	1,97	1,92	1,79	1,93	2,12	1,91	1,55	2,32

According to the results in Table 4.7, with the increase in the number of filaments, the weight loss of the carpets woven with 100% V-PP were reduced. however No correlation was found between recycling rate and thickness loss.

The weight loss curve of the carpet samples was given in Figure 4.11. and no correlation was found between filament numbers and thickness losses.

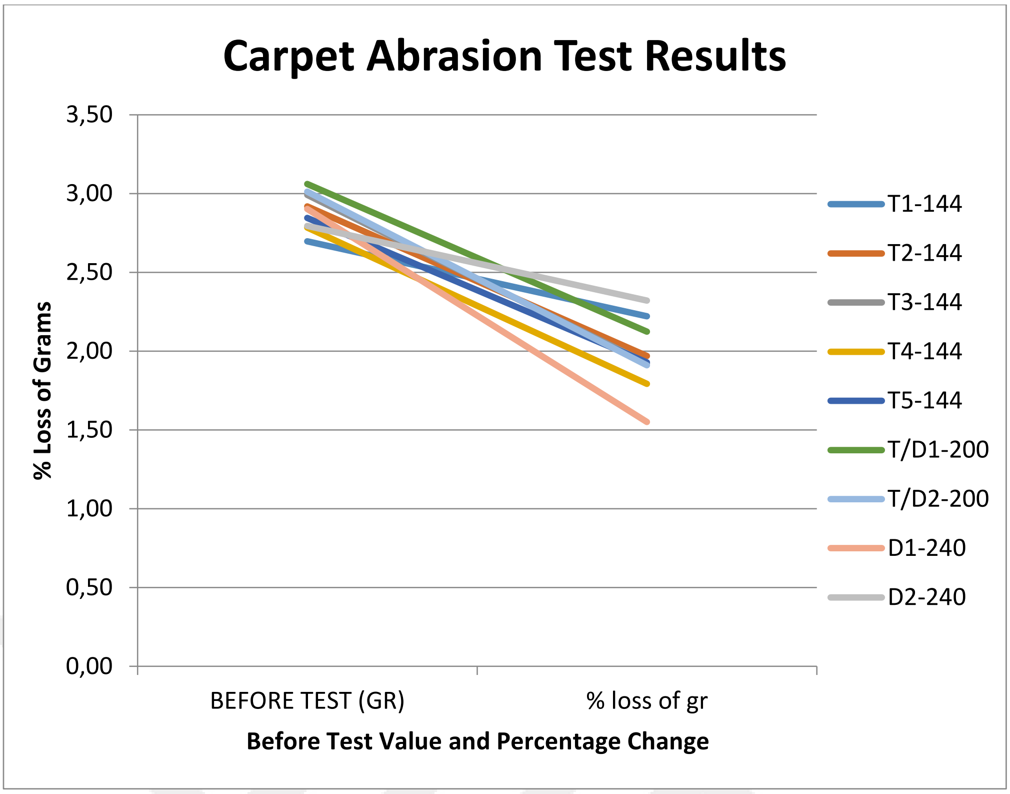

Figure 4.11 Comparison of weight loss values of carpet samples

CHAPTER 5

CONCLUSION

5.1 Yarn Test Analysis

In this thesis, the waste polypropylene yarns produced during BCF polypropylene carpet yarn and Wilton type (face to face) polypropylene carpet production were recycled in order to evaluate and their behaviors were examined as a result of the experimental studies.

As a result of the elongation test applied to the yarns, no correlation was found between the number of filaments and elongation, but it was observed that the elongation value increased as R-PP usage rate increased. The all samples of elongation values closest to the elongation value of the V-PP yarn 20% R-PP containing yarns and R-PP use of more than 20% were determined to affect tensile behavior.

As a result of the tensile strength test, it was observed that the tensile strength value increased in direct proportion with the increase in the number of filaments. It was observed that the use of R-PP did not constitute a trend between samples in the range of T1-144 and T5-144.

Consequently, shrinkage values of yarns containing 20% R-PP in all filament numbers were similar to those of V-PP BCF carpet yarns. Although the use of R-PP did not constitute a trend between samples in the range of T1-144 and t4-144, a 50% increase in shrinkage values increased. Here we can say the recycled increases the dyeability.

In result of the crimp constraction test, it was found that the crimp values decreased with the increase of filament counts and the use of R-PP did not significantly affect the crimp percentages of BCF carpet yarns.

As a result of the reflection spectrophotometer applied to BCF yarn samples, it was determined that the brightness of the yarns decreased and the yellowness increased as the recycled ratio increased. When the fiber sections of the yarns containing the same amount of recycled yarn were examined, lower color differences were observed especially in delta and delta / trilobal sections.

5.2. Carpet Test Analysis

Appearance retention test applied to carpets woven using R-PP according to CRI-4 scale; it was found that in the machine direction, an improvement in the appearance of carpet samples was observed with the use of R-PP. When the effect of cross section change was examined, an improvement in machine direction was observed. In the cross direction, a steady trend cannot be said with the increasing use of R-PP; it cannot be said that the change in cross-section constitutes a trend towards cross direction. It was also found that regional flares and crushes were found in the samples with recycle added carpet as a result of impact.

In the test results, loss of thickness under dynamic load, expressed as the simulation of walking on the carpet, was found to have the lowest thickness loss of V-PP carpet values in all filament counts, and the use of R-PP had a positive effect on thickness loss test results under dynamic loading.

In the result of weight loss with abrasion resistance, Increased use of R-PP showed increased weight loss in abrasion resistance test. Moreover the use of 100% R-PP decrease in weight loss with increasing filament counts was determined.

According to the tuft withdrawal force test, the force applied for the loop pulling was increased at the correct rate as the number of filaments increased. The effect of the use of R-PP on the loop tensile strength was concluded not significant.

According to the results of the thickness loss under long-term static load test, the thickness loss of all samples is dramatically decreased that was found. An increase in thickness loss was found in inverse proportion with the use of R-PP in carpets.

The over-all results showed that considering mechanical properties of BCF yarn and carpet samples, the acceptable performance were achieved as the ratio of R-PP in the yarn did not exceed 20% [37,38].

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