UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL&APPLIED SCIENCES

A STUDY ON WARP YARNS USED FOR CARPETS

M. Sc. THESIS

IN

TEXTILE ENGINEERING

BY

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DECEMBER 2008

A Study on Warp Yarns Used for Carpets

M. Sc. Thesis

in

Textile Engineering

University of Gaziantep

Supervisor

Inst. Dr. Fatma USKANER

By

Esin SARIOĞLU

December 2008

T.C.

UNIVERSITY OF GAZİANTEP
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NATURAL & APPLIED SCIENCES
TEXTILE ENGINEERING

Name of the thesis: A Study on Warp Yarns Used for Carpets
Name of the student: Esin SARIOĞLU
Exam date: 26.12.2008

Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

A STUDY ON WARP YARNS USED FOR CARPETS

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M. Sc in Textile Engineering
Supervisor: Inst. Dr. Fatma USKANER
December 2008, 113 Pages

A woven carpet includes three groups of yarns namely warp, weft, and pile yarns. There are two types of warp yarns which are important for backing structure of the carpets: stuffer and chain warp yarns. These yarns are generally produced as polyester/cotton (PES/CO), polyester/viscose (PES/CV) staple yarns or PES filament yarns. In this experimental work the mechanical properties of stuffer and chain warp yarns were investigated.

Warp yarns were investigated in two parts; in the first part warp yarns collected from Gaziantep carpet industry were tested to obtain their tenacity, elongation at break, initial modulus, toughness, and shrinkage values. Warp trials produced with one stage production technology as BCF and CF yarns were tested and the results were compared with commonly used warp yarns. Correlations between non-dimensional mechanical resistance of filament warp yarns and elongation were obtained.

In the second part, tensile test was performed on warp yarns raveled out from the carpet samples having different pile densities. The effects of weaving and latex processes on the mechanical property changes of both stuffer and chain warp yarns were determined and discussed.

Key words: warp yarn properties, stuffer warp, chain warp, carpet warp yarn

ÖZET

HALI İÇİN KULLANILAN ÇÖZGÜ İPLİKLERİ ÜZERİNE BİR ÇALIŞMA

SARIOĞLU, Esin
Yüksek Lisans Tezi, Tekstil Mühendisliği
Tez Yöneticisi: Öğr. Gör. Dr. Fatma USKANER
Aralık 2008, 113 Sayfa

Dokuma bir halı; çözgü, atkı ve hav ipliği olarak adlandırılan üç grup ipliği içermektedir. Halının arka semin yapısı için önemli olan iki tip çözgü ipliği vardır: dolgu ve zemin çözgü iplikler. Bu iplikler genelde poliester/pamuk (PES/CO), poliester/viskon (PES/CV) kesikli iplikler ve ya PES filament iplikler olarak üretilmektedir. Bu deneysel çalışmada dolgu ve zemin çözgü ipliklerinin mekanik özellikleri araştırılmaktadır.

Çözgü iplikleri iki kısımda incelenmiştir; birinci kısımda Gaziantep halı endüstrisinden toplanan çözgü iplikleri, kopma mukavemet ve uzaması, modülü, dayanıklılık ve çekme değerlerinin belirlenmesi amacıyla test edilmiştir. Tek aşamada üretim teknolojisi ile BCF ve CF olarak üretilen çözgü denemeleri test edilmiş ve sonuçlar yaygın olarak kullanılan çözgü iplikleri ile karşılaştırılmıştır. Filament çözgü ipliklerinin boyutsuz olarak mekanik direnci ve uzaması arasındaki korelasyonlar elde edilmiştir.

İkinci kısımda, farklı hav sıklığına sahip halı numunelerinden sökülen çözgü ipliklerine mukavemet testi uygulanmıştır. Dokuma ve lateks aşamalarının dolgu ve zemin ipliklerinin mekanik özellik değişimlerine etkisi belirlenmiştir ve tartışılmıştır.

Anahtar kelimeler: çözgü iplik özellikleri, dolgu çözgü, zemin çözgü, halı çözgü ipliği

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Inst.Dr. Fatma Uskaner for her continuous support, guidance, and encouragement throughout the course of my study and research.

I would like to thank to POLYSPIN A.Ş. especially Assoc. Prof. Dr. Yusuf Azrail Uskaner for supplying warp trials for this thesis.

The carpet samples for this thesis were produced in Yasin Kaplan Carpet A.Ş. I would like thank to Mutlu Dalcı, Alper Sarı and İbrahim Halil Nergiz. I would also thank to USAM Textile Laboratory for testing of yarns.

I would like thank my friends in Textile Engineering Department for their support. I also thank to H. İbrahim Çelik, C. İlknur Taşkın and H.İbrahim İçoğlu for their help in laboratory works and thesis.

Most of all, I would thank to my father, my mother, my sisters. They always provided heartfelt support and encouraged me.

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LIST OF ABREVIATIONS

AC	Alternative current
BCF	Bulk continuous filament
CF	Continuous filament
CV	Coefficient of variation
OE-rotor	Open-end Rotor Spinning System
PA	Polyamide (nylon)
PAN	Polyacrylonitrile (acrylic)
PES/CO	Polyester/ cotton
PES/CV	Polyester/ viscose
PES	Polyester
PES POY	Polyester partially oriented yarn
PID	Proportional-plus-integral-plus-derivative
PP	Polypropylene
RH	Relative humidity
US $ mln	United States dollars million
dtex	Decitex
cN/tex	Centi Newton per tex
gr/ m^3	Gram per meter cube
kg	Kilogram
kWh/kg	Kilowatt hour per kilogram
mm	Millimeter
m/ sec	Meter/second
s	Second
ε_y	Breaking elongation of the yarn
σ_y	Tenacity of yarn

CHAPTER 1
INTRODUCTION

1.1. Introduction

Carpet is one of the most important textile products in the world and it is a traditional Turkish textile product. Carpets are classified into two main groups in terms of the construction as hand-made carpets and machine-made carpets. Carpet production began first on hand-looms and then machine carpets succeeded the hand-made carpets. Machine carpets are preferred because of their low cost and high production rate. Construction of the machine-made carpets consists of the pile, weft, and warp yarns. The pile yarns are generally made from polypropylene (PP), polyamide (PA), acrylic (PAN), and wool. Jute is used as weft yarn. There are two types of warp yarns in carpet production; stuffer and chain warp yarns.

In Gaziantep, most commonly used stuffer warp yarns are PES/CO and PES/CV produced with OE-rotor spinning system. Filament stuffer warp yarns produced from PES at two stages; first stage is PES POY (polyester partially oriented yarn) production by melt spinning process, and second stage is either air-texturing or false-twist texturing including intermingling processes. The chain warp yarns made also from PES POY which is produced at two stages like stuffer warp yarns.

The production technologies both for stuffer and chain warp yarns require long production stages and they are time consuming and expensive. To produce more economical warp yarns, new systems, or trials must be experienced to save cost, time, and energy.

To produce more economical warp yarns POLYSPIN A.Ş was intended and produced warp trials on POLYSPIN BCF8 machine at one stage. It is obvious that one stage filament warp yarn production would be more economical than two stage filament warp yarn production and blended warp yarn production systems. However, there is no any valuable knowledge about the mechanical properties of warp yarns used in carpet production in literature. Therefore to compensate this gap an investigation about the mechanical properties of warp yarns are planned.

1.2. Objective of Thesis

The main objective of this work is to investigate the mechanical properties of warp yarns i.e. stuffer and chain warp yarns used in carpet production. Collected warp yarns mechanical properties i.e. tenacity, elongation at break, shrinkage value, toughness, and initial modulus values are determined. Then, the mechanical properties of one stage warp yarn trials produced as BCF and CF yarns are to be assigned.

In addition, warp yarns raveled out from the carpet samples are tested to determine the effect of weaving and latex processes on the yarns.

1.3. Structure of Thesis

In Chapter 2 of this thesis the Turkey carpet sector, carpet types, carpet yarns, and carpet yarn production systems are discussed. Then, Wilton carpet production system, carpet warp yarn production systems are explained in detailed form. In addition to these, the literature survey about yarn properties, warp yarns in weaving and carpets is reviewed.

Chapter 3 includes the description and coded representation of the collected warp yarns, warp trials and carpet samples. Apparatus of the experiments and measurement techniques are explained. Calculation of the initial modulus and toughness values of the yarns are given. Dimensional analysis of the filament warp yarns is made to create non-dimensional parameters.

Chapter 4 covers the experimental results and discussion. Experimental study concludes two sample groups. First group comprises collected stuffer and chain warp yarns. Tensile properties, initial modulus, toughness value, and shrinkage value of the warp yarns are determined and discussed. Tensile properties, initial modulus, toughness, and shrinkage value of warp trials produced with one stage system were also determined. For the second group, warp yarns raveled out from the manufactured carpet samples with different pile densities are tested. The tenacity and breaking elongation changes of the warp yarns are assessed for each carpet production processes (weaving and latex) and overall carpet production and results of these warp yarns are also discussed.

The conclusion of thesis and recommendations for further studies are presented in Chapter 5.

CHAPTER 2
BACKGROUND INFORMATION ABOUT CARPET PRODUCTION

2.1. Introduction

This study is related with warp yarns used in machine-made carpets. Basics of carpet types, machine-made carpets, carpet yarns and their production methods are introduced in this chapter. Literature survey related with carpets, warp yarns and their properties are also reviewed.

2.2. Carpet Industry in TURKEY and GAZİANTEP

Turkey has a significantly important place in the carpet industry around the world. Gaziantep has an important pay in the production of machine–made carpet in Turkey. It realizes approximately 70 % of carpet production of Turkey with 210 million m^2 annual production capacity [1]. Gaziantep also shares 5 % of world's carpet market [2]. From the viewpoint of textile sector in Gaziantep, 40 % of textile sector is dominated by spinning and 27 % by carpet manufacturers [3]. Raw materials used in carpet production (pile yarns, warp yarns) are especially provided from yarn spinning companies. Undoubtedly, manufacturers have a great deal of interest and investment in this sector because of its large pay in the export. Currently, due to the economical crisis in the textile industry, many attempts to decrease the cost of the end product have being made. So that, the change of the raw material, production of the carpets with a low quality, the use of the synthetic fibers instead of natural fibers (CO, wool, silk) compensate for the production cost providing the exposure of the crisis at least. Today, the production of the carpets appealing to different fancies in the means of design and appearance with a low cost is more forefront than the production of the carpets with a high quality. People want to buy carpets in colors and designs compatible with the current trend in home design. Because of these, they are fewer minds to the quality of the carpet than to its appearance. So this trend encourages industrials in the carpet sectors to produce carpets with low cost and high variety. Attempts to increase the variety satisfying the different demand and to decrease the cost became a promising field in these sectors. Carpet industry is separated into two sub-sectors as machine-made carpet and hand-made carpet.

At the first nine months periods of the 2007 export of the machine carpets became 585 million dollars, hand-made carpet export was 97 million dollars. Total carpet export has been raised % 0, 9 in the Turkey's general exports [4].

As was seen from Figure 2.1; 86 % of the total carpet export is machine carpet. Besides the quality, economic production of carpet is the main target of the carpet industry.

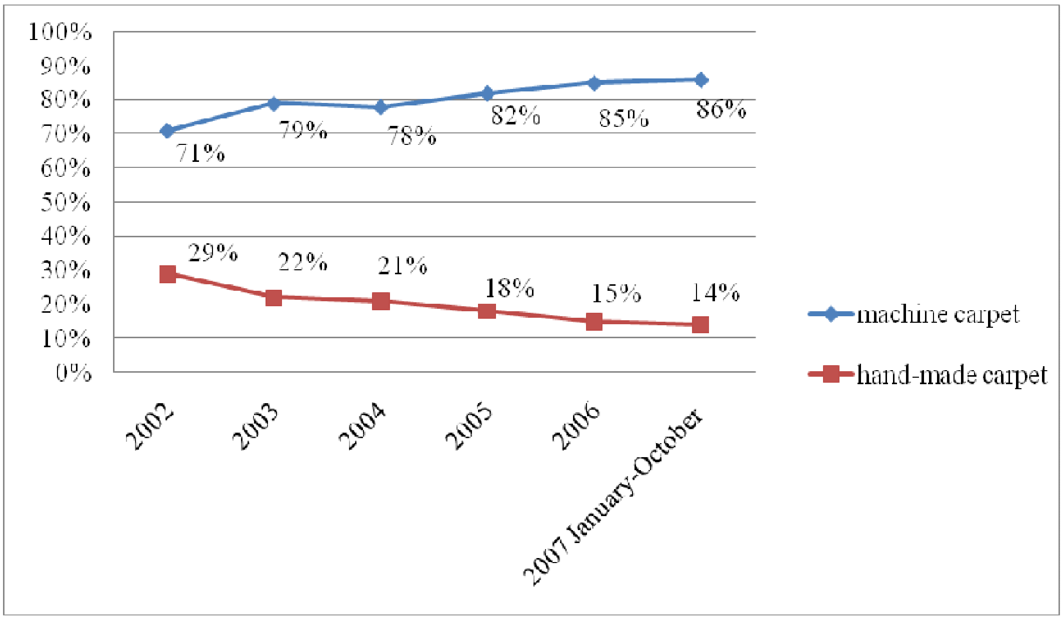


Figure 2.1 The rate of the carpet export (Unit: 1000 $) [4]

2.3. Carpet Types

Carpets are classified into two main groups according to the production methods as shown in Figure 2.2.

1. Hand-made carpets
2. Machine-made carpets

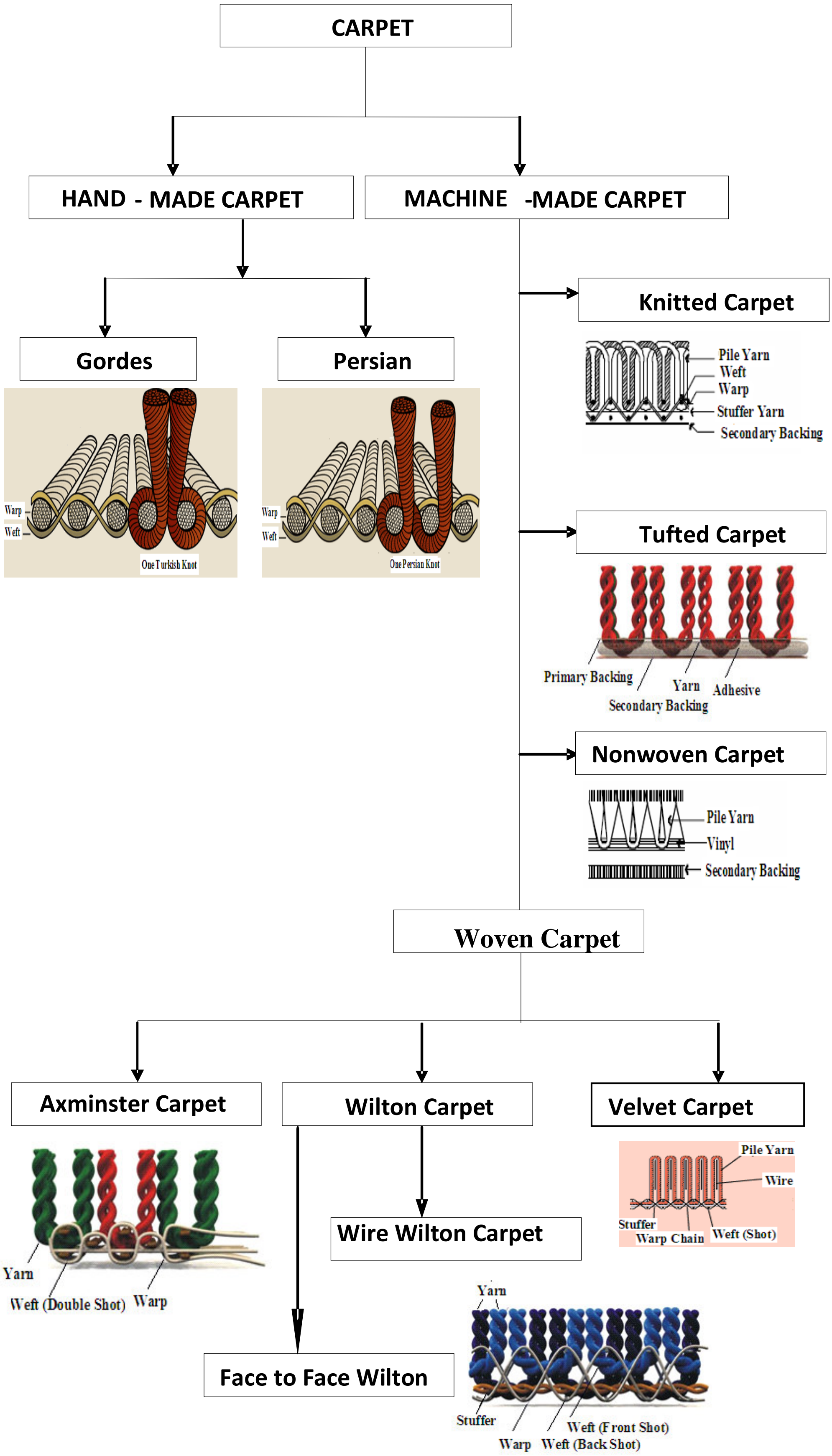


Figure 2.2 Classifications of carpets [5], [6], [7], [8]

2.3.1. Hand-made carpets

Since the first oil shock, consumers have been influenced by environmentalism and one consequence has been an increased demand for hand-knotted carpets. In particular, the small hand-knotting industries of India and Nepal expanded in the 1970s and 1980s to join Iran and Turkey as major producers. However, the productivity of the hand-made carpet is very small as compared with machine made carpet [9].

Hand knotted carpets are mainly produced by knotting the pile round the warp using the symmetrical Turkish (Ghiordes) knot or the asymmetrical Persian (Sehna) knot.

2.3.2. Machine-made carpets

Machine-made carpets are classified into 4 groups according to the production technology. They are woven, knitted, tufted, and nonwoven carpets as shown in Figure 2.2. The most popular machine-made carpets are woven carpets in Turkey especially in Gaziantep.

Woven carpet is an extension of the weaving process and uses three backing yarns to support the face or pile yarns (Fig.2 .3). The aim of the woven backing structure is to fasten and support the face (pile) yarns within the weave construction.

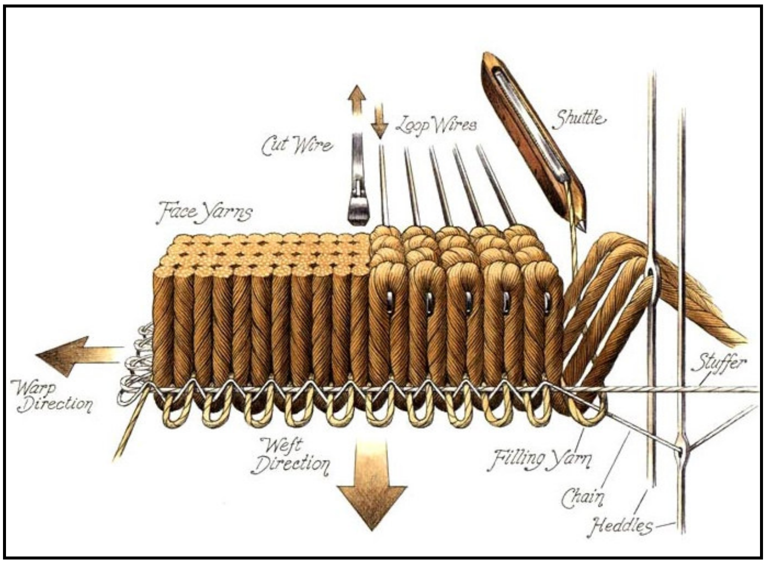


Figure 2.3 Woven carpet constructions [10]

The worldwide market potential for woven carpet and rugs is shown on Table 2.1. The latent demand for woven carpet and rugs is estimated $ 10.2 billion in 2011. The distribution of the world latent demand (or potential industry earnings), however, is not evenly distributed across regions. Asia & the Middle East is the largest market with 35.71 %, followed by North America & the Caribbean with 26.08 %, and then Europe with 25.02 % of the world market. In essence, if firms target these top 3 regions, they cover come 86.81 % of the global latent demand for woven carpet and rugs. Turkey is at the centre of these regions. Woven carpets are produced chiefly within the carpet types.

Table 2.1 Worldwide market potential for woven carpet and rugs (US $ mln): 2006 [11]

Region	**Latent Demand US $ mln**	**% of Globe**
Asia & the Middle East	2,479	35.7
North America & the Caribbean	1,811	26.1
Europe	1,737	25.0
Latin America	269	3.9
Africa	202	210
Oceana	86	1.2
Total	6,941	100.0

Woven carpets are classified as;

1. Axminster weaving
2. Wilton carpet
   - (i) Wire Wilton
   - (ii) Face-to face Wilton
     - -Single shed weaving
     - -Double shed weaving

Nowadays, face-to face Wilton type is commonly used.

2.4. Wilton Weaving

Two different systems are used to produce Wilton carpets. First one is wire Wilton system, the other one is Wilton face to face system.

2.4.1. Wire Wilton system

Wireloom weaving pre-dates Axminster weaving by many years. It takes two forms: Brussels weaving for loop-pile constructions and Wilton for cut pile.

Heald frames control the weaving of the backing and a jacquard mechanism causes pile yarn to be lifted over a 'wire' when its color is required in the design. Wires carrying a blade cut the pile on removal to create Wilton carpet, whereas 'round' wires leave loops to create Brussels carpet [9].

Pile that lays 'dead' in the backing may contribute to the cushioning effect of the carpet but increases the cost of the product, especially in multi-frame constructions. Figure 2.4 shows a typical weave structure. For economic reasons, Wilton weaving has become focused on two- or- three- frame designs woven in dense constructions for the contract market and to some extent on plain carpet. Classical styles of five- and- six- frame Brussels and Wilton carpets are still in demand in the upper market brackets [9].

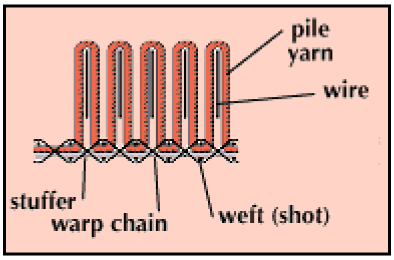


Figure 2.4 Wire Wilton carpets [6]

Wirelooms are unique in their flexibility for producing textured surface effects in both cut pile and loop pile. Pile yarns can be cut and loop form. A special 'wireless' loom for producing loop-pile textures and patterns has been intended. The loops are formed over temporary wefts, which in turns are supported by lancets- trips of metal suspended parallel to the warps at the point of weaving. The lancets function as gauges that determine pile height. Figure 2.5 shows a lancet supporting false picks (hollow circles) and a carpet structure having high loops formed over false picks and low loops formed over the backing weave [9].

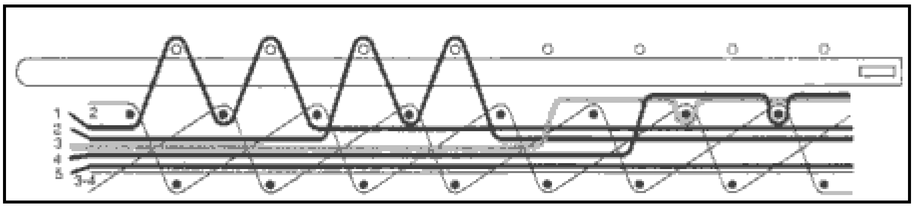


Figure 2.5 Principle of the loop pile master 32 wireless weaving machine [9]

2.4.2. Wilton face-to-face system

The weaving of two carpets face to face was pioneered by Van de Wiele in 1920s, and the technique has benefited from a sustained programmed of technical development so that it is now arguably the most sophisticated system of carpet manufacture. Face to face weaving is the principal system for manufacturing carpet squares and rugs in both traditional and modern designs, and is increasingly used producing wall-to-wall carpets [9].

The pile yarns in face-to-face weaving are selected by a jacquard mechanism, traditionally based on punched-card jacquards: electronic jacquards are supplied on new looms. The weft insertion mechanism on modern looms is by handover rapier that operates from large packages of yarn. Weft insertion may be by single-, double- or triple-rapier systems: each has its particular advantage, depending on the quality and style of the carpet to be woven [12].

Two backing fabrics are woven in parallel and as in Wireloom weaving the pile yarns are led to the point of weaving as warps. When a color is required in the design, the designated yarn is lifted (or dropped) from one backing to the other while the yarns are on the back surface in some constructions. An example weave structure is shown in Figure 2.6 [9].

Face-to-face looms are made up to 4.2 m wide. Modern patterning systems allow such wide looms to be used in a flexible way, weaving carpet squares of different widths and in different designs side-by-side [12].

The principal advantages of face-to-face weaving compared with wire Wilton are:

- higher rates of production
- the consumption of dead pile yarn is roughly halved in patterned carpets (it is shared between the top and bottom carpets)
- The cutting mechanism gives a very level surface [9].

Therefore, face to face Wilton looms are preferred and commonly used.

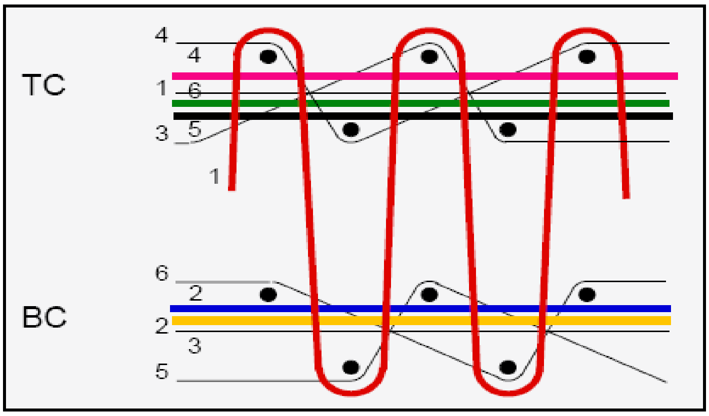


Figure 2.6 Weave structure of face-to-face carpet (Source: Michel Van de Wiele)

2.5. Carpet Fibers

Both natural and man-made fibers are used to weave carpets. CO, wool, silk, and jute fall under the natural fiber category while the commonly used synthetic fibers are PA, art silk, PAN, PES, and PP.

Traditional fiber of the carpet is wool and it is accepted as a standard fibers comparing with the others. Wool used in the making of carpets is mainly imported from Australia, New Zealand, and India (especially the Kashmiri wool). These are the best quality wools that create a luster of silky touch on the carpets. Wools are used to make hand knotted, woven and tufted carpets. But woolen carpet creates a foul odor if soaked into water and not dried. So the tiding process is a bit tedious [13]. Pile yarns are ring spun with 2-3 folded yarn. So that wool fibers are also spun, folded, and used by this way.

CO fibers are generally used as warp yarn in woven carpet. Jute fiber is generally used as weft yarns and its low extensibility and high modulus characteristics make jute preferred for this sector. Jutes are exported from Bangladesh.

Man-made fibers are separated into two groups as regenerated and synthetic fibers. Regenerated fiber as rayon is extracted from the wood pulp by chemical processes. Synthetic fibers are made from the petroleum or coal and also from derivatives of these. They are PA, PAN, modacrylic, PP, and PES.

About 97% of all carpets sold today are made with synthetic materials that are easy to maintain and can be adapted to a wide variety of styles and uses [14].

PA is one of the most important fibers used as pile. PA holds the most prominent position in the domain of synthetic fibers used in the making of carpets. This is durable, cheap, easily cleanable and also come in great designs and colors. Carpets that undergo heavy pressure regularly should be made up of PA for easy maintenance and high moisture resistant. The advanced technology has allowed PA carpet surfaces to maintain more friction thus allowing no dirt particles to stick on it [13]. PA can be used as pile yarn which is spun yarn form or continuous filament yarn form.

PP fibers are preferable and it is used in about 80 % of commercial carpeting because of the most economical fibers in the world [14]. PP is stain, mildew resistant, easy to clean; having low moisture absorbency makes it preferable for carpeting as pile yarn. PP can also be used in spun yarn form or continuous filament yarn form.

PAN is a wool-like fiber that is often used in velvet and level-loop carpets. It offers the look and feel of wool at much less cost, and is moisture and mildew-resistant. The one weak point for PANs is that they don't stand up to heavy traffic and so are not suitable for all household areas [14]. In England the import of the PAN carpet is forbidden because it is accepted that PAN’s fly is harmful for the human health.

PES fibers have an advantage of its cost than wool or PA. PES is commonly used in soft loop piles, making carpets that are luxurious and crush-resistant. PES is also basic fibers of warp yarns. Stuffer warp yarns are made from blended PES and chain warp yarns are made in the form of filaments. PES is known for its vibrant colors and it is naturally resistant to fading. It is easy to clean and resists water-based stains [14].

2.6. Carpet Yarns

Yarns used for carpet production can be classified into two groups as shown in Figure 2.7. These are;

1. Pile yarn; it is raw materials which visible on the surface of the carpet.
2. Backing raw materials: they are stuffer warp yarn, chain warp yarn and weft yarns which are not visible on the surface of the carpet and used for making carpet stronger and more voluminous.

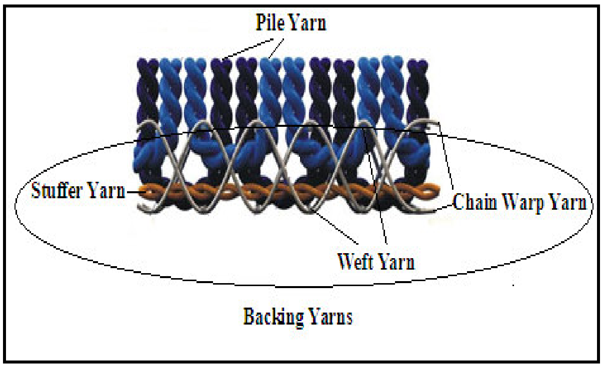


Figure 2.7 Carpet yarns

2.6.1. Pile yarn

The carpet industry utilizes both filament and spun yarns as pile materials. All of the yarn is bulked continuous filament (BCF). Heat set is applied to BCF yarn for using cut-pile carpets and spun yarns are also used for cut-pile carpets. BCF PP is widely used as pile yarns in face-to-face carpets [12].

Pile yarns are normally wound on cheeses and are mounted on frames, one for each color, and are led in parallel freely through the heald frames and into the relevant eyelets of the jacquard cords. To facilitate the mass production of some grades of PP carpet, pile yarns may be supplied on large bobbins, and correspondingly larger creels are required [12].

2.6.2. Backing materials

The backing structure of a woven carpet consists of chain warp, stuffer warp and weft yarns. The chain warp and the weft interlaced together from the basic backing fabric; the weft also holds the pile tufts in place. The stuffer warp yarns that lie straight in the backing provide the dimensional stability of the carpet and weft side positioning of the chain warp yarns and pile [12].

2.6.2.1. Chain warp yarn

Each pair of warp ends is constantly interchanged during the weaving process and is also subject to contacts with the stuffer and pile yarns.

The key properties required for chain warp are:

- Flexibility and high tensile strength to permit reliable working in the loom.
- High energy absorption, enabling it to accept peak forces during weaving.
- Low hairiness, to prevent excessive interaction during the shedding action.
- Fairly high inter-yarn friction, contributing to the binding of the overall structure.

It is usually necessary to provide two separate supply beams of chain warps to the loom. The upper and lower warps do not follow symmetrical paths and sometimes are let off at different tensions so as to achieve one relatively straight warp and one that is sinusoidal. Some face-to-face carpet structures have trios of chain warps, rather than the usual pairs. Two of them are chain warp yarns while third one is straight which is regarded as a stuffer warp. Beams are wound having the respective lengths of yarn required for the upper and lower chain warps.

The most commonly used materials are CO, PES/CO, PES, and PP. Jute yarns, commonly used for weft and stuffer warps, are only rarely used for chain warps because they are excessively hairy, virtually inextensible and provide lower tensile strength than other readily available materials.

CO

CO in 100% form has been the traditional chain warp for all types of woven carpet for many years. Linear density range is between 205 tex (Nm 12/3) and 170 tex (Nm 24/4), depending on the type of carpet to be woven.

At beaming, CO yarns are sometimes sized to reduce hairiness, thereby facilitating weaving. Sizing, if any, should be light so as to avoid creating too sleek a yarn that does not bind the structure firmly.

PES/CO

PES is often blended with CO for warp yarns in order to improve spinning efficiencies, especially in the finer counts, and to increase yarn strength, thereby reducing the risk of breaks at weaving. PES/CO chains may be treated by the weaver in a similar way to 100% CO yarns.

PP

PP chain warps may be fibrillated tape or roller-embossed film; slightly twisted (60 turns per meter) to give a low cost round yarn.

Yarn linear densities are usually in the range 90—133 Tex. Round fibers is not used because it does not grip the wefts as well as tape. To obtain increased dimensional stability, heat-set yarn may be used.

PES

Multi-filament PES is favored as chain warp in some carpet constructions, notably to meet flammability specifications where PP is unacceptable. Yarn linear density around 92 tex is used, twisted to about 100 turns per meter [12]. A particular advantage of PES is that it packs densely, so that longer warps may be beamed, providing longer runs between beam changes. PES is strong, resists abrasion in weaving [12]. Currently, PES filament yarns are widely used as for carpet yarns.

2.6.2.2. Stuffer warp yarn

The stuffer warp is held straight during weaving with a view to providing dimensional stability in the warp direction.

Jute yarns, similar to those used for weft, are highly satisfactory as stuffer yarns. Singles or plied yarns are used.

PP tape or split film yarns are used in the range 133-500 Tex, and must be twisted to minimize abrasion of the chain warps during weaving. Heat setting is essential for good dimensional stability.

CO yarns, identical to those used in the chain warp, are sometimes used as stuffer yarns [12].

An alternative of CO yarn; blended PES/CO yarns are commonly used in carpet sector. Besides, PES/CV, PES staple yarns, and PES filaments are also used as stuffer warp.

2.6.2.3. Weft yarn

Clearly, the weft of a carpet should have adequate strength to hold the carpet together, but since yarns usually have more than adequate strength, weavability is a more important criterion. Dimensional stability is the key carpet property provided by the weft.

Jute yarns have proved highly satisfactory as weft because of their high modulus and low extensibility. Linen is sometimes used in high quality traditional Wilton carpets [12].

2.7. Warp Yarn Production

Warp yarns used in carpet production are generally made from blended PES with CO and CV in staple yarn form or PES filament air-textured or false-twist textured with intermingled yarn.

Conventional warp yarn production systems are grouped as;

1. Short staple yarn production system
2. Two stage filament production system

An alternative method, one stage filament production system is added to conventional ones in this work. This alternative method is proposed by POLYSPIN A.Ş. and there are some experiments about this method. Schematic view shown in Figure 2.8 is plotted for carpet yarns and their production methods.

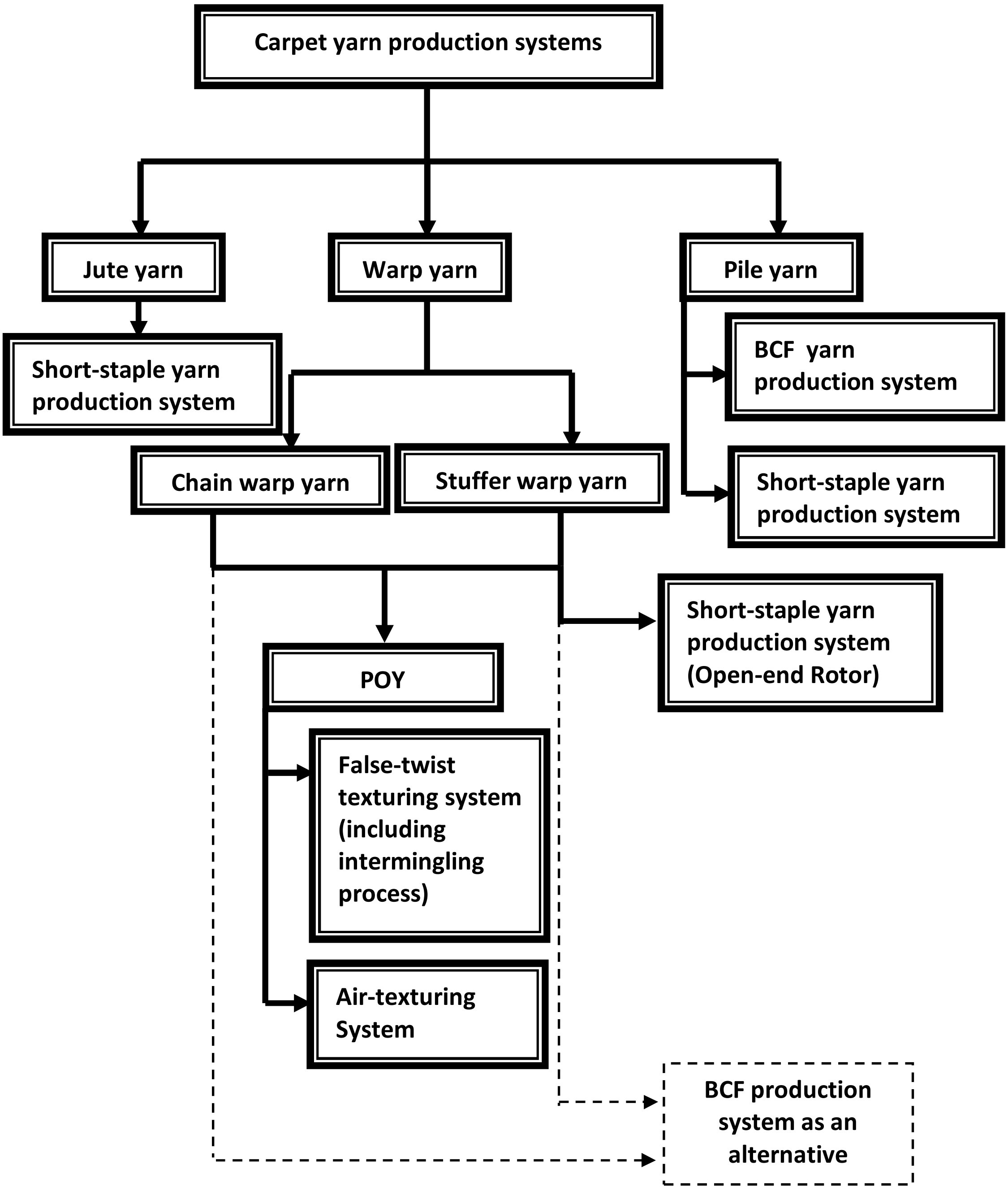


Figure 2.8 Production methods of carpet yarns

2.7.1. Short-staple yarn production system (OE-Rotor System)

The processing step of the short-staple yarn is as follows [15].

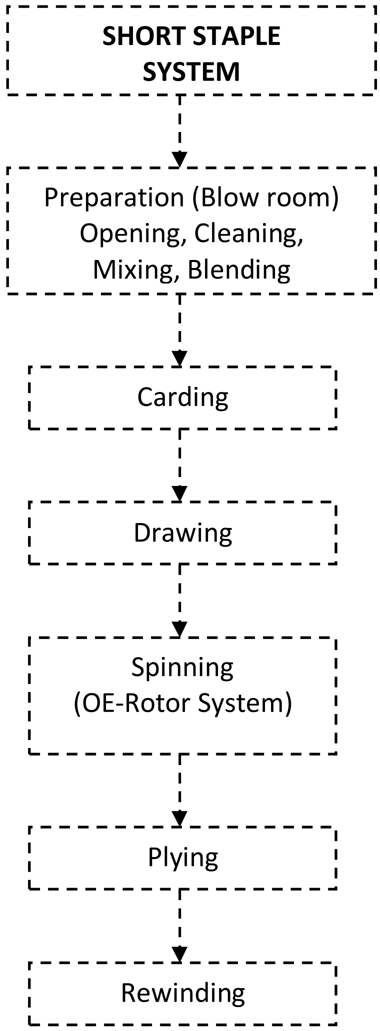


Figure 2.9 Production order of the OE-rotor spinning system [15]

Blow room

The main tasks of the blow room are; opening the flocks of the fibers. Cleaning operation is the next duty of the blow room and it is the process to eliminate approximately 40-70 % of the foreign materials in blow room. Dust is removed by suction devices and dust elimination takes place at all stages of the spinning process. Fibers are blended by bale openers at various ratios by weight from the bales to collect the sequentially arriving bunch of fibers from individual bales and mix them thoroughly. Blow room must ensure that raw materials are evenly delivered to the cards.

Carding

The card is the known as the heart of the spinning mill. It is a strong relationship between the well carding operations with quality of the yarn.

Blow room opens the raw materials to the flocks, but card must open to the stage of the individual fibers. This is essential to enable elimination of impurities. The degree of cleaning achieved by card is very high, in the range of 80-95 %.

The card scarcely improves long-term blending, since the residence time of the material in the machine is too short. It improves transverse blending because, apart from OE spinner, the card is only machine to process individual fibers.

The card can be given task of creating partial longitudinal orientation of fibers, but not that of creating complete parallelization. In order to be able to deposit the fiber material, to transport it and process it further, and appropriate intermediate product must be formed. This is sliver [16].

Drawing

Drawframe plays an important role on evenness of the yarn, as it improves evenness over short, medium, and, especially, long terms. According to the required quality of the yarn, the number of the passage can be added. To obtain an optional value for strength in the yarn characteristics, the drawframe arranges parallel in the fiber strand of the fibers by way of draft. In addition to parallelizing, doubling also provides a degree of compensation of raw material variation, by blending. Blending is composed of synthetic/synthetic and CO/synthetic fiber. Drawframe is equipped with appropriate suction removal systems; more than 80 % of the incoming dust is extracted [17].

OE-rotor spinning

Rotor spinning involves the separation of fibers by vigorous drafting, and then recollection and twisting of the fibers in rotor as shown in Figure 2.10.

In the actual OE-rotor spinning machine, drawframe sliver is entered to a spring loaded feed plate and feed roller. Fibers within the sliver are then individualized by a combing roller covered with saw tooth wire clothing. Once opened, the fibers pass through a transport tube in which they are separated further and parallelized before being deposited on the inside wall of the rotor.

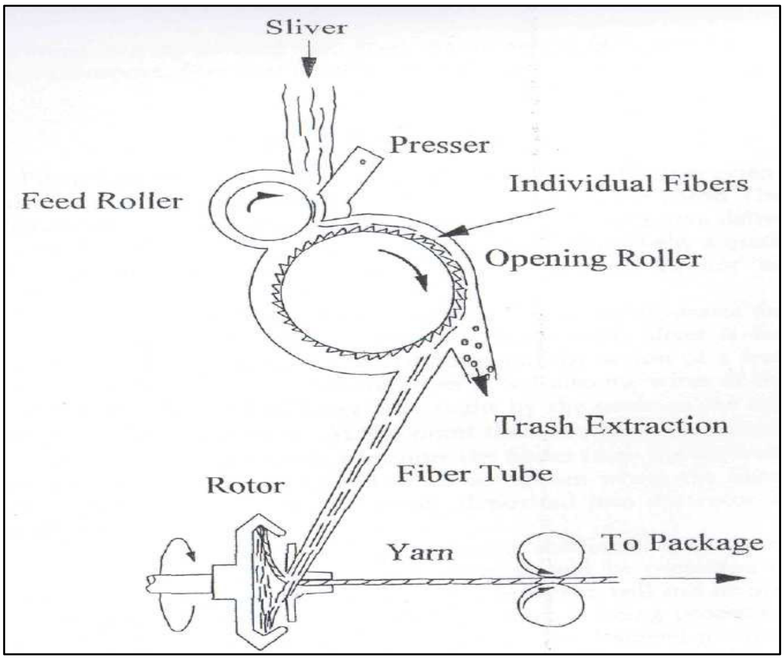


Figure 2.10 OE-rotor spinning [18]

Centrifugal forces, generated by rotor turning at high speeds, causes the fibers to collect along the wall of the rotor, form a ring. The fiber ring is then swept from the rotor by a newly formed end of yarn which contains untwisted fibers. With each rotation of rotor, twist is inserted, converting the fiber bundle into yarn as it is pulled out of the rotor through a navel. The yarn is then taken up onto a cross wound package [18].

Plying and rewinding

Folded yarn production is achieved in plying machine for the further process and the yarn is wound on to the cross- wound packages which yarn will be used in weaving, knitting etc.

2.7.2. Two stage filament yarn production

This type of the stuffer yarn made from the PES fiber is firstly produced as POY and then texturing process is applied. The typical spinning speed for POY is in the range of 2600-3800 m/min. [19]. The production of the POY filament is represented in Figure 2.11.

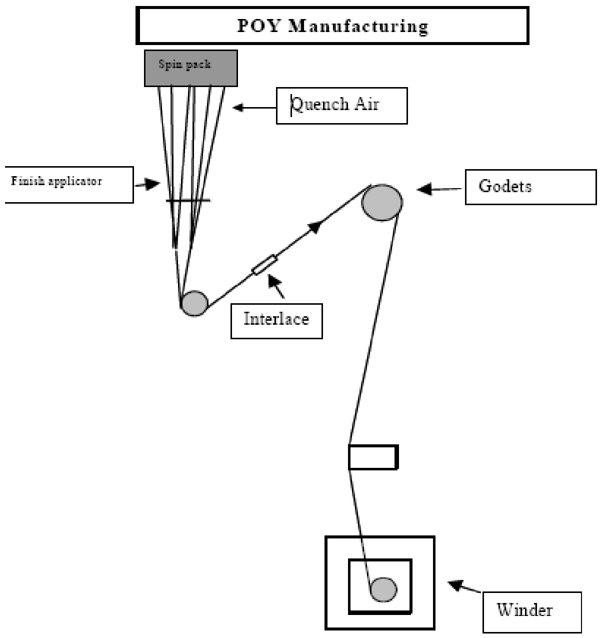


Figure 2.11 POY production line [19]

Filament warp yarns are classified into two production groups for the aim of the usage. These yarns for both stuffer and chain warp yarn are produced by air- texturing and false-twist texturing (including intermingling process) systems.

2.7.2.1. Air- texturing system

Air textured yarns are produced from thermoplastic, cellulosic or non-organic filament yarns using turbulent fluid, which is usually compressed air [20].

The air texturing process is mostly applied to the POY. One or more ends of filament yarn are overfed at a constant rate to a special air jet, which blows, depending on the amount of overfeed between the inlet and outlet feeds, the yarns into a continuous string of smaller and larger loops. The individual filaments are compacted by the air stream, which stabilizes the loops. Water is added in front of the jet to lubricate the yarn, so that there is less yarn to jet friction inside the jet and the formation of loops becomes more efficient. The water is blown off the yarn at the jet exit and the yarn is basically dry when it is wound onto a package. Core effect air textured yarn is used widely when high bulk and volume is required. The core yarn is overfed to the jet with less overfeed than the effect yarn. [21].The schematic representation of the core effect air textured yarn production is shown in Figure 2.12.

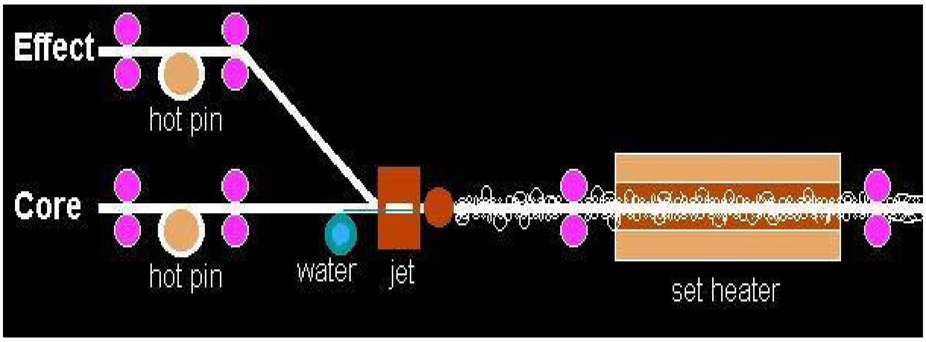


Figure 2.12 Core effect air texturing process [21]

Texturing processes cause deformations to occur in heat softened filaments and these deformations are retained when filament are cooled.

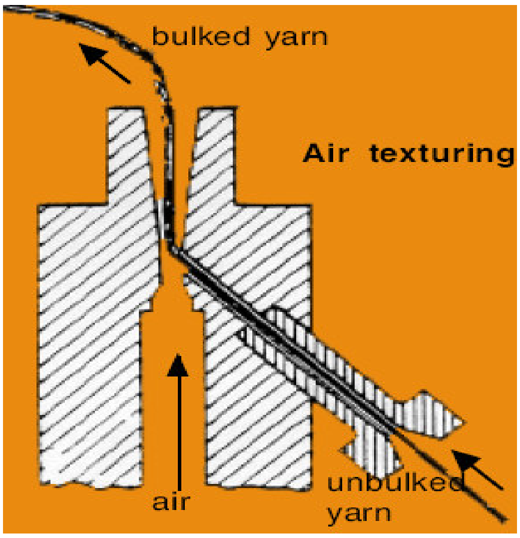


Figure 2.13 Air texturing unit [22]

The air texturing process uses a turbulent jet of air to displace and entangle the filaments in any continuous filament yarn, causing the originally smooth surface of the yarn to become broken up by small filaments and tangles [22]. This process occurs almost instantaneously in a jet (Figure 2.13).

2.7.2.2. False-twist texturing (including intermingling) system

POY is the standard feed yarn for the texturing process. It is a continuous filament yarn spun at a speed, which is, for example for PES, around 3200 m/min [21]. The production of the false-twist textured yarn is shown in Figure 2.14.

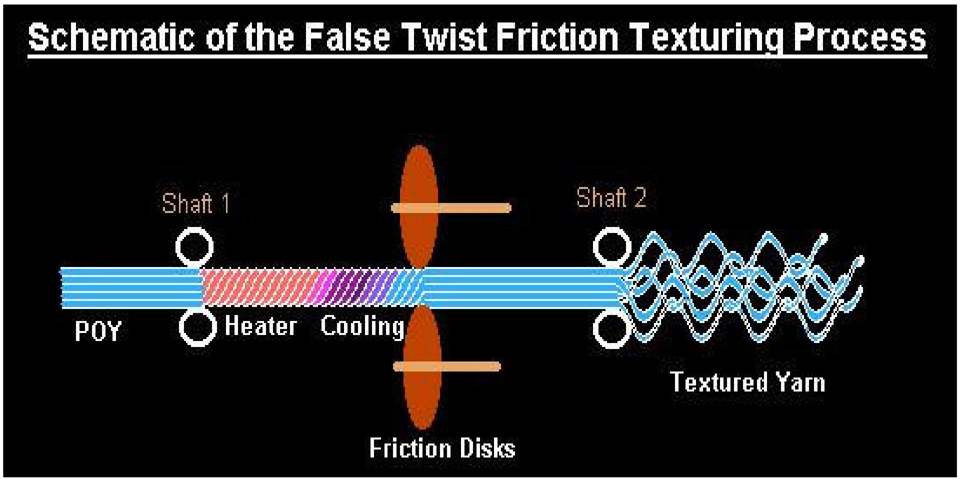


Figure 2.14 False-twist friction texturing process [21]

Shaft 1 is the input feeding device for the POY. From here the yarn is fed to Shaft 2. When POY is fed into the machine, the yarn has to be drawn. The speed of shaft 2 is always higher by the factor of the necessary draw ratio for the particular yarn and process. The yarn is simultaneously twisted and drawn. The twisting is done with a friction device, such as a set of rotating friction disks. Friction disks insert the necessary false twist into the running yarn, so that the yarn can get textured. But there are other twisting devices such as belts. After Shaft 1 there is a yarn heater, which heats the yarn to a temperature where it can be thermo-set. Right after the heater is normally a cooling plate, which must cool the yarn to a substantially lower temperature in order to permanently thermo-set the twist. As the yarn is released from Shaft 2 we observe how each single filament is trying to assume the three dimensional helix formation it was set in. After the texturing process, intermingling is carried out mainly to simulate the protective twist obtained in false-twist texturing.

Most synthetic multifilament yarns are intermingled:

- flat multifilament (undrawn or drawn) for textile and technical application,
- texturized yarns for textile products and carpets (tufting) [23].

Çirkin, S., [24] studied about the effect of texturing process variables on physical properties of yarn (2006). To investigate the change of yarn properties according to production variables, each variable were changed between controlled levels. The changes in shrinkage, tenacity, breaking elongation etc. of the yarns were determined by shifting the texturing process parameters.

The intermingling jet is illustrated in Figure 2.15; the air stream is directed onto the yarn perpendicularly and intermingles the individual filaments to form a distinct knot. In carpet industry, periodical intermingled yarns with variety of the linear density according to the area of usage are used as shown in Figure 2.16.

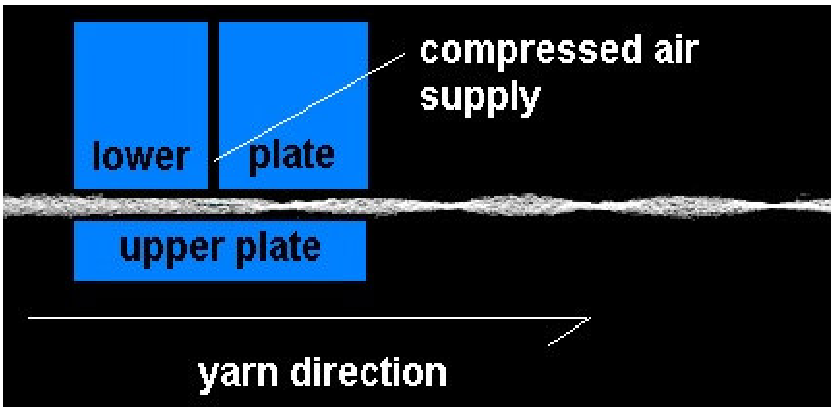


Figure 2.15 Intermingling process [25]

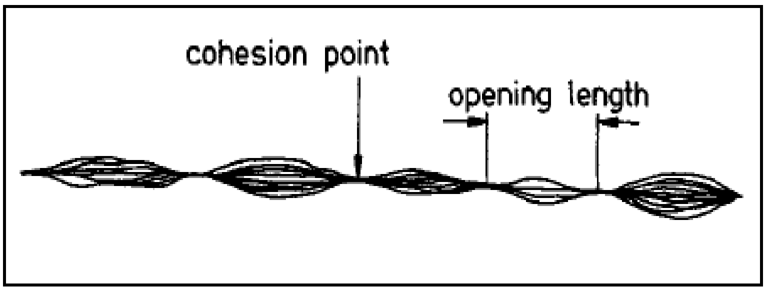


Figure 2.16 Periodical intermingled yarns [23]

The intermingling process results in a loose association of filaments having cohesion point which are responsible for the filament cohesion.

The number of intermingling nodes per unit length, their mechanical stability, and their distribution is determined by:

- construction details of the tangling jets and their positioning in the yarn path,
- process conditions (air pressure, yarn speed and tension, etc.),
- yarn constitution (flat, textured, filament count, spin finish, wet or dry) [23].

2.7.3. One stage filament yarn production (Alternative method)

BCF yarns are generally used as pile yarns in carpet weaving. PP, PES, and PA can be used as raw materials. However, POLYSPIN A.Ş. intended to produce one stage warp yarn by using their POLYSPIN BCF8 machine. BCF and CF filament warp yarns can be produced on the same machine. The CF production includes polymer spinning and intermingling without texturing.

2.7.3.1. BCF production system

Generally BCF and CF (except texturing process) yarn production systems include all or in part the following units;

1. crystallizator
2. dryer
3. dosing unit
4. extruder
5. spinning
6. quenching
7. spin finish
8. drawing
9. texturing
10. entangling (intermingling) and
11. winding [26].

In extrusion spinning processes generally thermoplastic polymers like PES, PA and PP are converted into fibers and yarns. Starting material is polymer in the form of chips. Properties of yarns depend on type of polymers and process parameters of manufacturing systems [26]. The production line is shown in Figure 2.17.

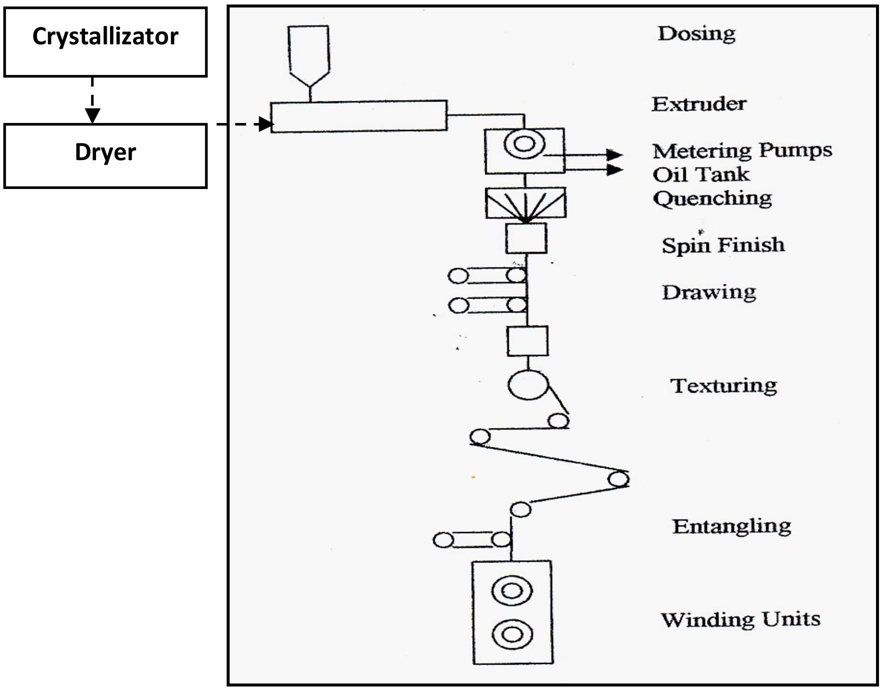


Figure 2.17 BCF yarn production line [26]

Crystallizator and dryer for PES chips:

Pretreatment process is necessary to achieve the PES filament yarn production which is differed from the PP BCF production. Firstly, crystallization process of the PES granules is achieved in order to form hard surface that is necessary to avoid sticking of granules to each other. Crystallization is a process obtained by combination of drying and mixing [26]. Processing of PES at 120 °C for half an hour is generally enough for good crystallization. After crystallization PES chips are dried at 160 °C in six hours [26]. BCF machine with dryer and crystallizator is shown in Appendix H [27].

Dosing unit:

Dosing systems are used to feed masterbatches into raw material prior to feeding extruder. Batch type and continuous type dosing system are available. Depending on the method of measurement for mixing ratio, dosing units are classified as gravimetric or volumetric types. In the gravimetric dosing units weight ratios of raw materials and additives controlled where as in volumetric dosing units volume ratios of raw material and additives are controlled [26]. Digital gravimetric dosing unit is generally used [28].

Extruder:

The mixed materials i.e. chips and masterbatch enter to the extruder. Extruder machines having a heated barrel and a rotating screw where raw material is melted. The mixed materials became a melt of the chips at the exit of the extruder by heating step by step shown in Figure 2.18 [22].

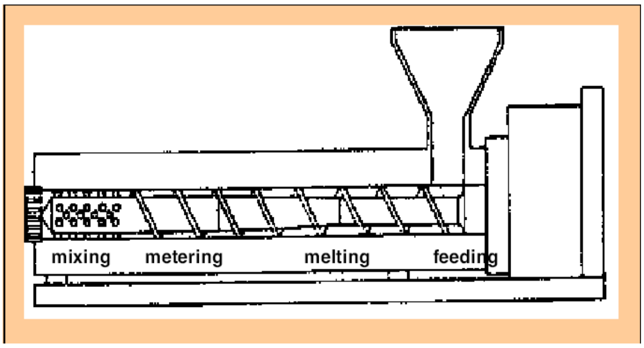


Figure 2.18 Lay out of an extruder [22]

The temperature of the molten polymer in extruder is from 220- 270 °C degrees [28]. To produce PES filament the temperature of the extruder is 240 °C degrees.

Quality of the yarn depends on the stability and homogeneity of the melt in the extruder. In order to obtain homogeneity in the melt dynamic and static mixers are used in the melt line. Pressure at the exit of the extruder is measured and kept constant, this is very important for obtaining denier stability [26].

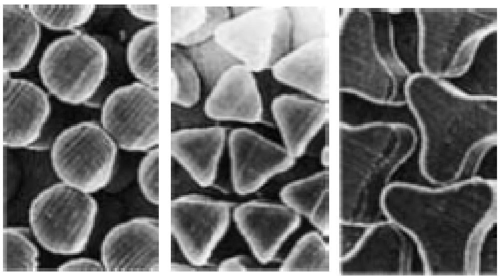
Spinning:

The molten polymer emerges from the exit end of the extruder and enters to gear pumps manifold.

Pumps meter the polymer melt and feed it into the individual spin packs. The pump and spin pack assembly determine whether a high quality yarn emerges or thread breaks. Pumps are driven by AC motor and worn gear box combination. Pumps, manifolds, and spin pack are located inside an oil-tank which ensures homogeneous and constant temperature polymer melt spinning [26].

The molten material is guided separately to the spinneret which is given in Figure 2.19 by effect of the pressure to produce filaments. According to the usage orifice shape of the spinneret vary from trilobal to the circular as shown in Figure 2.20.

Figure 2.19 Spinneret [29]



(a) **(b)** **(c)**

Figure 2.20 Cross-sectional shape of the filament (a) Round, (b) Triangular, (c) Trilobal [23]

Quenching:

In the spinning of molten polymers melt spinning begins with a cooling of the molten filaments after it leaves the spinneret. At the same time, the filament is pulled downwards towards the take up section and this resulting tension in the molten filament provides a stretching action in the molten filament itself. The quench air bows the filaments out to tension and steady those [30].

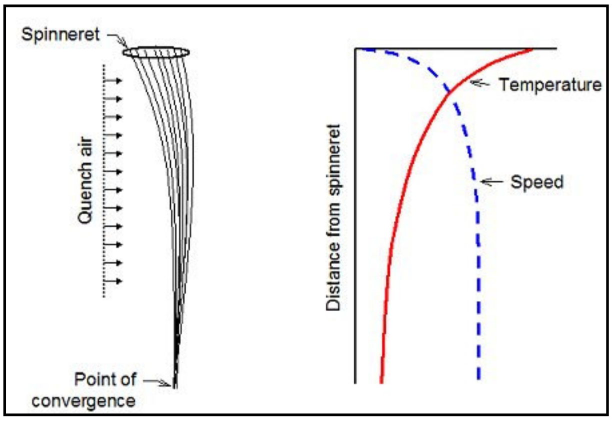


Figure 2.21 Cooling of the filament [30]

The quench system used in BCF machine includes chiller unit, filtering and heat exchanger unit, double-suction centrifugal fan, inverter, and quenches cabinet. Cooling air speeds of 0.3-0.6 m/sec at a temperature about 14-16 °C degrees are used [26]. For PES filament cooling air is at 15 °C.

Spin-finish:

The multifilaments which are solidified by cooling process are passed through the nozzles to take the required oil [31]. The spin-finish consists of different components such as lubricating oils, antistatic agents, emulsifiers and antibacterial agents. Spin finish liquid reduces friction and optimizes the yarns processing characteristics [26].

Drawing:

In order to obtain better molecular orientation drawing is necessary. The yarn must be above its glass transition temperature to draw satisfactorily. The multifilaments are drawn to achieve the desired properties for the end use. The different speed of the godets and heat provide to orient the yarn and lengthen filaments [31]. The ratio of the godet speeds is the draw ratio.

The draw godets are driven by vector controlled AC drives. In hot drawing the godets are internally heated. In the heating system PID control is used [32]. The godets are heated to approximately 100- 150 °C to make it easy for drafting PES materials on the machine. The drawing ratio varies from 2.5 to 3.5 [33]. Surface of the godets are plasma ceramic coated and surface temperature are measured and controlled [26].

BCF texturing:

Texturing is a process for modifying continuous filament yarns in order to give those improved properties of bulk, stretch, warmth, and opacity.

BCF texturing process is generally achieved by hot fluid jet. During process, yarn is heated by stream or hot air and transported to the heated texturing section shown in Figure 2.22. In this section yarn is bulked and put forwarded by pressurized air [34]. The texturing process achieves at 160-170 °C with air pressure at 6-7 bar [33]. Crimped yarn come to the cooling drum, as seen in Figure 2.22 consists of rotating drum with a mesh surface through which air is drawn. The ambient air passes through the bulked yarn, which is in the form of a plug though less compressed, and this passage of air provides the required cooling [20].

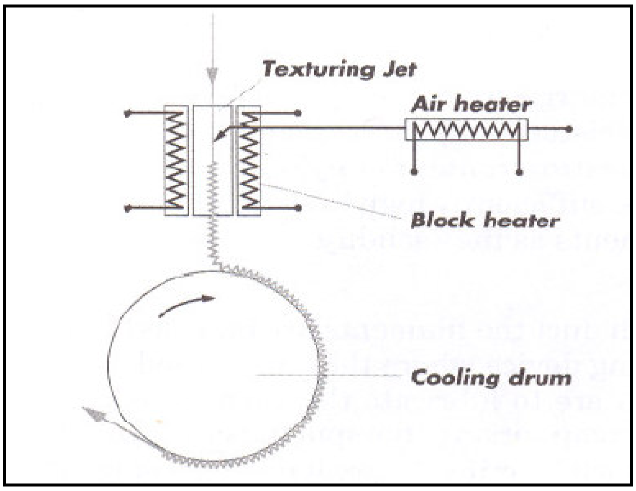


Figure 2.22 Principle of hot fluid texturing [12]

Entangling or intermingling:

Bulked yarn to be textured must have a slight twist to be a yarn form. In BCF yarn production techniques, instead of twist yarn necessary cohesion to the filaments is given with intermingling.

Friction between the fibers provides the essential cohesion forces to hold the staple fibers together. There are no cohesion forces between the filaments owing to parallel filament structure. So that, intermingling process makes the random and bulked filaments into intermingling yarn by means of cold compressed air jet illustrated in Figure 2.23. Air flow in the jet affects on the filament as vertically. There are no chemical or physical changes of the filaments by intermingling process, only filament are replaced [34]. The intermingled process is achieved at 6-8 bar pressurized air. The filament is periodically intermingled with 30-35 points in meter [33].

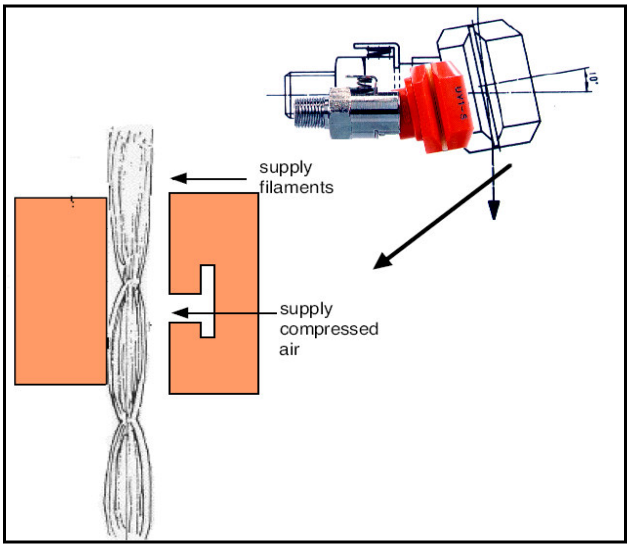


Figure 2.23 Intermingling of filaments [22]

Winding:

Finally, yarn is wound on to a package by fully automatic winders.

2.7.3.2. After treatments

Twisting;

Additional twisting process is necessary for the yarn.

Fixation;

After twist insertion, twist of yarn is desired to be fixed without deformed. It is applied by means of fixation process either by saturated steam or hot air [34].

2.8. Warp Preparation

Backing yarns are prepared for weaving by direct beaming: a sectional warper can produce uneven carpets. Figure 2.24 shows the principle of face to face carpet weaving techniques. Typically, there are two reeds, and the front one oscillates slightly to improve the regularity of beaming.

In Gaziantep, direct beaming process is generally used for both stuffer and chain warp yarns. Although, sectional warping operation is used to demands of slightly tension of chain warp yarn. There is no optional tension control of the warp yarns during beaming; the quality control of the tension is only detected randomly and according to the experience.

To weave face-to-face carpet, all beams are placed at the back of the machine (Fig. 2.24) and for top and bottom carpet, 4 stuffer and 8 chain warp yarn beams are necessary. Beam tension is regulated by weight in Wan de Viele machine. Stuffer yarns lie along the carpet straightly, but chain yarns accompany the weaving to put the pile yarns together. Therefore, weight of the stuffer beams is heavier than the chain beam.

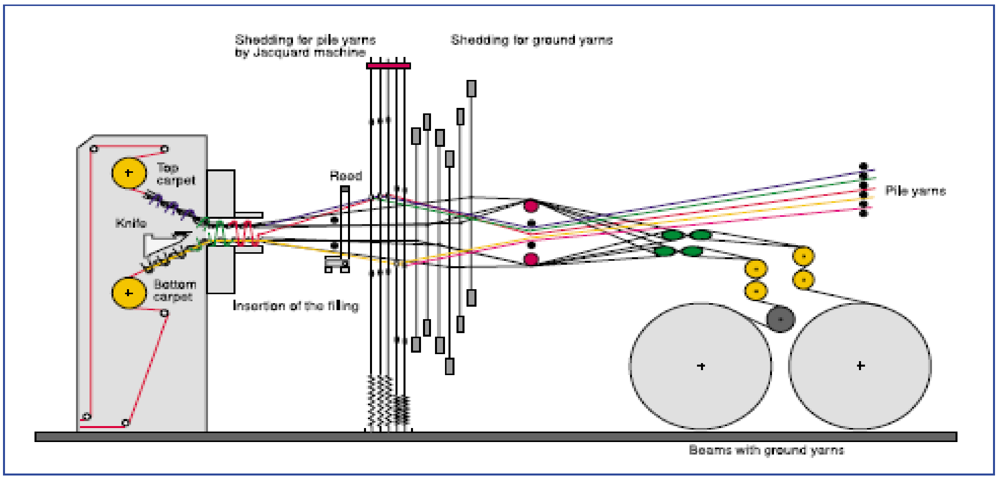


Figure 2.24 Principle of the face-to-face carpet weaving technique (with two rapiers) (Source: Michel Van de Wiele)

2.9. Ground Weaves

Shedding the backing materials (warp yarns) for weaving is achieved by heald frames that are actuated by a cam mechanism. Cam boxes must be changed to produce different ground weaves. Warp tensions may be tight or slack, according to the requirements of the weave. The beam stand incorporates warp stop motions to eliminate weaving faults that would otherwise result from yarn breakages.

When designating a carpet structure, it is necessary to define the backing weave and pile weave separately. When there is just a pair of chain warps, the ground weave is defined simply by the sequence of weft shots above or below a warp (e.g., 1/1 (Figure 2.25)).

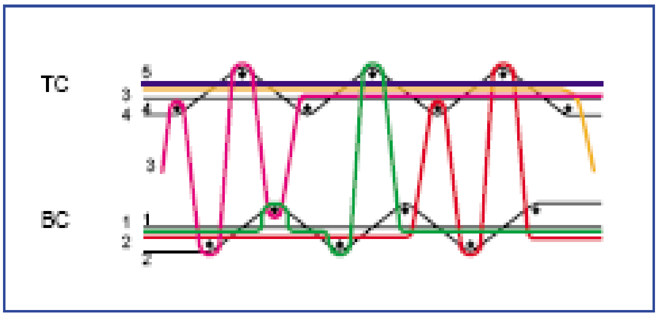


Figure 2.25 1/1 V weave structure with incorporated dead pile (ground structure 4x (1/1)) (Source: Michel Van de Wiele)

A weave diagram is necessary to complete the detail, making it apparent how many colors (frames) of pile yarns are used and whether the dead pile is floated on the back of one of the carpets or incorporated within the backings [12].

2.10. Literature Survey

The aim of this study is to investigate the warp yarn properties used in carpet production. Although a lot of studies were found about warp yarns in weaving fabric, there were not sufficient resources for carpet weaving. Especially, effects of pile yarn properties on carpet performance and BCF pile yarn production method have researched.

Therefore, we separate the literature survey with the following parts;

1. Research on, yarn tenacity, breaking elongation, toughness, elasticity, and initial modulus.
2. Research on the warp yarn tension during weaving.
3. Research on carpet in general.

2.10.1. Research on fiber blending effect, yarn strength, breaking elongation, toughness, elasticity, and initial modulus

Mechanical properties of yarn are directly affected by the raw material properties, fiber blend ratio (if the yarn is blended), fiber strength, fiber elongation, twist etc.

Bayramoğlu, E.Ç. [35], has studied the effects of number of fibers in cross-section of the yarn on breaking strength/ elongation of different blend ratio of PES/CO ring spun yarn (1995). There were seven 30 tex ring spun yarn with different blend ratio of PES/CO such as 12.5/87.5, 20/80, 31.3/ 68.7, 50/50, 68.7/31.3, 80/20, and 87.5 /12.5**.** CO combed slivers and PES carded slivers were blended in drafting machine with a certain ratio. Besides yarn strength, yarn elongation was also examined and location of the fibers in the cross-section of the yarn was photographed. Ideal ratio has put forward as 65/35 % of PES/CO as a result of the long researches' on mechanical properties of the yarn. By increase in the ratio of the PES fiber in the yarn, it was detected both strength and elongation values of the yarns increased.

Matsumoto, K., Kim, W., and Lee, K. [36], studied on toughness of various fibers using the stress-strain curves (1996). The influence of tensile test conditions such as strain-rate, temperature, humidity had been analyzed. It was proposed that tensile properties of a fiber should be evaluated not only by strength and elongation, but also by toughness. It was detected that there was a linear relationship between the breaking stress and toughness value. On the other hand, toughness value increased a little with extension increases.

Çelikkanat, Ş.S. [37], has studied on the CO melange yarn characteristics such as strength/elongation, unevenness, stress/strain behavior, elasticity etc. properties using alternated PES ratio (2000). Two sets of samples were selected. At first, yarns were selected and produced as Ne 30/1 100%, 67/33 % and 33/67 % CO/ PES blend ratio. Second set of the yarns were Ne 30/1 CO mélange yarn with 1%, 20 %, 40 %, 61 %, 8 %, 100 % dyed fiber ratio. Tests were performed on the Uster Tester 3 and Uster Tensorapid to determine the hairiness, evenness, neps, thin places, thick places, strength, elongation etc. For the first set; when PES ratio increases, breaking force and elongation will also increase. And for second set; it was detected dyed fiber ratio was important on yarn unevenness.

Enhoş, S.A. [38], has examined the effects of blend factors that influence yarn tenacity properties (2001). PAN /CV, PES /CV yarns with various ratios of PES, PAN, CV produced as Ne 20/1 and 30/1. They were tested to determine the effect of these parameters on yarn strength. Strength tests were performed on Uster Tensorapid 3 according to the CRE (constant rate of extension) principle and unevenness tests were made on Uster Tester 3. The theoretical and practical results were compared. Theoretical results were found to be different from practical one.

Palaniswamy and Mohamed [39], studied the effect of single yarn twist and ply to single yarn twist ratio on strength and elongation of two ply CO yarn (2005). Also, the effect of ply to single yarn and cable to ply yarn twist ratio on strength and elongation of ply and cable multifilament yarn were examined.

Baykal, P.D., Babaarslan, O., Erol R. [40], studied on the strength elongation properties of PES /CO blended rotor yarns by using blend ratios and yarn count as predictors (2006). Five different blend ratios were determined as 0/100, 25/75, 50/50, 75/25, 100/0 PES/CO. These yarns were spun to yarn with five different yarn count such as; 36.9 / 29.5 / 24.6 / 21.1 / 18.5 tex. Uster Tensorapid-3 was used to determine the strength and elongation of the yarns. Regression analysis is used to calculate the relationship between independent variables (yarn count and blend ratios) and response variables (strength and elongation). According to the experimental results, the strength of the blended yarn decreased with changing of PES ratio from 0 to 25 %. The breaking elongation of yarns increased with changing of PES ratio from 10 to 90 %. For both strength and breaking elongation the higher correlation coefficients were estimated between actual and predicted values.

Cyniak, D., Czekalski, J., Jackowski, T, Popin, L. [41], analyzed the quality parameters of CO/ PES rotor yarn blends with various contents of the components and different length distributions of the CO fibers (2006). They examined yarns with two linear densities of 20 tex and 30 tex, manufactured with an R1 rotor spinning frame from Rieter. The blend ratios were changed in steps of 12.5% within the range from 100% CO fibers to 100% PES fibers. Produced yarns were analyzed by laboratory tests, and linear density, number of twists, breaking force, elongation at break, work to break, tenacity, elasticity degree, linear density unevenness, hairiness, and faults were determined. Uster tester is used for this purpose and statistical analysis was applied. As a conclusion for tenacity and elongation at break, the linear density of the yarn manufactured and the percentage share of CO fibers in the blends with PES fibers have significant influence on the tenacity values. The tenacity of yarns increases independently of the linear density. However, elongation at break is dependent the linear density of the yarn and 100 % PES fibers have the greatest values of elongation at break.

2.10.2. Research on the warp yarn tension during weaving operation

Kovacevic, S., Hajdarovic, K., Grancaric, A.M. [42]. have measured the breaking force of warp yarns taken per segments on the loom using the same warp on three different looms (2000). To simulate the deformation of warp yarns, samples from the same warp beam were taken and, after various conditions of cyclic stress on a dynamometer. The most approximate degree of warp deformation is that occurs in the weaving process per segments on the loom and per weave types. It was included in the deformation caused by stress. Fabrics of the same densities in three different weaves were woven on two different looms, and six fabric samples were produced as 100 m long each. Warp samples were also taken from the looms and designated by segments after weaving each weave type. Two weaving machines were achieved which are MAV SACM and Sulzer for this study for three types of weave; plain, twill and satin. After the testing results indicated that the greatest irreversible deformations of the warp yarns occur in the front shed and in the beating-up zone.

Gahide, S.F. [43], has studied on MEMS (micro- electro- mechanical- system) based detection device was used to monitor warp tension and end breaks in weaving

(2001). A macro prototype device (sensors, software, and hardware) to monitor warp tension and break was designed and built.

Turhan,Y., Eren, R. [44], investigated the warp tension change by changing weft density from a lower to a higher value in a weaving machine with electronic take up and electronic let off motions (2004). For this study plain fabric was woven on PICANOL (OMNI) weaving machine with 150 denier warp and weft yarns. Tension measurements of warp yarns were achieved on tension meter from the slack to the tight weave by chancing pick density which is defined as the number of weft yarns in each centimeter. Warp tension and cloth fell distance were measured at certain intervals from the beginning of weaving with a new pick density. The length of fabric woven until the cloth fell reached its steady state value was determined. The warp tension measured until the steady state cloth fell values was analyzed. When weft density increased, tightness faults were observed until weaving conditions to be permanent.

Lappage, J. [45], has studied the weaving performance of the eight experimental yarns which spun to two counts (31 and 37 tex) and two twist levels (105 and 120 α twist) (2005). End breaks were found to be due to failed splices, abrasion failure, and thin places and also balloon effect of the spinning process. The indicidence of thin-place breaks was found to increase with increasing irregularity or coefficient of variation of the yarn, and as the linear density of the yarn decreased. Thin place end breakage rate which determines the yarn count limit for acceptable weave ability. It was shown how to predict the thin-place end breakage rate from the yarn and loom parameters.

Dayık, M., Kayacan, M.C., Çaliş, H., Çakmak, E. [46], have studied on the control of the let-off system by measuring the warp tension by means of Gene expression programming (GEP), one of the Evolution Programming methods (2005). For this control, the function of warp tension occurring in a complete rotation of the main shaft of weaving loom was determined by the method of GEP. Particularly, during the shed opening and beat-up processes to make warp tension constant, warp beam was rotated clockwise and counterclockwise. The values of warp tension obtained by GEP were compared with the values of conventional controlled methods. As a conclusion, the obtained warp tension values were 11.2% less than values of classical approach. At the same time it was also provided that break rate of warp tension is decreased by 20%. It had shown that GEP is an effective tool for the decreasing of warp break rate.

Lee and Seyam et al. [47], investigated inexpensive methods to detect warp breaks using nontraditional technique that would pave the way to automate warp break repair (2006). For this study, a system that can detect warp breaks using MEMS accelerometers as sensors was developed for Jacquard weaving. Four MEMS accelerometers were mounted on selected harness cords of a harness tie operated by a Staubli Jacquard head, which was mounted on an ELTEX rapier weaving machine of one meter wide. Five yarn types were selected such as CO, CO/ PES 50/50 %, PES spun, PES filament and spectra yarn. During weaving the tension varies due to yarn breaking elongation caused by shed opening and closing and beat up. The highest tension variation was experienced by the spectra yarn due to its high modulus followed by the PES filament yarns. This means that the total tension values for these two yarns were the highest among the five yarns studied.

2.10.3. Research on carpet in generally

Erkesim, M.A. [48], has studied the technological behavior of wool, PAN and wool/CV blends of the machine made carpets (1995). Carpets were selected random according to their production methods such as Wilton with double rapier and tufted. Static electricity, pile height, pile weight, thickness loss under mechanical effect and compression, abrasion, static loading, pile density, dimensional stability, pile yarn withdrawal tension, flammability, water fastness, light fastness etc. tests were achieved.

Berkalp, Ö.B. [49], examined difference of the carpet performance of using wool, PAN, and PP pile yarn for selected two different pile heights and tuft with fixing other parameters (1997). Pile yarns were selected as wool (Ne 15/3), PAN (Nm 10, 5/2), and PP (1800 dtex). Stuffer warp yarn was Ne 14/4 PES /CO and chain warp yarn was Ne 14/3 PES yarn. Weft yarn used for this study was jute yarn 4800/2 dtex. Carpets were woven on Van de Wiele carpet machine double rapier. Pile heights of carpets were 7 and 9 mm and weft density of produced carpets were 500 and 600 wefts per meter. Hexapod drum, Wira abrasion instrument, Wira withdrawal force instruments and Wira pile thickness measurement device were used to test these carpets. According to the abrasion testing, PAN carpets had the highest value 600 picks/m and with 9 mm height. Measurement of the thickness loss was made by means of Hexapod drum. According to this test, highest thickness loss was determined on the PP carpet. PAN carpet had the highest value of withdrawal force.

Tekin, M. [50], has studied the properties of carpet produced by Wilton face-to face carpet weaving system (2002). Wool, PAN, and PP carpets were selected for this study. Decrement of the thickness under dynamic and static loading under tension tests were performed for these carpets. Thickness loss of the PAN carpet under static force had the highest value and thickness loss of the wool carpet under dynamic force had the highest value among the others.

Dereli, T., Görür, G., Uslu, E. [51], studied on the cost analysis and determination of quality factors for machine-made PP carpets and presented a systematic approach (2004). With the developed systematic approach, not only the cost of a carpet were going to be found based on the required quality parameters, but also the carpet manufacturing parameters for a given unit-cost.

Dalcı, S. [52], investigated the effects of carpet production parameters on carpet performance. PAN and PP piles were chosen, because of their popularity in carpet yarn industry in Turkey (2006). Using of 16 carpet samples having two different pile densities, four different pile heights, tuft withdrawal strength, appearance, pilling, losses of thickness under dynamic loading, loss of thickness in short and long term under static loading were examined. As a result, the tuft withdrawal strength of the PAN fibers was higher than the PP carpets. Both of the PAN and PP carpets had high pilling resistance. The PAN carpet had lower loses of thickness under dynamic loading than PP carpets. PP carpets had higher loss of thickness under short term static loading, for long term static loading they had lower loss of thickness than PAN carpets.

CHAPTER 3
MATERIALS AND METHODS

3.1. Materials

In this work warp yarns are investigated to determine the mechanical properties of both stuffer and chain warp yarns produced with different technologies. Warp yarns are investigated in two parts;

1. determination of mechanical properties of warp yarns used in carpet industry
2. examination of the effects of weaving and latex application on the tensile properties of warp yarns.

In the first part; 56 warp yarns used by Gaziantep carpet manufacturers were collected and tested to determine the mechanical properties. 28 of these yarns were used as stuffer warp yarns and 28 of them were used as chain warp yarns. The raw material of all collected warp yarns is generally PES and blending of PES with CO and CV. Although these collected warp yarns were produced from different raw materials with different technologies all of them are used in Wilton face-to-face weaving looms in Gaziantep. In addition, 5 warp trials produced with one stage production system were also tested.

In the second part of this work, sample carpets were produced by using 197 tex 70/30 % PES/CV OE-rotor yarn as stuffer yarn and 67 tex PES false-twist textured intermingled filament as chain warp yarn in YASİN KAPLAN CARPET A.Ş. 197 tex yarn was preferred because of its widely usage in carpet industry as a stuffer warp yarn. 67 tex false-twist textured intermingled PES filament for chain warp was chosen due to its compatibility with the Wilton face-to-face machine used in our study. Preparations of samples are given in Figure 3.1.

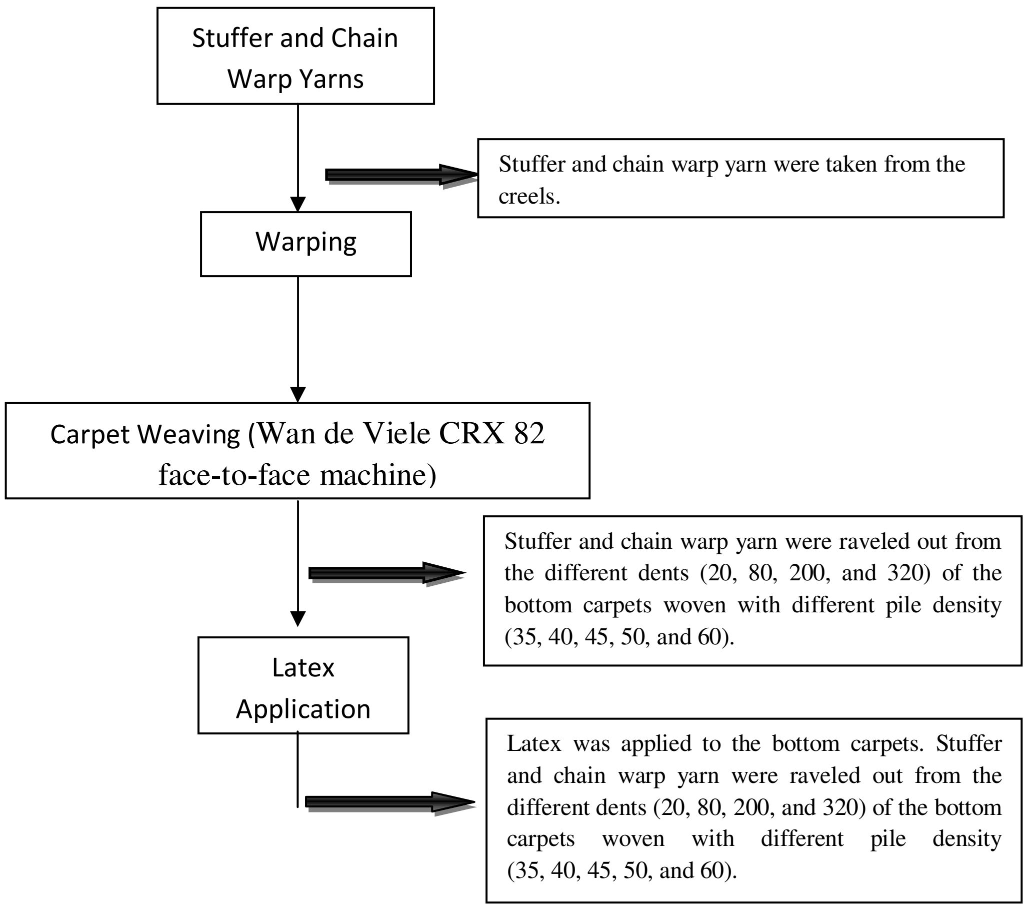


Figure 3.1 Sample preparation order

10 sample carpets were produced for 5 different pile densities to determine the tensile property change of warp yarns with and without latex application.

3.1.1. First group of the samples

56 warp yarns for woven carpet production have been collected from different factories. 28 of collected warp yarns were used as stuffer warp yarns by Gaziantep carpet firms. These yarns were produced from blended PES/CO and PES/CV as staple yarns or PES filaments with different technologies.

Blended stuffer warp yarns are produced with OE-rotor spinning and plied. Filament stuffer warp yarns are produced with two steps. As was mentioned in Chapter 2, single step warp yarn production could be more economical from the conventional warp yarn production methods.

POLYSPIN A.Ş. produced some warp trials on BCF machine which build in İran. In this work 5 warp trials as one stage warp yarn production samples were tested and results were discussed in Chapter 4. 3 of these warp trials are produced as BCF (Bulked Continuous Filament) yarns and 2 of them are CF (Continuous Filament) yarns.

28 of collected 56 warp yarns were used as chain warp yarns and they were produced by two step warp yarn production methods (air-texturing and false-twist texturing including intermingling process) from PES POY (Partially Oriented Yarn).

A coding system was used for easy analysis of test results of collected warp yarns. Yarn type, yarn definition, and types of the raw materials, blending ratios and yarn linear density were coded for both stuffer and chain warp yarns and are given on Tables 3.1, 3.2, 3.3, respectively. At the beginning of this code "WB" is used for BCF warp trials and "WC" is used for CF warp trials.

The collected samples were tested to determine tenacity and breaking elongation, twist, blending ratio, linear density, and shrinkage. Test methods and calculations are given at section 3.2.

The code of the yarns which defines the yarn characteristics of collected stuffer and chain warp yarns are listed in Table 3.4, 3.5, respectively. Warp trials yarn characteristics are given on Table 3.6.

Table 3.1 Codes of the yarn type and types of raw materials using within the carpet as warp yarns

Number	Yarn Type	Code
1	Short-Staple /Stuffer Warp Yarn	SS
2	Filament /Stuffer Warp Yarn	SF
3	Filament/Chain Warp Yarn	CF
Number	**Type**	**Code**
1	Polyester (PES)	P
2	Cotton (CO)	C
3	Viscose (CV)	V

Table 3.2 Codes of blending ratio

Number	Blending Ratio (%)	Code
1	100/0	B_1
2	85/15	B_2
3	80/20	B_3
4	70/30	B_4
5	65/35	B_5
6	60/40	B_6

Table 3.3 Codes of the linear density of warp yarns

Number	Linear Density (tex)	Code
1	211	T_{211}
2	209	T_{209}
3	202	T_{202}
4	197	T_{197}
5	183	T_{183}
6	178	T_{178}
7	167	T_{167}
8	150	T_{150}
9	139	T_{139}
10	122	T_{122}
11	119	T_{119}
12	116	T_{116}
13	100	T_{100}
14	89	T_{89}
15	69	T_{69}
16	67	T_{67}

Table 3.4 Codes of the stuffer warp yarns

Number	Linear Density (tex)	Fiber	Blending Ratio (%)	Code
1	211	PES/CO	65/35	$SSPCB_5T_{211}$-1
2	211	PES/CO	65/35	$SSPCB_5T_{211}$-2
3	211	PES/CO	65/35	$SSPCB_5T_{211}$-3
4	197	PES/CO	65/35	$SSPCB_5T_{197}$
5	197	PES/CO	60/40	$SSPCB_6T_{197}$-1
6	197	PES/CO	60/40	$SSPCB_6T_{197}$-2
7	197	PES/CO	70/30	$SSPCB_4T_{197}$-1
8	197	PES/CO	70/30	$SSPCB_4T_{197}$-2
9	197	PES/CO	70/30	$SSPCB_4T_{197}$-3
10	197	PES/CO	70/30	$SSPCB_4T_{197}$-4
11	197	PES/CO	70/30	$SSPCB_4T_{197}$-5
12	197	PES/CO	85/15	$SSPCB_2T_{197}$-1
13	197	PES/CO	85/15	$SSPCB_2T_{197}$-2
14	197	PES/CV	65/35	$SSPVB_5T_{197}$-1
15	197	PES/CV	65/35	$SSPVB_5T_{197}$-2
16	197	PES/CV	70/30	$SSPVB_3T_{197}$
17	197	PES/CV	80/20	$SSPVB_3T_{197}$-1
18	197	PES/CV	80/20	$SSPVB_3T_{197}$-2
19	197	PES/CV	85/15	$SSPVB_2T_{197}$-1
20	197	PES/CV	85/15	$SSPVB_2T_{197}$-2
21	178	PES	100	$SFPB_1T_{178}$-1
22	178	PES	100	$SFPB_1T_{178}$-2
23	167	PES	100	$SFPB_1T_{167}$
24	150	PES	100	$SFPB_1T_{150}$
25	122	PES	100	$SFPB_1T_{122}$-1
26	122	PES	100	$SFPB_1T_{122}$-2
27	122	PES	100	$SFPB_1T_{122}$-3
28	100	PES	100	$SFPB_1T_{100}$

Table 3.5 Codes of the chain warp yarns

Number	Linear Density (tex)	Fiber	Code
1	122	PES	$CFPB_1T_{122}$-1
2	122	PES	$CFPB_1T_{122}$-2
3	122	PES	$CFPB_1T_{122}$-3
4	122	PES	$CFPB_1T_{122}$-4
5	122	PES	$CFPB_1T_{122}$-5
6	122	PES	$CFPB_1T_{122}$-6
7	122	PES	$CFPB_1T_{122}$-7
8	122	PES	$CFPB_1T_{122}$-8
9	122	PES	$CFPB_1T_{122}$-9
10	122	PES	$CFPB_1T_{122}$-10
11	122	PES	$CFPB_1T_{122}$-11
12	122	PES	$CFPB_1T_{122}$-12
13	122	PES	$CFPB_1T_{122}$-13
14	116	PES	$CFPB_1T_{116}$
15	100	PES	$CFPB_1T_{100}$
16	89	PES	$CFPB_1T_{89}$-1
17	89	PES	$CFPB_1T_{89}$-2
18	89	PES	$CFPB_1T_{89}$-3
19	89	PES	$CFPB_1T_{89}$-4
20	69	PES	$CFPB_1T_{69}$
21	67	PES	$CFPB_1T_{67}$-1
22	67	PES	$CFPB_1T_{67}$-2
23	67	PES	$CFPB_1T_{67}$-3
24	67	PES	$CFPB_1T_{67}$-4
25	67	PES	$CFPB_1T_{67}$-5
26	67	PES	$CFPB_1T_{67}$-6
27	67	PES	$CFPB_1T_{67}$-7
28	67	PES	$CFPB_1T_{67}$-8

Table 3.6 Codes of the warp trials

Number	Linear Density (tex)	Fiber	Code
1	209	PES	$WBFPB_1T_{209}$
2	202	PES	$WBFPB_1T_{202}$
3	183	PES	$WBFPB_1T_{183}$
4	139	PES	$WCFPB_1T_{139}$
5	119	PES	$WCFPB_1T_{119}$

3.1.1.1. The characteristics of the warp yarns

The warp yarns production is achieved on basically three systems. One of these systems is OE-rotor spinning system for short-staple stuffer warp yarns. The others are air-textured and false-twist textured systems for filament warp yarns. Approximate raw material properties and some considerations are given in following sections;

OE-rotor spinning

Generally, to produce warp yarns three fibers are used in OE-rotor spinning; PES, CV, and CO. The blending ratio of these fibers varies from 100 % PES to 60/40 % PES/CO or PES/CV for stuffer warp yarns. The basic characteristics of these fibers used for OE-rotor spinning system are given on Table 3.7. In OE-rotor spinning systems, minimum usable length for CO fiber is 25.4 mm; therefore the fiber lengths are taken generally greater than this value [53]. On the base of the information from the warp yarn manufacturers, the specifications of fibers used for the production of the warp yarns for carpet industry are; the length of PES fiber is 38 mm, the length of the CO fiber is in the range of 27-30 mm, and the length of the CV fiber is 38 mm. In addition, the fineness of the fibers used for warp yarns are; PES fiber is in the range of 1.2-1.4 dtex, CO fiber is 1.4-1.6 dtex and CV fiber is 1.4 dtex. They are in the range of values given on Table 3.7.

Table 3.7 Characteristics of the fibers used for OE-rotor yarn [53]

Material	Length (mm)	Fineness (dtex)	Strength (cN/dtex)	Elongation (%)
PES	32-40	1-1.7	2.5-6.5	15-50
CO	26-38	1.2-2.2	2-5	6-10
CV	32-40	1.3-1.7	2-2.5	15-17

Air-texturing and false-twist texturing systems

The raw material of both air-texturing and false-twist texturing systems is POY. To produce warp yarns between the range of the linear density from 178 tex to 67 tex obtained POY properties ranges are given on Table 3.8. SASA and Korteks are the main suppliers of the POY yarn for carpet industry in Turkey and they provide approximately 80 % of POY demands for this sector. The specifications of POY are given on Table 3.8, they were formed by using the ranges taken from SASA and Korteks.

Table 3.8 General characteristics of the POY

Raw materials	**POY (Partially oriented yarn)**
Number of filaments	68-96
Drawing ratio (D/R)	1.65-1.95
Strength (cN/tex)	20-25
Elongation (%)	110-140
Linear density (dtex)	500-600
Spin finish (OPU) (%)	0.32-0.42
Shrinkage at boiling (%)	50-70

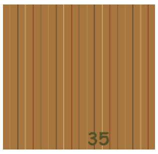
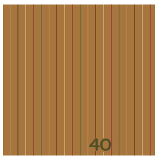
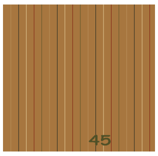
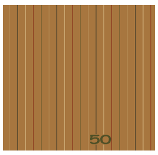
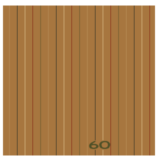
3.1.2. Second group of the samples

In the second part of this work; carpet samples were prepared to determine the effect of weaving and latex application on the tensile property changes of warp yarns. Sample carpets were manufactured in YASİN KAPLAN CARPET A.Ş., by using 197 tex 70/30 % PES/CV OE-rotor stuffer warp yarn and 67 tex PES false-twist textured intermingled chain warp yarn. Wan de Viele CRX 82 face-to-face machine was used for this purpose. Carpet samples weaving parameters are shown on Table 3.9. Preparation step of carpet samples and the tested warp yarns taken from different production steps are shown in Figure 3.1.

3.1.2.1. Warp preparation, weaving, and latex processes

To evaluate the tensile property changes of the stuffer and chain warp yarns from warping to the end product (including latex). Stuffer and chain warp bobbins were taken from the creel. These yarns were tested to determine initial warp yarn properties. Totally, 10 bottom carpets were produced with 5 different pile densities and these carpets were used for this study. Five bottom carpets with different pile densities were taken after weaving. Warp yarns (stuffer and chain warp yarns) were raveled out from specified dents of each carpet for tensile test. Dent refers to the space between wires of the reed, heddles, or harness through which warp end are drawn [54]. Latex was applied for the other five bottom carpets and then warp yarns (stuffer and chain warp yarns) were also raveled out from specified dents of each carpet after latex application. Styrene/butadiene polymer was used as backcoating material. To obtain the optimum application this polymer was applied with the same machine speed which was 5 m/min. Tensile tests were performed for each raveled yarns from carpet samples and results were analyzed as a percentage of the tenacity and breaking elongation changes of both stuffer and chain warp yarns.

Table 3.9 Weaving machine parameters

Pile Density	**Machine productivity (number of weft insertion/minute)**	**Stuffer Beam Weight (kg)**	**Chain Beam Weight (kg)**	**Number of Lancet/10 mm**	**Jute yarn count as weft yarn (14.400 yards/libre)**
	**135**	**70**	**25**	**22**	**13/2**
	**130**	**70**	**25**	**22**	**13/2**
	**130**	**80**	**15**	**22**	**11/2**
	**130**	**80**	**15**	**22**	**11/2**
	**130**	**80**	**15**	**22**	**13/1**

Second group of samples taken from carpets are coded according to the yarn type, carpet sample, pile density, and dents of the reed are given on Table 3.10. Definitions for the change of tensile properties of warp yarns after weaving and after latex processes are listed on Table 3.11

Table 3.10 Codes of the yarns raveled out from the carpet at a certain region

		Code	
Pile Density	**Dent Number**	**Stuffer Warp Yarn**	**Chain Warp Yarn**
35	20	S35-20	C35-20
35	80	S35-80	C35-80
35	200	S35-200	C35-200
35	320	S35-320	C35-320
40	20	S40-20	C40-20
40	80	S40-80	C40-80
40	200	S40-200	C40-200
40	320	S40-320	C40-320
45	20	S45-20	C45-20
45	80	S45-80	C45-80
45	200	S45-200	C45-200
45	320	S45-320	C45-320
50	20	S50-20	C50-20
50	80	S50-80	C50-80
50	200	S50-200	C50-200
50	320	S50-320	C50-320
60	20	S60-20	C60-20
60	80	S60-80	C60-80
60	200	S60-200	C60-200
60	320	S60-320	C60-320

Table 3.11 Definition of both tenacity and breaking elongation changes for stuffer and chain warp yarns

	Definition
A1	= (σ_{aw}/ σ_y)*100 (The change of the tenacity of the **stuffer warp yarn** after weaving)
A2	= (σ_{al}/ σ_{aw})*100 (The change of the tenacity of the **stuffer warp yarn** between weaving and latex)
A3	= (σ_{al}/ σ_y)*100 (The change of the tenacity **stuffer warp yarn** for overall carpet production)
B1	= (ε_{aw}/ε_y)*100 (The change of the breaking elongation of the **stuffer warp yarn** after weaving)
B2	= (ε_{al}/ε_{aw})*100 (The change of the breaking elongation of the **stuffer warp yarn** between weaving and latex)
B3	= (ε_{al}/ε_y)*100 (The change of the breaking elongation **stuffer warp yarn** for overall carpet production)
C1	= (σ_{aw}/ σ_y)*100 (The change of the tenacity of the **chain warp yarn** after weaving)
C2	= (σ_{al}/ σ_{aw})*100 (The change of the tenacity of the **chain warp yarn** between weaving and latex)
C3	= (σ_{al}/ σ_y)*100 (The change of the tenacity **chain warp yarn** for overall carpet production)
D1	= (ε_{aw}/ε_y)*100 (The change of the breaking elongation of the **chain warp yarn** after weaving)
D2	= (ε_{al}/ε_{aw})*100 (The change of the breaking elongation of the **chain warp yarn** between weaving and latex)
D3	= (ε_{al}/ε_y)*100 (The change of the breaking elongation **chain warp yarn** for overall carpet production)

As shown on Table 3.14, subscripts “aw”, “al”, and “y” is for after weaving, after latex and initial yarn respectively.

3.2. Methods

Test methods and instruments used in this experimental study are given in following sections.

3.2.1. Yarn strength

Yarn strength is measured by James H. Heal Titan Universal Strength Tester 2 as shown in Figure 3.2 available in USAM Laboratory in Çukurova University. TS 245 EN ISO 2062 (250 mm 250 mm) “Yarn From Packages Determination of Single-end Breaking Force and Elongation at Break” is used to determine the tenacity and elongation of the yarn. 20 tests were performed for each yarn. The tests output were obtained as tenacity (cN/tex) and extension (%) diagram and also mean values of tenacity, extension, and time at break (s) [55].

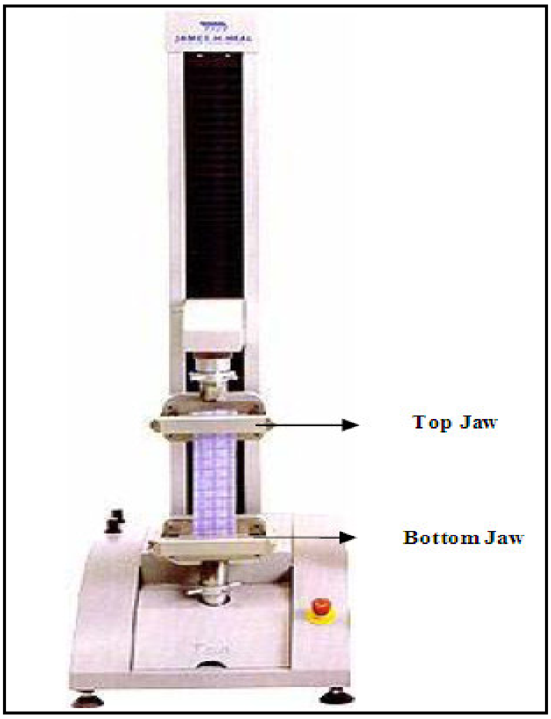


Figure 3.2 Titan universal strength tester

Tenacity is defined as the specific stress corresponding with the maximum force on a force/extension curve.

Specific stress is a measurement of stress in the case of yarns as their cross-sectional area is not known. The linear density of the yarn used instead of the cross-sectional area as a measure of yarn thickness. The unit of the specific stress is cN/tex.

The calculation of the specific stress is shown as follows [56];

Specific stress = Force (cN) /linear density (tex) (3.1)

Elongation is the increase in length of the specimen from its starting length expressed in units of length. The distance that a material will extend under a given force is proportional to its original length; therefore elongation is usually quoted as strain or percentage extension.

It is calculated as follows;

Elongation (percentage extension)=(Elongation (mm)/initial length (mm))*100..(3.2)

Precondition is applied to specimens for at least 4 hour by laying each specimen separately on the screen atmospheric temperature of 21±1 C° degree and relative humidity 65 ±2 % RH. 20 tests were made for each warp yarn samples and warp yarns raveled out from the carpet samples. Tensile test results of the both stuffer and chain warp yarns of 1st group of samples are given in Appendix A1 and Appendix A2, respectively. Warp trials mechanical properties are given in Appendix I. For the 2nd group of samples tensile test results are shown in Appendix E1 and Appendix E2, for stuffer and chain warp yarns, respectively.

3.2.2. Yarn twist

Twist is defined as a yarn term describing the number of turns per inch and direction of twist of either the singles or plies around their axes. Twist direction is either right or left handed, also called Z or S-twist [57].

TS 242 "Determination the Degree of Twist in Single and Multiple Yarn, and Count Variation Caused by Twist in The Twisted Yarn" is used to determine the twist values of the samples by Prowhite Yarn Twist Counter TT13-A.

Short-staple yarns of the samples discussed in section 3.1 had been spun by OE-rotor spinning method, so that twist of the single yarn could not be determined [57]. Folded twist value of the stuffer warp yarns were measured and results of the stuffer warp yarns are given in Appendix A1.

3.2.3. Blending ratio

TS 4739 "Methods of Identification of Textile Fibers" is used to identify the fiber types within the yarn [58].

TS 1700 "Textile Binary Fiber Mixtures-Quantitative Chemical Analysis" is used to determine the amount of fiber types within the blended yarns [59].

To determine the amount of the fibers within the blended yarns, three of each 1 gram yarns were solved in M-kresol to remove the PES fiber. The residual fiber was either cotton or viscose. The remaining amount of fiber was weighted and blending ratios of yarns were calculated as percentage.

3.2.4. Linear density

TS 244 EN ISO 2060 "Textiles-Yarn from Packages- Determination of Linear Density (mass per unit length) by the Skein Method" is used to determine the linear density of the yarns [60] and results of the both stuffer and chain warp yarns are shown in Appendix A1 and Appendix A2, respectively.

3.2.5. Yarn shrinkage

ASTM D 2259-9602 "Standard Test Method for Shrinkage of Yarns" is used to determined the shrinkage values of the yarns in percentage within boiling water [61]. Boiling shrinkage test method can be used for yarns made from any fibers or combination of fibers [24,34, 61]. In Korteks and SASA, PES POY and PES textured yarn quality specifications are also based on this test. Pre-tension is essential to determined the elongation in length of the yarn before and after boiling. Yarns are waited in boling water for 30 minutes. 5 measurements for each yarn before and after boiling were determined.

After all examination, shrinkage values of the yarns to the nearest 0.1 % were calculated with following equation:

$$\text{Shrinkage, \%} = 100 * (A-B) / A \tag{3.3}$$

where;

A = original loop length of each skein
B = final loop length of each skein

Shrinkage test results for both stuffer and chain warp yarns are given in Appendix B.

3.2.6. Calculation of initial modulus

ASTM D 2256-9702 “Standard Test Methods for Tensile Properties of Yarns by the Single-Strand Method” is used to calculate the initial modulus of the warp yarns [62].

Modulus as a general term means the slope of the force elongation curve and it is a measure of the stiffness of the material that is its resistance to extension. If the curve is plotted in terms of stress against strain the units of modulus are the same as those of stress that is force per unit area such as Pascals. For the examination of the yarn, the tenacity (specific stress) (cN/tex) - extension (%) curve was used [56].

Figure 3.3 shows the tenacity-breaking elongation (extension) measurement output results of one sample yarn which was tested for 20 times.

The initial modulus of the warp yarn samples were calculated on tenacity-extension curve. The initial modulus was calculated by dividing specific stress at any point along the BD line by the strain at the same point (measured from the Point B, defined as zero strain) which is shown in Figure 3.4.

3.2.7. Calculation of toughness

Toughness is the total energy required to break the materials. To calculate the toughness, when using the force-elongation curves, a line from the point of maximum force for each specimen perpendicular to the elongation axis is drawn. The bounded area by the curve, the perpendicular, and the elongation axis are measured by means of an integrator or a planimeter, or the area of the chart is cut under the force- elongation curve, this curve was separated into squares and these squares were counted [56].

The toughness of a material is proportional to its cross-sectional area or, more conveniently for yarns and fibers, the linear density as the breaking load is proportional to the cross-sectional area.

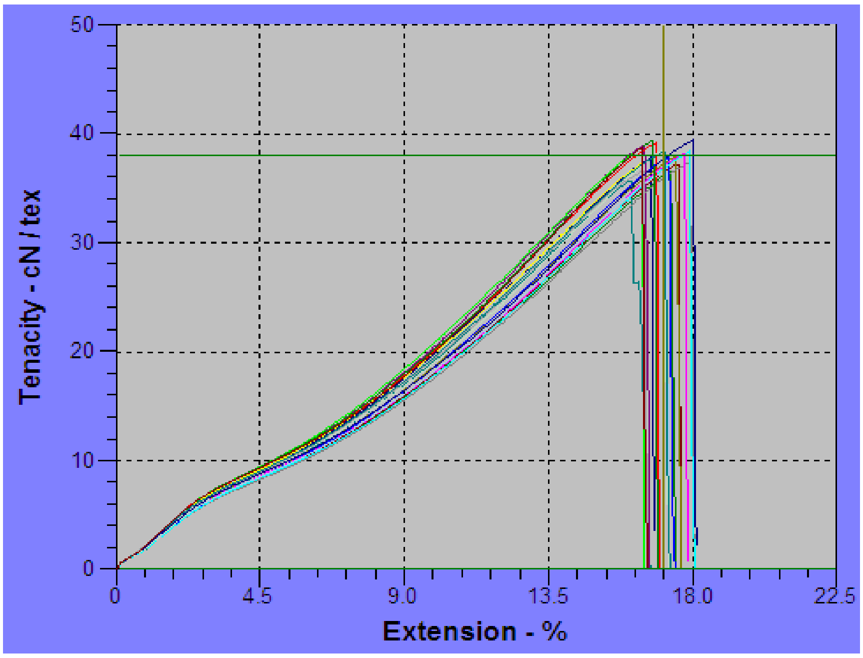


Figure 3.3 Tenacity-breaking elongation (extension) curve of 197 tex 70/30 % PES/CV OE-rotor yarn

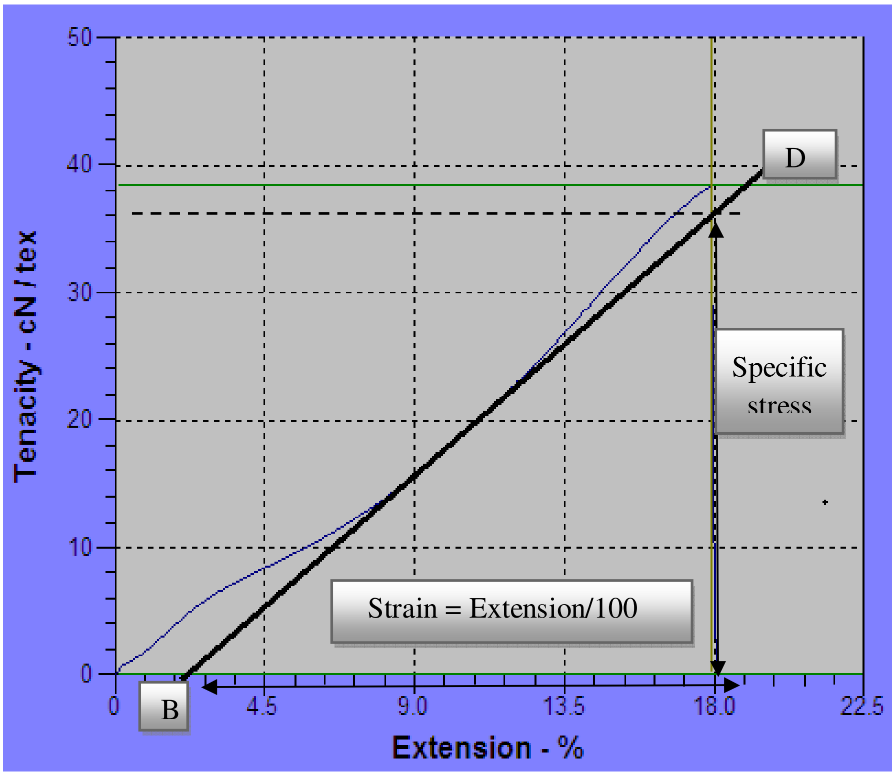


Figure 3.4 Tenacity - extension curve

The toughness is also proportional to the original length of the material as the elongation of the material is dependent on this. Therefore in order to compare materials it may be necessary to use the specific toughness:

Specific toughness= toughness/ (mass/unit length)* initial length (3.4)

For comparative purposes when the tests use a common gauge length the initial length may be omitted from this formula [56].

Toughness values of the samples were determined by drawing unit squares and counting them under the tenacity- extension curve. The unit of toughness was also calculated as cN/tex. The toughness- initial modulus values of both stuffer and chain warp yarns are given in Appendix C1 and Appendix C2, respectively.

3.3. Dimensional Analysis

The method of dimensional analysis is used in every field of engineering, where problems with many variables are handled. This method derives from the condition that each term summed in an equation depicting a physical relationship must have same dimension. By constructing non-dimensional quantities expressing the relationship among the variables, it is possible to summarize the experimental results and to determine their functional relationship [63].

Dimensional analysis is based on the principle that all additive or equated terms of a complete relationship between the variables must have the same net dimensions. The analysis starts with the preparation of a list of the individual dimensional variables (dependent, independent, and parametric) that are presumed to define the behavior of interest [64].

In textile there are a few studies about the dimensionless analysis. The dimensional analysis was performed by this theorem for the following studies;

Shustov, Yu.S. [65], studied the empirical dependences of the breaking load of ring and pneumatic spinning yarn made of viscose, PES, PA, and PAN fibers on the breaking load, linear density, staple fiber length, the twist and the linear density of the yarn (2001). Yarn breaking load was analyzed using by similarity theory and dimensional analysis. The dependence of the yarn breaking load on its structural parameters were established by using similarity theory and dimensional analysis.

Shustov, Yu.S., Shustov, E.Yu. [66], developed an analysis on wear resistance of the yarn by taking fibers as a function of the initial parameters of the fibers and filaments by using scaling theory and dimensional analysis (2002). The empirical dependence of PES, PAN, and CV yarns wear resistance on the linear density, bulk density of the fibers and filaments, staple length of the fibers, and yarn twist were achieved.

Shustov, Yu.S. [67], studied the empirical dependences of the breaking load of fabrics made of CV, PES, PA, and PAN yarns (2002). Use of dimensional analysis makes it much easier to find the functional type of multi parameter dependences. It was found that the breaking load of a fabric increases directly with the breaking load of the warp threads, number of warp thread and weaving type.

Shustov, Yu.S., Sporykhina, V.I. [68], developed a method for determining the breaking load of blended yarn using interpolation theory (2003). To predict the breaking load of cotton- Lavsan yarn produced by ring and air spinning systems as a function of the initial properties and percentage content of natural and chemical fibers Lagrangian polynomials was obtained.

3.3.1. Dimensional analysis according to Buckingham's Π theorem

Dimensional analysis of breaking load of the blending yarn could not be analyzed because there has not been required information about the characteristics especially fiber length, fineness, twist etc. of the raw materials of the blended yarn. Dimensional analysis is applied to physical variables of filament warp yarns.

In this study Buckingham's Π theorem is used to determine the dependence breaking load of the filament yarns made of PES on linear density of yarn and fiber, number of filament, time to break, density and elongation at break.

To analyze filament yarns according to the Buckingham's Π theorem, a physical phenomenon having ***n*** physical variables σ_y, T_f, ρ_y , ΔL, L, t, , T_y are considered and ***k*** basic dimensions *(L, M,* T) are used to describe them [62]. The dimensions of these physical variables are given on Table 3.12.

The phenomenon is expressed by the relationship among **7 – 3 = 4** non-dimensional groups which are expressed as **Π_1, Π_2, Π_3, Π_4.** In other words, the equation expressing the phenomenon as a function *f* of the physical variables is substituted by the following equation expressing it as a function ***Φ*** of a smaller number of non-dimensional groups.

$$f\,(T_y, T_f, \rho_y, \Delta L, L, t, \sigma_y) = 0 \qquad (3.5)$$

$$\boldsymbol{\Phi}\,(\Pi_1, \Pi_2, \Pi_3, \Pi_4) = 0 \qquad (3.6)$$

The equation 3.5 the variables are, σ_y =Tenacity of the yarn, T_y = Linear density of the yarn, T_f = Linear density of fiber (tex per filament), ρ_y = Density of the fiber, ΔL=Elongation, L = First length of the yarn, t = Time at break.

Table 3.12 Dimensions of the physical variables

Physical variable	Dimension
σ_y	$M.L/T^2$
T_y	M/L
T_f	M/L
ρ_y	M/L^3
ΔL	L
L	L
t	T

To calculate the non-dimensional groups T_y. ΔL. t. are selected as repeating parameters. Then the following Π terms are constructed as described in ref (62).

$$\Pi_1 = T_y^a.\ \Delta L^b.t^c.\ \sigma_y$$

$$\Pi_2 = T_y^a.\ \Delta L^b.t^c.\ T_f$$

$$\Pi_3 = T_y^a.\ \Delta L^b.t^c\ \rho_y$$

$$\Pi_4 = T_y^a.\ \Delta L^b.t^c\ .L$$

The supercripts a, b, and c are calculated as in the followings;

$\Pi_1 \quad = T_y^{a}.\ \Delta L^{b}.t^{c}.\ \sigma_y$

$M = a + 0 + 0 + 1 = 0 \longrightarrow a = -1$

$L = -a + b + 0 + 1 = 0 \longrightarrow b = -2$

$T = 0 + 0 + c - 2 = 0 \longrightarrow c = 2$

$\Pi_1 \quad = T_y^{-1}.\ \Delta L^{-2}.t^{2}.\ \sigma_y$

$$\boldsymbol{\Pi_1 = \frac{\sigma_y\, t^2}{T_y.\ \Delta L^2}} \tag{3.7}$$

$\boldsymbol{\Pi_2 \quad = T_y^{a}.\ \Delta L^{b}.t^{c}.\ T_f}$

$M = a + 0 + 0 + 1 = -1 \longrightarrow a = -1$

$L = -a + b + 0 - 1 = 0 \longrightarrow b = 0$

$T = 0 + 0 + c + 0 = 0 \longrightarrow c = 0$

$\Pi_2 \quad = T_y^{-1}.\ \Delta L^{0}.t^{0}.\ T_f$

$$\boldsymbol{\Pi_2 = \frac{T_f}{T_y}} \tag{3.8}$$

$\boldsymbol{\Pi_3 \quad = T_y^{a}.\ \Delta L^{b}.t^{c}.\rho_y}$

$M = a + 0 + 0 + 1 = 0 \longrightarrow a = -1$

$L = -a + b + 0 - 3 = 0 \longrightarrow b = 2$

$T = 0 + 0 + c + 0 = 0 \longrightarrow c = 0$

$\Pi_3 \quad = T_y^{-1}.\ \Delta L^{2}.t^{0}.\ \rho_y$

$$\boldsymbol{\Pi_3 = \frac{\rho_y\, \Delta L^2}{T_y}} \tag{3.9}$$

$\mathbf{\Pi_4} \quad = \boldsymbol{T_y^{a}.\ \Delta L^{b}.t^{c}\ .L}$

M = a + 0 + 0 +0= 0 ⟶ a = 0

L = -a + b + 0 +1= 0 ⟶ b= -1

T = 0 + 0 + c + 0 = 0 ⟶ c = 0

$\Pi_4 \quad = T_y^{0}.\ \Delta L^{-1}.t^{0}\ .L$

$$\boldsymbol{\Pi_4 = \frac{L}{\Delta L}} \qquad (3.10)$$

The calculated 4 Π terms are;

$$\boldsymbol{\Phi\left(\frac{\sigma_y\, t^2}{T_y.\ \Delta L^2},\ \frac{T_f}{T_y},\ \frac{\rho_y.\ \Delta L^2}{T_y},\ \frac{L}{\Delta L}\right) = 0}$$

Note that; $\Pi_2 = T_f/\ T_y = 1/n$ where n can be considered as number of filaments.

It is possible to obtain new non-dimensional terms from measurable quantities by further reducing one Π term.

$\Pi_{x1} \quad = \Pi_1.\Pi_3$

$$= \frac{\sigma_y\, t^2.}{T_y.\ \Delta L^2}\left(\frac{\rho_y\, \Delta L^2}{T_y}\right)$$

$$\boldsymbol{\Pi_{x1} = \frac{\sigma_y.\ t^2.\ \rho_y}{T_y^{2}}} \qquad (3.11)$$

$\Pi_{x2} \quad = 1/\ \Pi_4$

$$\boldsymbol{\Pi_{x2} = \Delta L/L} \qquad (3.12)$$

$$\Pi_{x3} = \Pi_1 * \Pi_3 * (1/\Pi_2)^2$$

$$= \frac{\sigma_y \, t^2.}{T_y . \Delta L^2} \left(\frac{\rho_y . \Delta L^2}{T_y}\right) . \left(\frac{T_y^2}{T_f^2}\right)$$

$$\boxed{\Pi_{x3} = \frac{\sigma_y . t^2 . \rho_y}{T_f^2}} \qquad (3.13)$$

Π_{x1} represents mechanical resistance of filament yarns in terms of raw materials and linear density of yarns.

Π_{x2} represents elongation of filament yarns in non-dimensional form.

Π_{x3} represents mechanical resistance of each filament of yarns in terms of raw materials and linear density of filaments.

Graphs are drawn in Chapter 4 with Π_{x1}, Π_{x2}, Π_{x3} parameters which will assist the different yarn characteristics. Calculation results for both stuffer and chain warp filament yarns are given in Appendix D1 and Appendix D2, respectively.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

First group of the samples are composed of blended and filament stuffer warp yarns and filament chain warp yarns as discussed in Chapter 3. These samples were tested to investigate the mechanical properties of warp yarns used in Gaziantep carpet industry.

Warp trials produced with BCF and CF production systems were also tested to determine their mechanical properties.

In the second group, warp yarns revealed out from the carpet samples were tested to determine tensile property change of warp yarns.

All measurements and calculated data for those groups were analyzed and graphs were drawn with Sigma Plot 2000 Exact Graphs and Data Analysis Program.

In this chapter experiments are categorized and explained as follows for yarn samples and for carpet samples, respectively.

For Warp Yarn Samples;

- Mechanical properties including tenacity (cN/tex) – breaking elongation (%), twist value and blending ratio of staple yarns, density of blended stuffer warp yarns were determined. Results of the stuffer and chain warp data are given in Appendix A1 and Appendix A2, respectively.

- Non-dimensional parameters Π_{x1} ($\sigma_y * t^2 * \rho_y / T_y^2$), Π_{x3} ($\sigma_y * t^2 * \rho_y / T_f^2$) and Π_{x2} ($\Delta L/L$) of both stuffer and chain warp yarns are given in Appendix D1 and Appendix D2, respectively.

- Toughness and initial modulus of all warp yarn samples were calculated and data are given in Appendix C1 and Appendix C2 for both stuffer and chain warp yarns, respectively.

- Finally, representative yarns for each different characteristic were selected and tested to determine shrinkage behavior in percentage and data are given in Appendix B.

For warp trials;

- Tensile properties, linear density, toughness, initial modulus and shrinkage values of the warp trials are given in Appendix I.

For carpet samples;

- The stuffer and chain warp yarns (197 tex 70/30 % PES/CV OE-rotor yarn and 67 tex PES false-twist textured yarn, respectively) used in the production of the sample carpets were tested.

- To determine the effect of weaving and latex application, both stuffer and chain warp yarns were raveled out and tested to assign their tenacity and breaking elongation. Percentage changes of tenacity and breaking elongation data of raveled yarn with respect to initial yarn of carpets were evaluated and given in Appendix E1 and Appendix E2 for stuffer and chain warp yarns, respectively.

4.2. Evaluation of First Group of Samples

4.2.1. Conventional warp yarns used in Gaziantep carpet industry

Spun yarns produced with OE-rotor spinning technology and PES textured yarns have been used as a stuffer warp yarn in Gaziantep carpet industry. The usage level of PES air-textured and PES false-twist textured yarns is increasing because of its lower cost and more simple production. Both air-textured and false-twist textured PES yarns are used as chain warp yarns in the carpet sector.

Mechanical properties of stuffer warp yarns

Tenacity-elongation:

Basic mechanical properties of a yarn are tenacity and elongation values. Carpet manufacturers select warp yarns according to these properties. However there is no standard knowledge or published data related about warp yarn properties.

Stuffer warp yarns used in Gaziantep carpet industry are produced with OE-rotor spinning technology from blending PES/CO or PES/CV staple yarns. These yarns are first produced as 12/1 or 14/1 spun yarns, and then these yarns are folded to 4 or 5 by giving folded twist values, respectively. In Appendix A1, collected stuffer warp yarns produced with OE-rotor spinning technology are listed from 1 to 20 with different codes showing yarn character and mechanical properties. In addition to spun yarns, filament yarns produced from PES POY by air texturing or false-twist texturing technologies are also used as stuffer warp yarns. In Appendix A1, collected stuffer filament warp yarns are listed from 21 to 28.

The tenacity values of stuffer warp yarns collected from Gaziantep carpet industry are shown in Figure 4.1. Although the raw material of the yarns, production technologies are different all of these yarns were used in face to face Wilton carpet production as stuffer warp yarns. According to Figure 4.1, the maximum tenacity value is 41 cN/tex approximately, and the minimum value is 21.39 cN/tex.

Breaking elongation with respect to the yarn type is illustrated in Figure 4.2 for different stuffer warp yarns used in carpet industry. As shown in Figure 4.2, the maximum elongation value is 23 %, and the minimum value is 13 %, approximately.

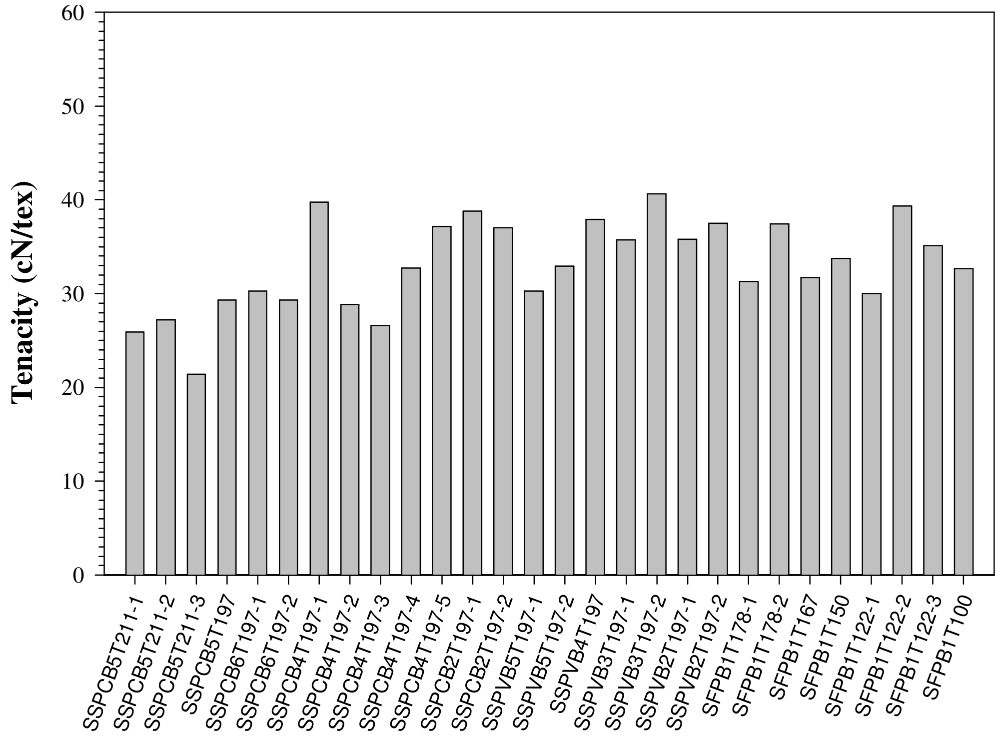


Figure 4.1 Tenacity of the stuffer warp yarns

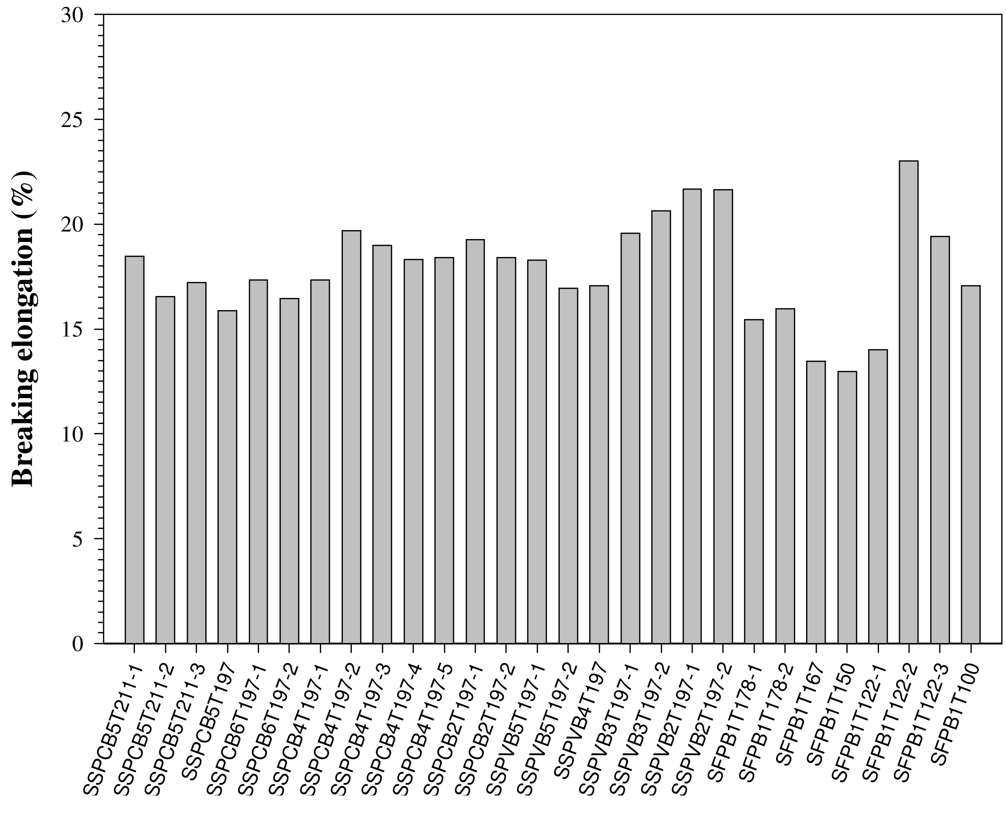


Figure 4.2 Breaking elongation of stuffer warp yarns

Toughness- initial modulus:

Toughness and initial modulus are the essential on the yarns mechanical properties. Warp yarns are exposed to tensional loadings during weaving operation. Toughness represents the energy absorption capacity of the materials. Warp yarns must have sufficient toughness to withstand these loadings. So, the higher the toughness value, the greater the energy is required to break the yarn.

Toughness values were calculated and plotted for collected stuffer warp yarns as in Figure 4.3. In this Figure, the toughness values of stuffer warp yarns are changing from 189 cN/tex to 648 cN/tex. However most of the stuffer yarns have a toughness values between 189 cN/tex to 423 cN/tex.

Modulus is also important tensile property of the yarn. The higher the modulus, the stiffer the yarn is. The higher the modulus of a yarn, the less it extends for a given force [54]. Initial modulus values of the stuffer warp yarns are given in Figure 4.4.

As seen from this figure, the maximum and minimum value of initial modulus the stuffer warp yarns are 329 cN/tex and 136 cN/tex, respectively. Filament warp yarns have comparatively higher initial modulus values than spun yarns.

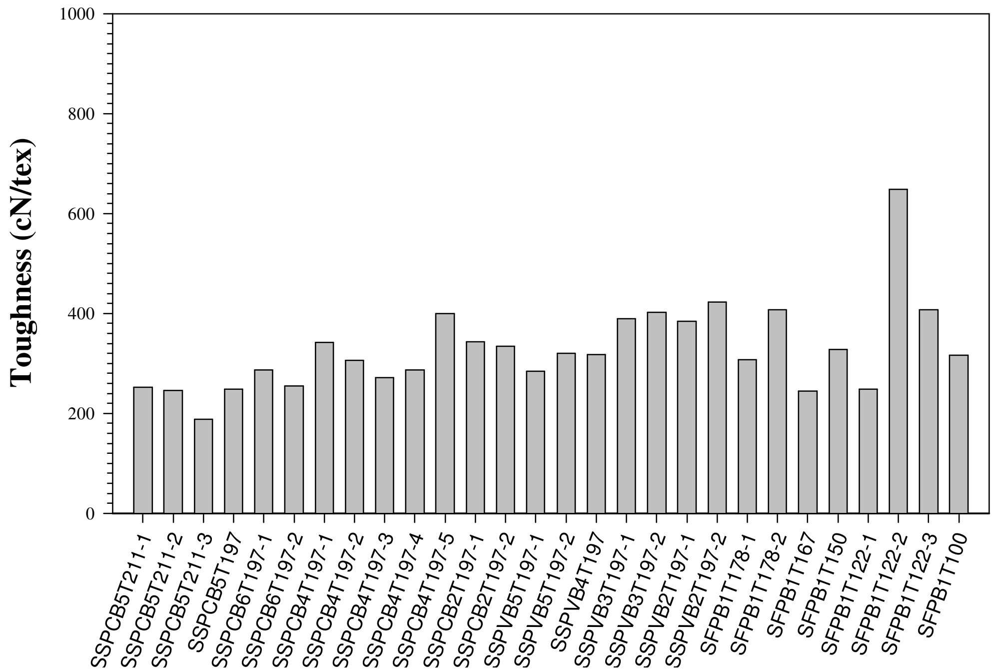


Figure 4.3 Toughness of the stuffer warp yarns

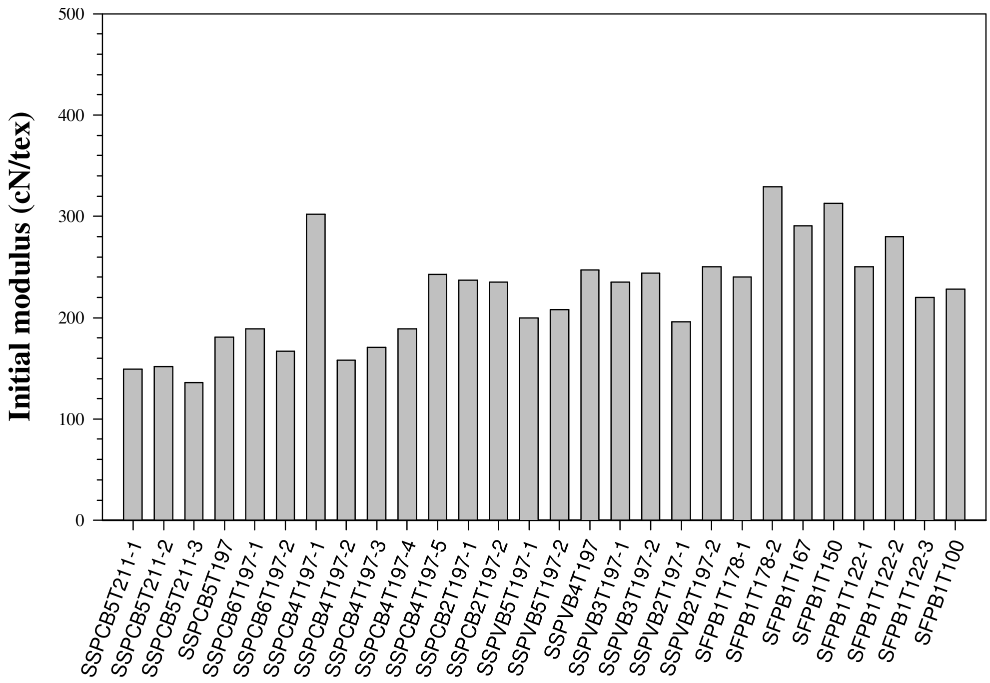


Figure 4.4 Initial modulus of stuffer warp yarns

Shrinkage value:

Shrinkage behavior of the yarns used in carpet industry is important, because carpets are subjected to heat during latex application. Therefore shrinkage test to the warp yarns was performed and measured shrinkage values are plotted in Figure 4.5 for stuffer warp yarns. Shrinkage behavior of spun yarns which are PES/CO and PES/CV blends are found to be in the range of -3.1% to -1.5%. For these yarns the blending ratios of PES are 65 % and higher than this ratio. Heat set are generally applied to cotton class PES staple fibers, therefore PES staple fiber characteristics dominate the spun yarn characteristics. The shrinkage values of PES/CO and PES/CV stuffer warp yarns are closer to each other with different linear density and blending ratio.

Heat set can be applied or not to filament yarns produced with air texturing and false twist texturing systems. Therefore yarns are named as (non-heat set) stretch yarns or (heat set) set yarns. Boiling shrinkage values of non-heat set yarns are changing about -8% to -5.5 [24,34], while boiling shrinkage values for set yarns it is less than -2% [34].

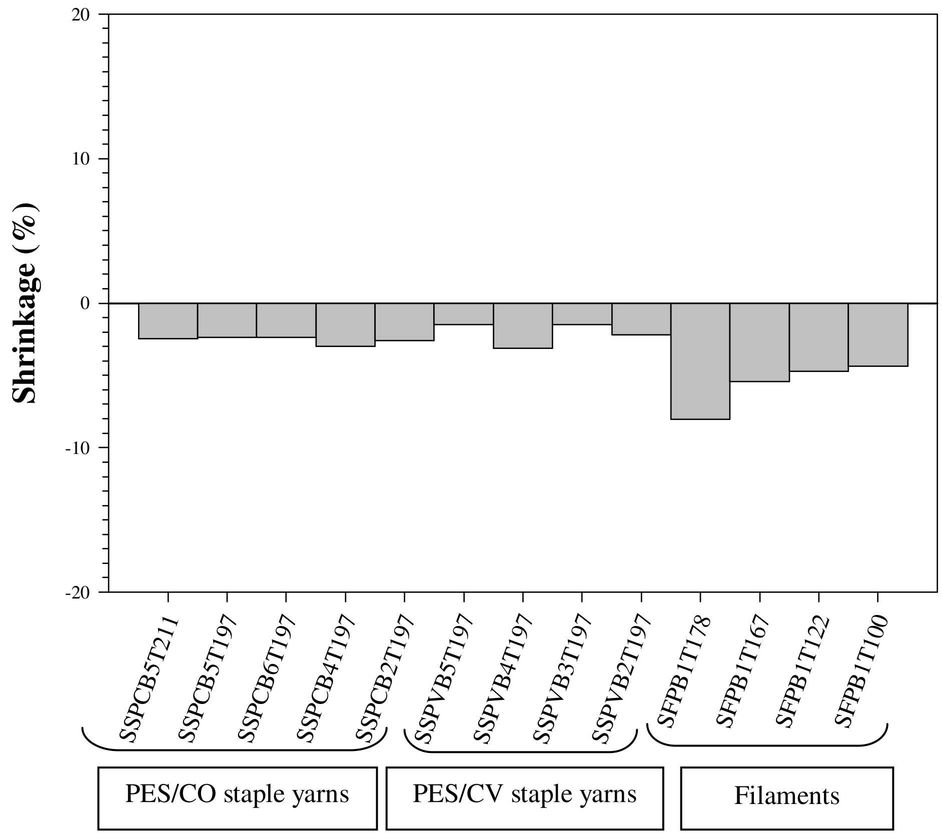


Figure 4.5 Shrinkage values of the stuffer warp yarns

According to the Figure 4.5, the minimum shrinkage value is – 8.06 % and the maximum is the – 4.38 % for collected filament warp yarns.

Mechanical properties of chain warp yarns

Like stuffer warp yarn, chain warp yarns must have sufficient tenacity and breaking elongation to achieve a good performance without break during the weaving operation. In general, 122, 116 and 89 tex air-textured and 100, 69 and 67 tex false-twist textured including intermingling PES filament yarns are used in carpet production as chain warp yarns.

Tenacity- breaking elongation:

Tensile tests are applied to 28 chain warp yarns collected from different firms. Tenacity values of chain warp yarns are shown in Figure 4.6. All of the tenacity values are between 33.31 cN/tex – 38.32 cN/tex except that of $CFPB_1T_{89}$-1 coded yarn having 50.43 cN/tex. In the textured yarn specifications taken from Korteks and SASA, tenacity values are also in this range.

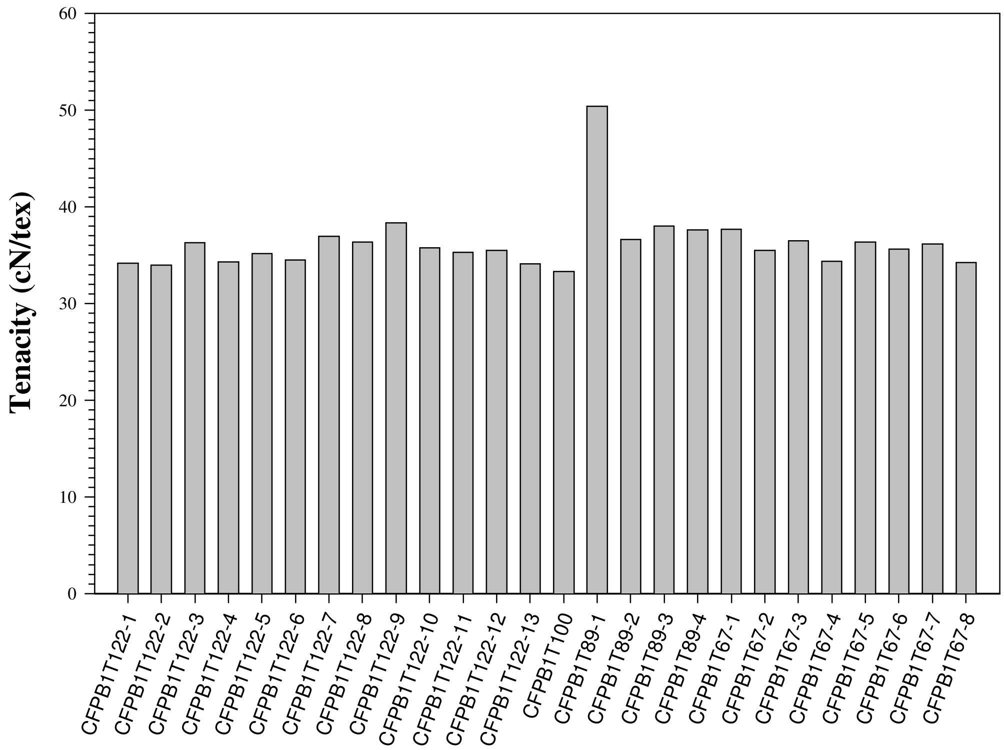


Figure 4.6 Tenacity of the chain warp yarns

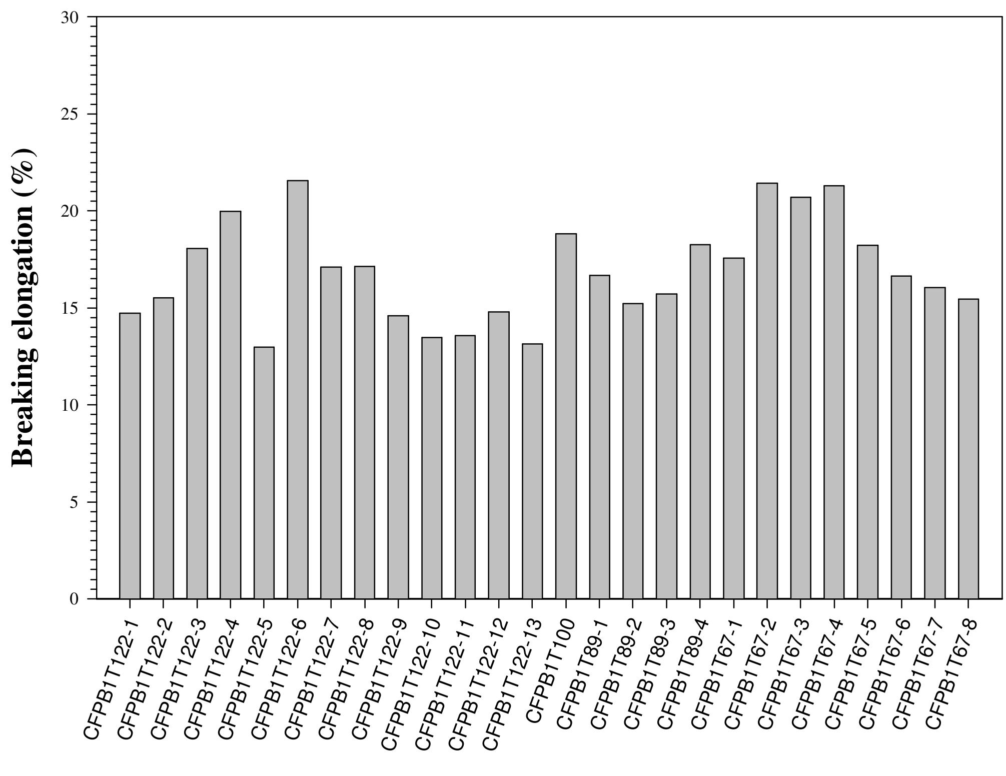


Figure 4.7 Breaking elongation of the chain warp yarns

Breaking elongation values of chain warp yarns are plotted in Figure 4.7. As illustrated in this figure the maximum and minimum breaking elongation of chain warp yarns are 21.54 % and 12.96 %, respectively.

Toughness-initial modulus

The yarns must have an adequate toughness value to withstand the mechanical forces without breaking during carpet production. The toughness values of the chain warp yarns which commonly used for carpet industry are shown in Figure 4.8.

In Figure 4.8, the maximum and minimum toughness values are 531 cN/tex and 249 cN/tex, respectively. Since the toughness is the area under tenacity-elongation graph, the effective parameters are elongation as well as tenacity. The higher the toughness means high energy absorption to accept peak forces during weaving. Chain warp yarns are subjected the higher dynamic forces than stuffer yarns. Toughness values of to higher dynamic forces than stuffer yarns. Toughness values of chain warp yarns shown in Figure 4.8 are seem to be comparatively higher than that of stuffer warp yarns shown in Figure 4.3. In addition, initial modulus of the chain warp yarns is shown in Figure 4.9. The maximum and minimum initial modulus value is 429 cN/tex, and 182 cN/tex, respectively.

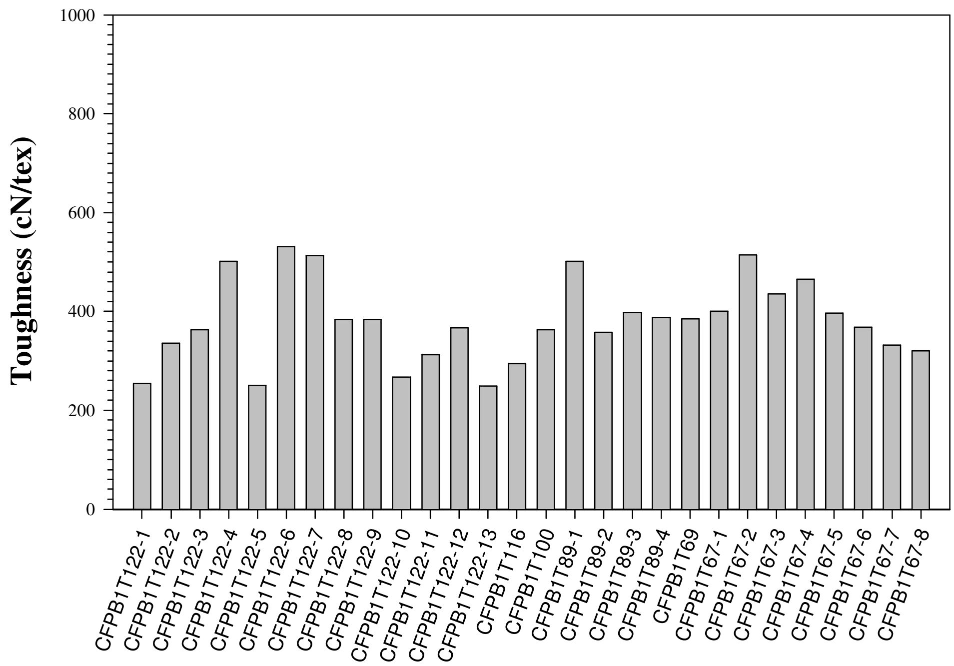


Figure 4.8 Toughness of the chain warp yarns

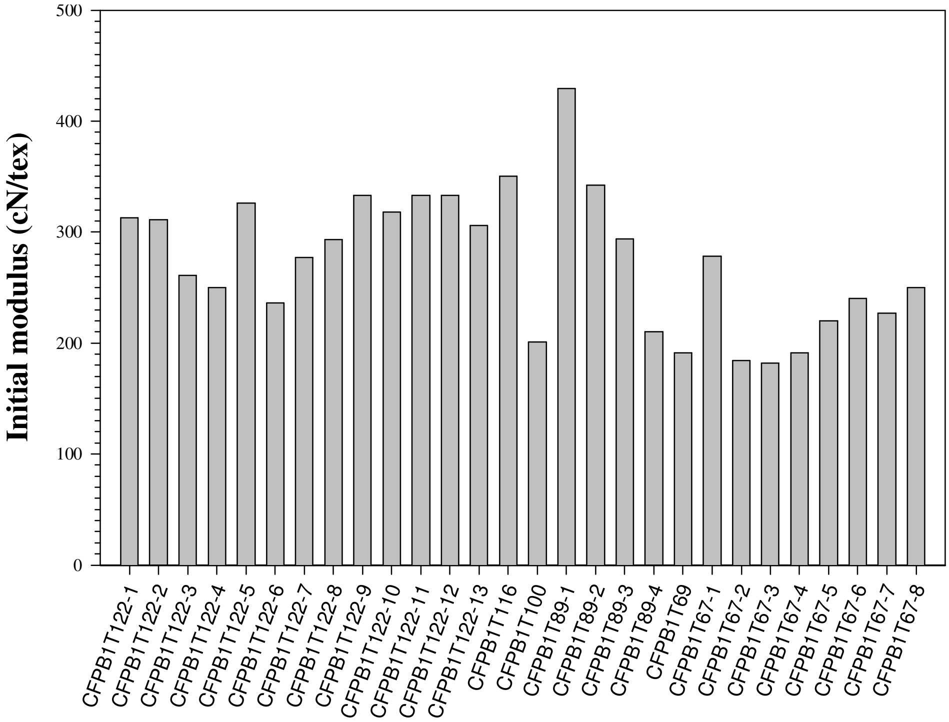


Figure 4.9 Initial modulus of the chain warp yarns

Shrinkage value

For chain warp yarns, the shrinkage values are plotted for air-textured and false-twist textured intermingled yarns having various linear densities and they are illustrated in Figure 4.10. According to the figure, production systems of the filament affect the shrinkage value. All filaments are produced from PES POY. The maximum shrinkage value is – 8.42 % and the minimum is the – 4.71 %. Shrinkage values of air-textured yarns are seen to be comparatively higher than that of false-twist textured yarns.

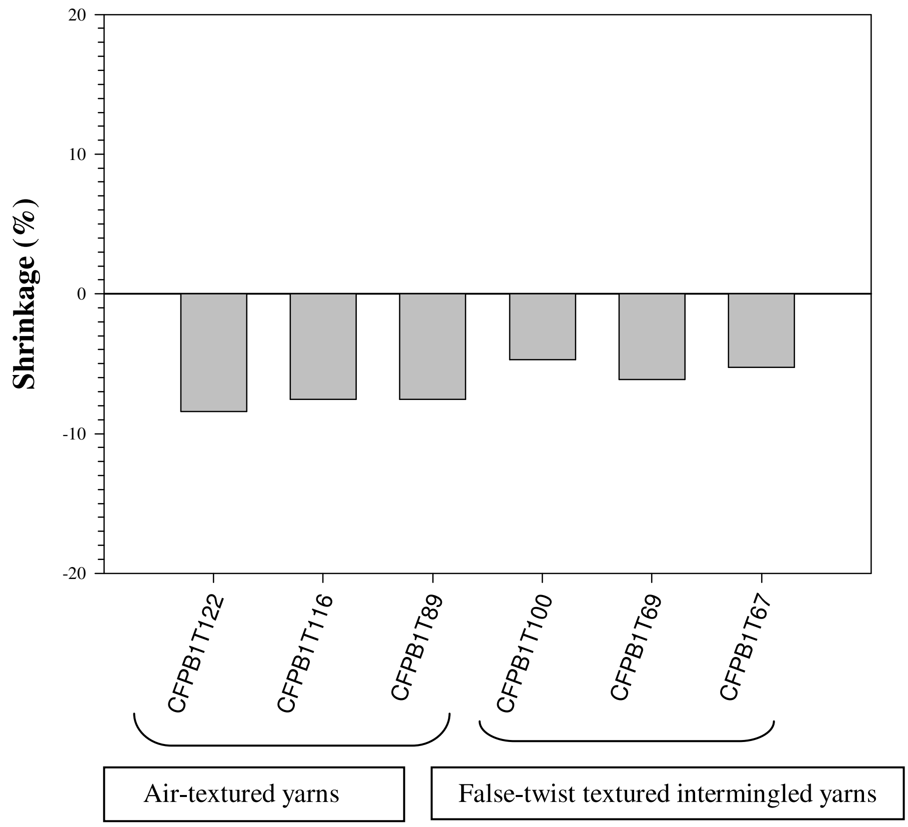


Figure 4.10 Shrinkage values of the chain warp yarns

4.2.2. Warp trials produced with one stage system

There are 5 warp trials produced on BCF machine. Among these yarns 139 tex and 119 tex warp trials are produced as CF yarns. In addition, 209 tex, 202 tex and 183 tex warp trials were produced as BCF yarn. The production parameters of both CF and BCF yarns are given in Appendix G1 and Appendix G2, respectively. First two BCF trials having 209 tex and 202 tex linear densities were given to carpet manufacturers in Iran. Mechanical properties of these warp trials are given on Table 14 in Appendix I. In this work, in addition to conventional warp yarns, warp trials are tested to determine mechanical properties.

Tenacity-breaking elongation

The tenacity values of the warp trials are shown in Figure 4.11. In this figure, the highest tenacity value is 34.12 cN/tex and the minimum one is 23.53 cN/tex. Two BCF yarns having linear density of 209 tex and 202 tex have tenacity values of 31 and 34 cN/tex, respectively. These values are also in the range of tenacity values of stuffer warp yarns shown in Figure 4.1.

Elongation values of warp trials are plotted in Figure 4.12. The minimum breaking elongation of the warp trials is 16.31 % while the maximum is 24.68 %. These values are not small as compared with elongation values of stuffer warp yarns shown in Figure 4.2.

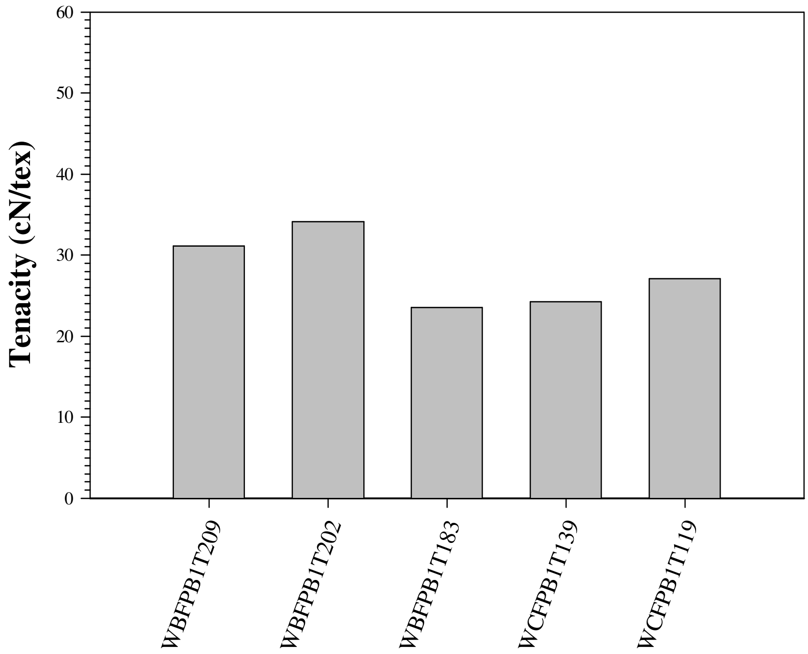


Figure 4.11 Tenacity of the warp trials

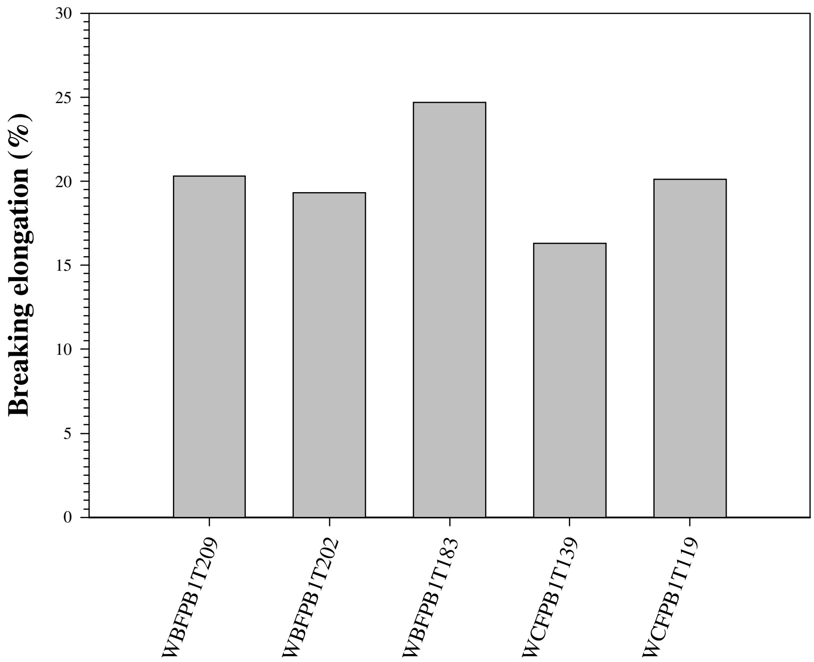


Figure 4.12 Breaking elongation of the warp trials

Toughness-initial modulus

The toughness of the warp trials with respect to the yarn type is illustrated in Figure 4.13. According to this figure, 119 tex warp trial has the highest toughness value which is 552 cN/tex. In addition, the lowest value is 312 cN/tex. Toughness values of BCF warp trials are about 400 cN/tex.

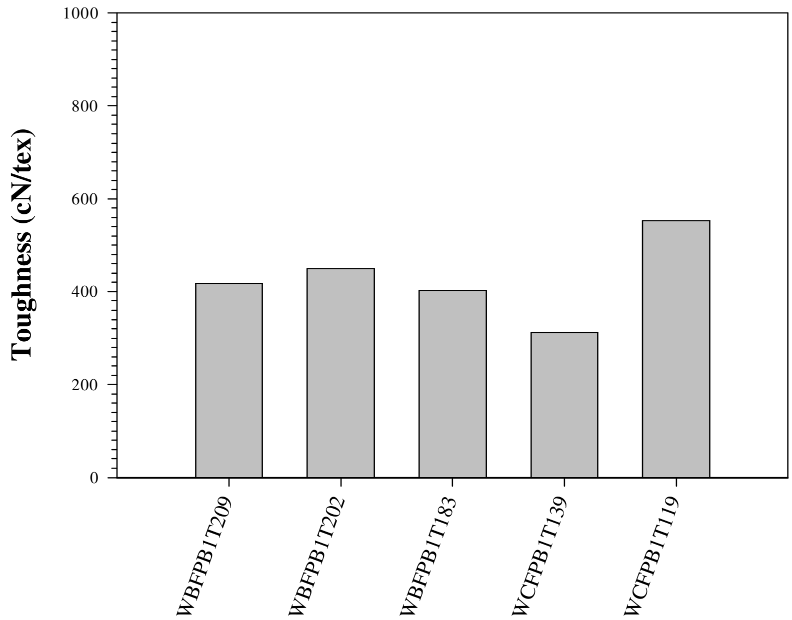


Figure 4.13 Toughness of the warp trials

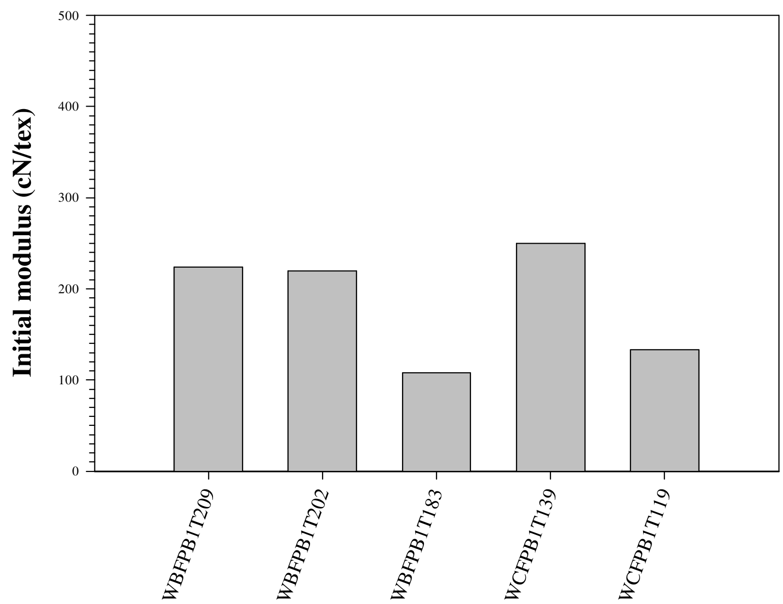


Figure 4.14 Initial modulus of the warp trials

The initial modulus of warp trials is shown in Figure 4.14. In this figure, the minimum initial modulus value is 133 cN/tex and the maximum one is 250 cN/tex.

Shrinkage value

The shrinkage values of the warp trials are shown in Figure 4.15. In this figure, 139 tex and 119 tex warp trials produced as CF without texturing have higher shrinkage then the others. It may be due to the production methods. Because texturing process which makes yarn heat-set is omitted for production of CF yarn. Shrinkage values of CF yarns are about – 14 % and this values are small as compared with shrinkage values of conventional filament warp yarns given in Figure 4.5 and 4.10. However, shrinkage values of BCF yarns shown in Figure 4.15 are about – 5 % and this values are in the range of shrinkage values of conventional filament warp yarns.

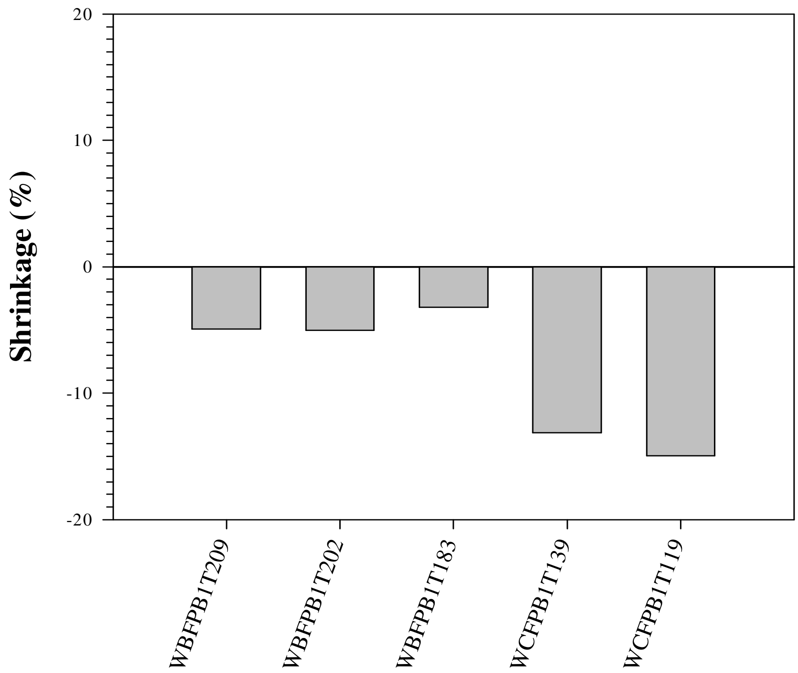


Figure 4.15 Shrinkage value of the warp trials

In this study, some warp trials produced as BCF and CF yarns are tested and compared with conventional warp yarns. CF warp trials have smaller tenacity, higher elongation and very low shrinkage values and may not suitable to used as warp yarns. However mechanical properties (tenacity, breaking elongation, toughness, initial modulus and shrinkage values) of two BCF warp trials are in the range of conventional warp yarn properties discussed in section 4.2.1. By making more systematic investigation about one stage warp yarn production system BCF technology can be used in warp yarns production. Besides mechanical properties of warp yarns, economic considerations are important.

4.2.3. Economic considerations

There are some researches about the energy requirement of spun yarn processes and air-textured yarn processes. In the researches of Wilson (1984), energy requirement for 167 dtex 67/33 PES/CO yarns is given as 4.41 kWh/kg, and energy requirement for 167 dtex air-textured PES yarn at 600 m/min is given as 3.1 kWh/kg. It is claimed that; if 167 dtex yarn are used as folded, the energy requirement will decrease to 1.8 kWh/kg [34, 69].

Energy requirement of air-texturing machine which produces warp yarn is approximately found as 1.1 kWh/kg for 122 tex PES warp yarn. This machine uses PES POY as raw material and energy requirement for PES POY production is approximately 0.65 kWh/kg. Therefore total energy requirement for 122 tex air-textured PES yarn is approximately 1.75 kWh/kg. On the other hand energy requirement of 122 tex BCF PES yarn is only 1 kWh/kg.

As a result, the advantage of one stage warp yarns production as compared with conventional ones can be given as;

1. PES BCF yarns are produced directly from PES chips as raw material. OE-rotor spinning technology use PES, CO and CV staple fibers which require staple fiber production. PES textured yarns are produced at two stages; PES POY production and air-texturing or false-twist texturing systems. PES POY is produced by polymerization or PES chips.

2. Production of BCF yarn is more simple and fast.

3. Labor and logistic costs for BCF yarn are lower.

4. Energy requirement for BCF production is lower than that of conventional warp yarn production methods.

Warp yarns are not very special yarns. Different types of yarns produced with different technologies can be used in carpet weaving looms. If the carpet weaving loom requirements can be achieved, BCF yarns may also be used as warp yarns. Required mechanical properties for BCF warp yarns can be obtained by adjusting process parameters.

PP BCF yarns are widely used in carpet production as pile yarn. Similarly, PES BCF yarns may also be a choice as more economical and sufficient warp yarns for carpet weaving looms.

4.3. Dimensional Analysis of Warp Filament Yarns

In addition to tenacity- breaking elongation analysis, dimensional analysis has been performed for both stuffer and chain warp filaments. If we obtain relationships between the calculated non-dimensional parameters for filament yarns, we may probably predict the properties of other similar yarns.

For filament yarns the following non-dimensional parameters given in equation 3.11, 3.12, and 3.13 are found to be;

$$\Phi \left(\frac{\sigma_y * t^2 * \rho_y}{T_y^2},\ \Delta L/L,\ \frac{\sigma_y * t^2 * \rho_y}{T_f^2} \right) = 0 \qquad (4.1)$$

First parameter in eqn. 4.1 represents non-dimensional mechanical resistance of filament yarn, second one is elongation and third one is non-dimensional mechanical resistance of each filament. In the following section, experimental data in non-dimensional form are plotted for stuffer and chain warp filament yarns.

Stuffer warp filaments

For stuffer warp filament yarns Π_{x1} is plotted with respect to Π_{x2} and result is shown in Figure 4.16. Π_{x1} is related with non-dimensional mechanical resistance of filament yarns and Π_{x2} is the breaking elongation of this yarn. Linear density values of collected filament yarns and their filaments are given on Table 4.1. Although the yarn linear density varies from 178 tex to 64 tex, linear density of each filament of collected yarns are close to each other (0.29 -0.35 tex/filament).

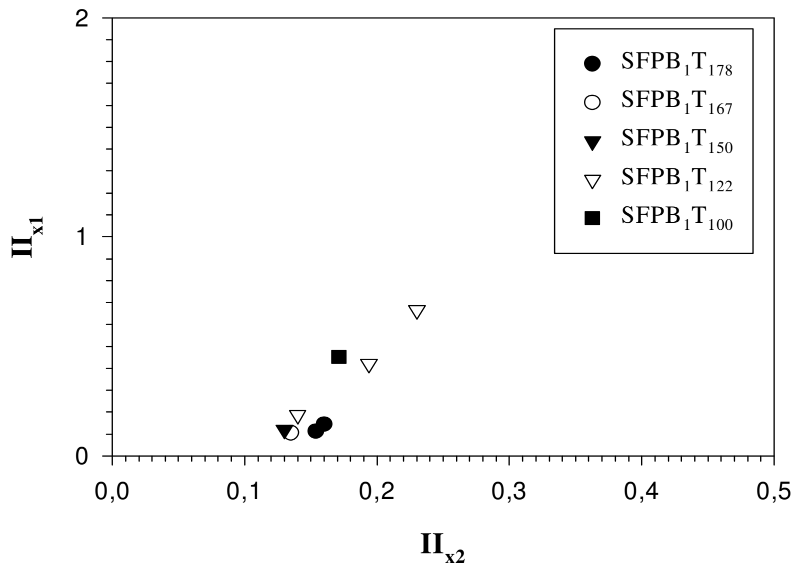


Figure 4.16 Dimensional analysis of stuffer warp filament yarns

Table 4.1 Linear density of yarns and filaments

Linear Density of Yarn (tex)	**Linear Density of Filaments (tex/filament)**
178	0.31
167	0.29
150	0.39
122	0.32
116	0.30
100	0.34
89	0.31
69	0.35
67	0.34

Therefore to plot non-dimensional mechanical resistance of each filament, Π_{x3}, with respect to elongation, Π_{x2}, may be more suitable representation.

Then Π_{x3} values which are related with non-dimensional mechanical resistance of each filament are plotted against Π_{x2} and graph is shown in Figure 4.17.

As a result of regression analysis, it can probably say there is a linear relationship between Π_{x3} and Π_{x2} for stuffer warp filaments that are commonly used in Gaziantep carpet industry.

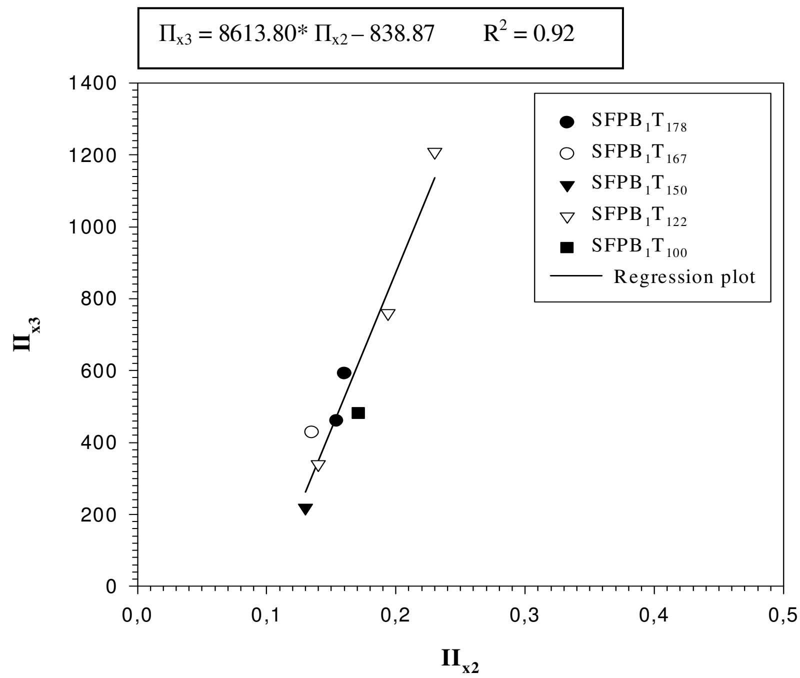


Figure 4.17 Dimensional analysis of stuffer warp filaments

As illustrated in Figure 4.17, for stuffer warp filaments there is a linear relationship between Π_{x3} and Π_{x2} and this relationship can be represented with;

$$\frac{\sigma_y * t^2 * \rho_y}{T_f^2} = 8613.80 * (\Delta L/L) - 838.87 \qquad (4.2)$$

Chain warp yarns

The non-dimensional mechanical resistance of chain warp yarns, Π_{x1}, is plotted against elongation; Π_{x2}, and shown in Figure 4.18. According to this figure, there is a linear relationship between Π_{x1} and Π_{x2} for different values of linear density of chain warp yarns. As the linear density of chain warp yarns decreases from 122 tex to 67 tex the slope of non-dimensional mechanical resistance of filament yarns with elongation increases.

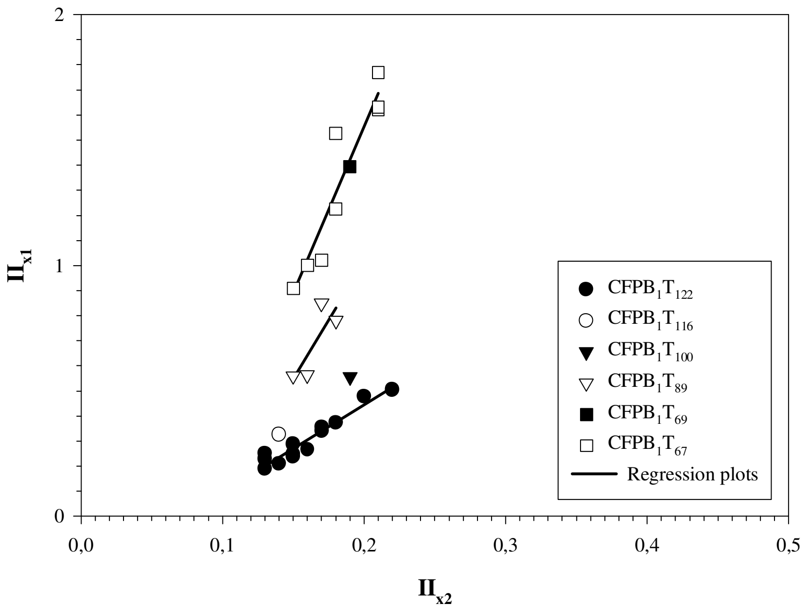


Figure 4.18 Dimensional analysis of chain warp filament yarns

The linear relation between Π_{x1} and Π_{x2} for different linear densities can be represented with the following empirical relations;

Linear Density	**Equation**		
122 tex	$\frac{\sigma_y * t^2 * \rho_y}{T_y^2} = 3.47 * (\Delta L/L) - 0.25$	$R^2 = 0.93$	(4.3)
89 tex	$\frac{\sigma_y * t^2 * \rho_y}{T_y^2} = 9.45 * (\Delta L/L) - 0.87$	$R^2 = 0.67$	(4.4)
67 tex	$\frac{\sigma_y * t^2 * \rho_y}{T_y^2} = 13.29 * (\Delta L/L) - 1.10$	$R^2 = 0.88$	(4.5)

Non- dimensional mechanical resistance of chain warp filaments, Π_{x3}, are plotted against non-dimensional elongation Π_{x2} and shown in Figure 4.19.

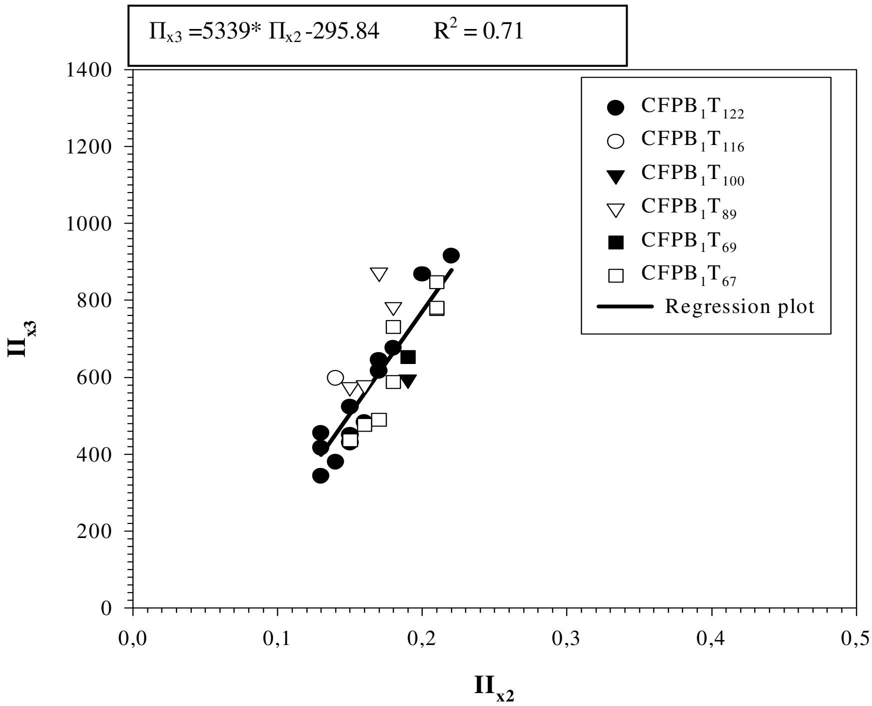


Figure 4.19 Dimensional analysis of chain warp filaments

The linear relationship between non-dimensional mechanical resistance of chain warp filaments and breaking elongation shown in Figure 4.19 can be approximated with following empirical equation;

$$\frac{\sigma_y * t^2 * \rho_y}{T_f^2} = 5339 * (\Delta L/L) - 295.84 \qquad R^2 = 0.71 \qquad (4.6)$$

Empirical relations were determined as a result of dimensional analysis and by using measured mechanical properties of the collected warp yarns. Filament density of all yarns are in the order of 0.29- 0.35 tex/filament. More exact deductions could be obtained as a result of systematic filament yarn sampling and measurement.

4.4. Evaluation of Second Group of Samples

To evaluate the performance of both stuffer and chain warp yarn raveled out from the prepared carpet samples described in Chapter 3 were tested. Percent variation of tenacity and breaking elongation values of warp yarns after weaving and after latex application were drawn according to dent number and pile densities.

10 carpet samples were woven at 5 different pile densities: 35, 40, 45, 50, and 60. Two bottom carpets for each pile density were taken and latex was applied to one of them. Both stuffer and chain warp yarns were raveled out from each carpet at 20, 80, 200, and 320 dents. Tenacity and breaking elongation values of each raveled warp yarns were measured and non-dimensionalized with initial warp yarn values and coded as on Table 3.11. 197 tex PES/CV OE-rotor yarn was used as stuffer warp yarns and 67 tex PES false-twist textured yarn was used as chain warp yarn.

Tenacity, breaking elongation, and both of these values coefficients of variations (CV %) in percentage are given as follows;

for stuffer warp yarn is:

σ_y= 37. 94 cN/tex CV (%) = 2.79; ε_y=17. 06 % CV (%) = 3.39

and for chain warp yarns is:

σ_y= 34. 27 cN/tex CV (%) = 5.30; ε_y=15. 45 % CV (%) = 7.31

Changes in tenacity and elongation values are given in Appendix E1 and Appendix E2 for both stuffer and chain warp yarns, respectively. The coefficient of variations (CV %) for tensile test of the stuffer and chain warp yarns after weaving and after latex processes are given in Appendix F1 and Appendix F2, respectively.

Stuffer warp yarn

Changes in tenacity and breaking elongation were drawn for both after weaving and after latex application according to dent number and pile densities. Figure 4.20 (a), (b), and (c) show the change in tenacity of stuffer warp yarn with pile densities after weaving, A1, after latex, A2, and overall carpet production, A3, respectively.

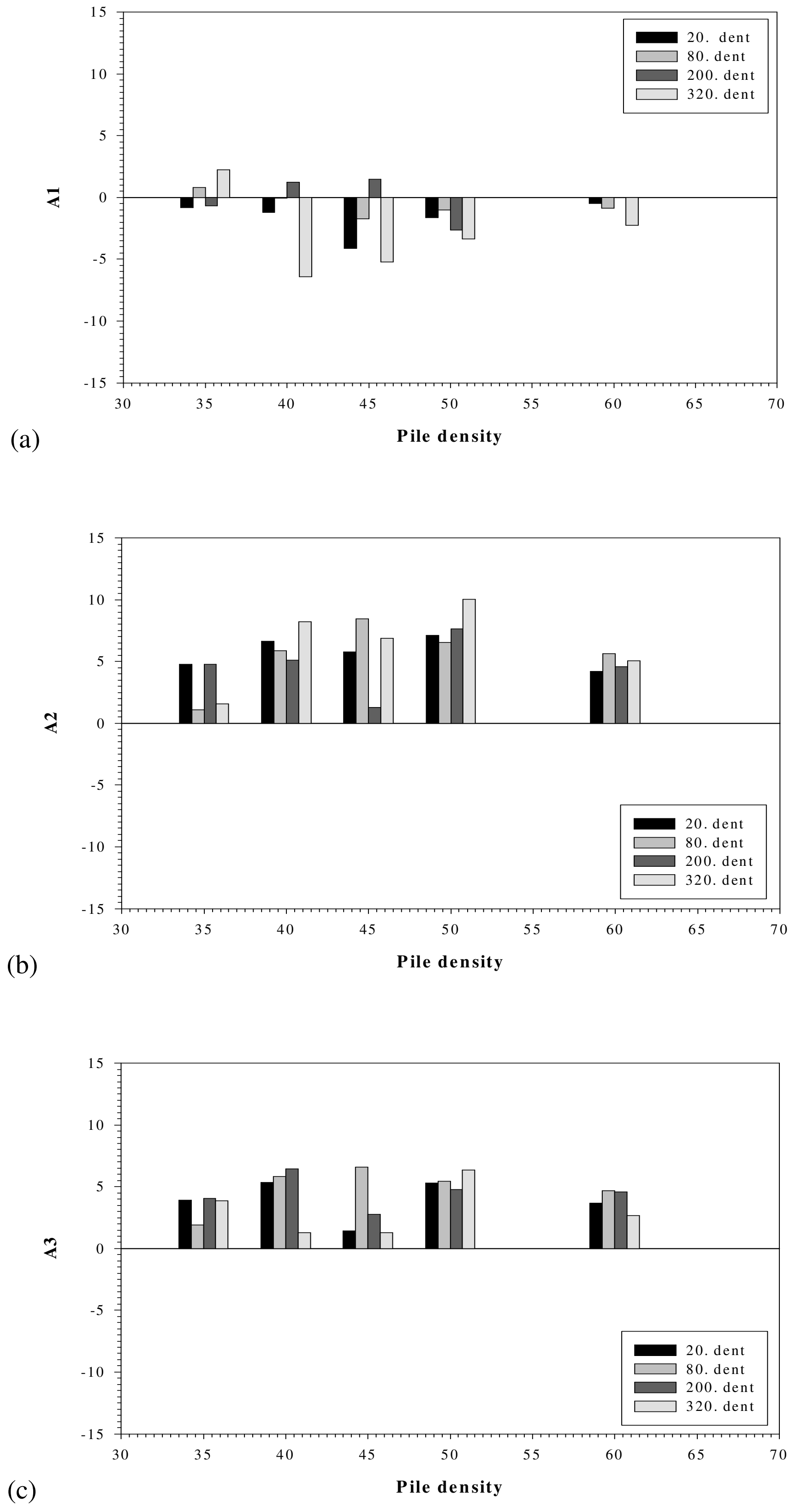


Figure 4.20 Change in tenacity of stuffer warp yarns versus pile density
(a) Weaving affect, (b) Latex affect, (c) Overall carpet production

In general, there is a decrease of the tenacity values of the stuffer warp yarn after weaving as shown in Figure 4.20 (a).

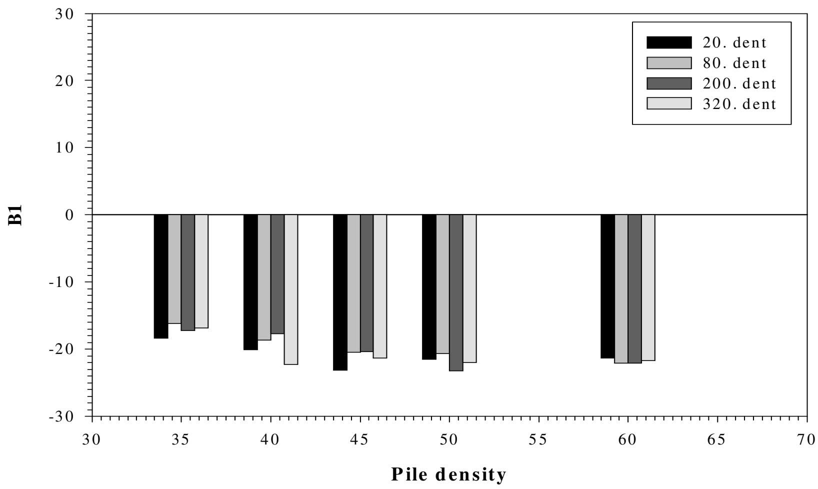
The latex application raises the tenacity of all raveled yarns for all pile densities. Since latex covers yarn without penetrating in it and film sheet is formed, so the stiffness of the yarn increases. So the tenacity of stuffer yarns also increases as shown in Figure 4.20 (b). As a result, tenacity of the stuffer warp yarns increases for overall carpet production shown in Figure 4.20 (c). There are no regular changes of the tenacity. The tenacity change from the creel to the end product is approximately 7 %. Yarns raveled out from the carpet woven with 50 pile density have the highest increase in tenacity between 20. and 320. dents in average. The pile density has not regular effect on increase of the tenacity of the stuffer warp yarn for overall carpet production.

Changes in breaking elongation of raveled stuffer warp yarns with pile density after weaving, B1, after latex, B2, and overall carpet production, B3 are shown in Figure 4.21 (a), (b), and (c), respectively.

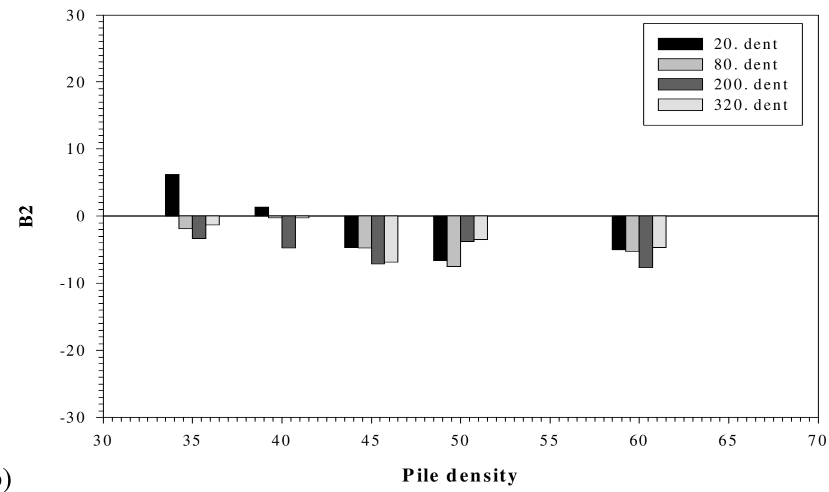
For all pile densities the elongation of the stuffer warp yarns decrease during weaving operation as illustrated in Figure 4.21 (a). Since latex makes yarn stiffer, the elongation values continue to decrease for pile densities and are shown in Figure 4.21 (b).

Effects of both weaving and latex application on the elongation of the stuffer warp yarns are shown in Figures 4.21 (c) in the view of pile density. Tested yarns from the 60 pile density and 320. dent number have the maximum elongation change which is approximately -30 % . It is seen that from the Figure 4.21 (c), the elongation of the stuffer warp yarns decrease from 35 pile density to 45 pile density. Between 45 pile density to 60 pile density, this trend is not continued.

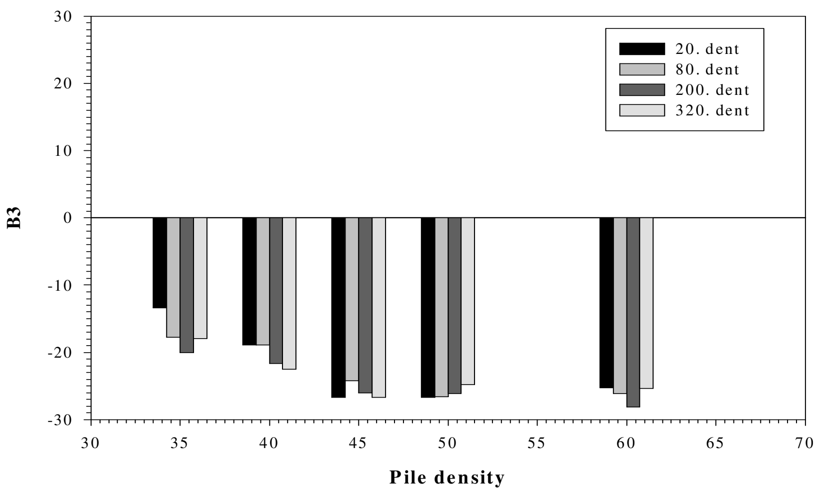
As a result, for overall carpet production about stuffer warp yarns illustrate that the tenacity of yarns increases and elongation of yarns decrease in overall carpet production.



(a)



(b)



(c)

Figure 4.21 Change in breaking elongation of stuffer warp yarn versus pile density (a) Weaving affect, (b) Latex affect, (c) Overall carpet production

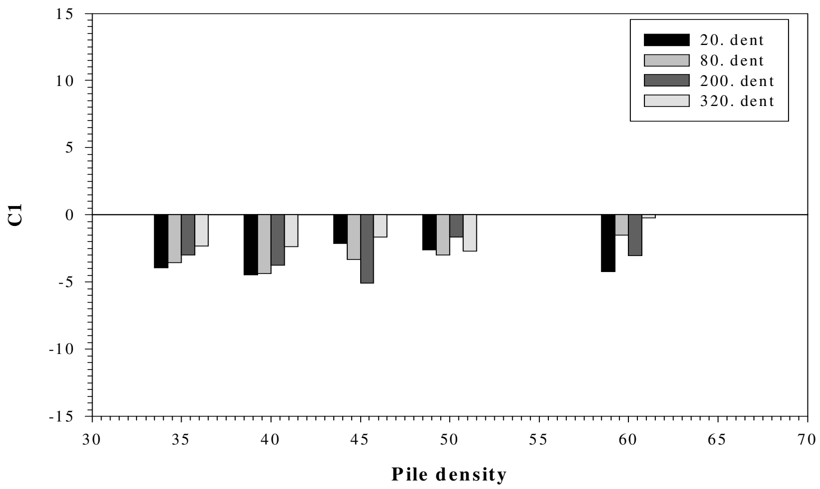
Chain warp yarn

To determine both weaving and latex effect on tenacity and breaking elongation of the yarn, tenacity and breaking elongation variations of the chain warp yarns were also examined for different pile densities and dent numbers. Figure 4.22 (a), (b), and (c) show that change in tenacity of chain warp yarns with pile densities after weaving, C1, after latex, C2, and overall carpet production, C3, respectively.

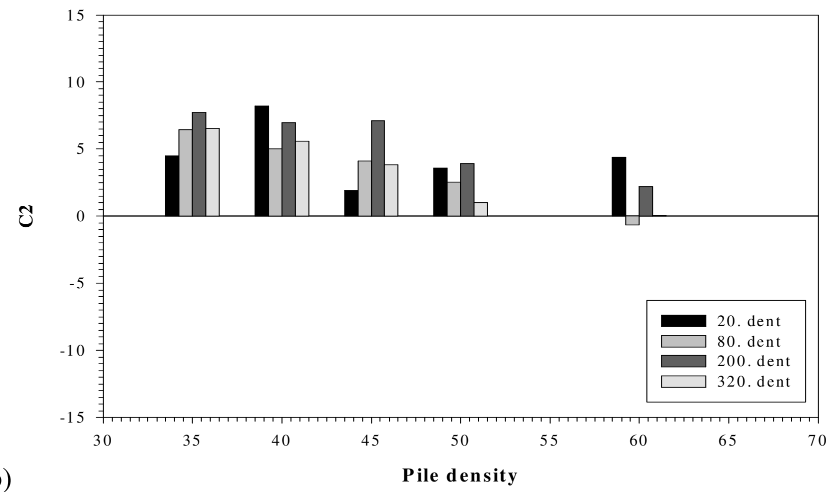
As shown in Figure 4.22 (a), weaving has a deduction effect on tenacity of chain warp yarns for all pile densities. It is resulted from the tensional forces acting on the chain warp yarns during weaving. However, in Figure 4.22 (b) tenacity versus pile density arise after latex. In general, for overall carpet production the tenacity between creel and after latex has not changed significantly. The average change is below 5 % which is illustrated in Figure 4.22 (c). Change in tenacity of the chain warp yarns decrease with from 35 pile density to 60 pile density.

Elongation changes of the chain warp yarns with respect to pile density are shown in Figure 4.23 (a), (b), and (c) which for weaving effect, latex effect and overall carpet production, respectively.

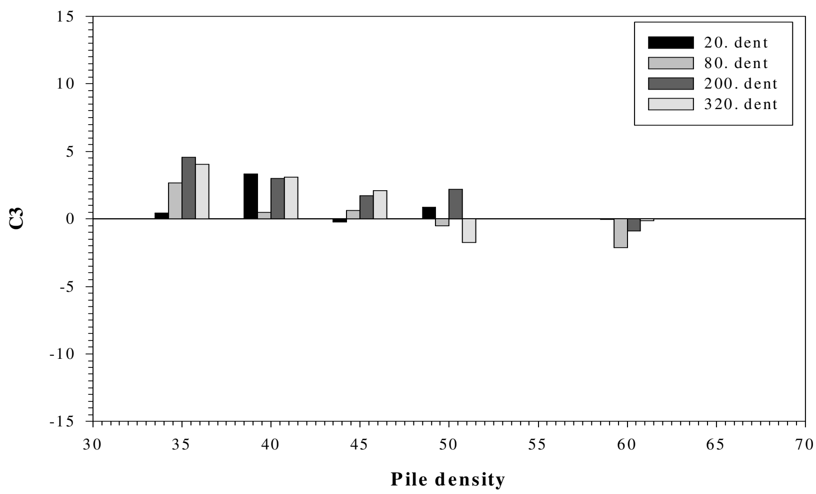
Weaving has no important effect on the elongation changes of the chain warp yarns as shown in Figure 4.23 (a). Latex has a positive effect on the elongation approximately in the range of 4-21 %. Chain warp yarns gains zig zag effect due to the weaving construction. Latex process makes this zig zag effect permanent. Thus, as shown in Figure 4.23 (b) the elongation of the chain warp yarns increase. Therefore, the elongation of the chain warp yarns are affected positively for overall carpet production as illustrated in Figure 4.23 (c).



(a)

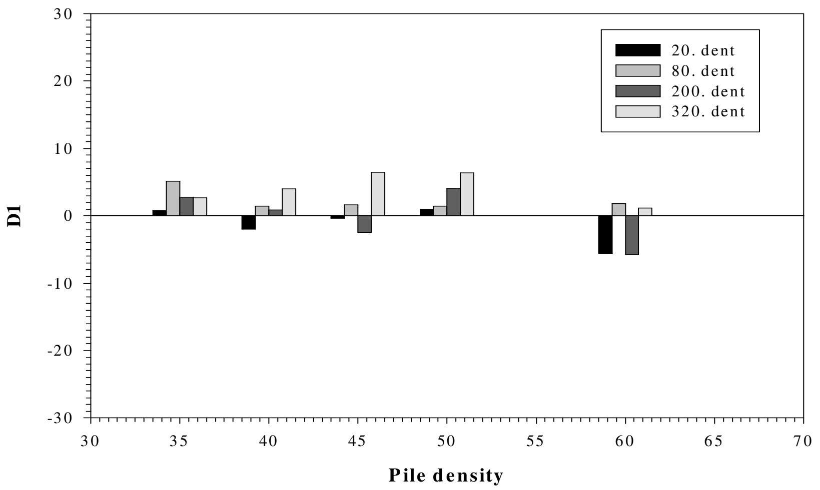


(b)

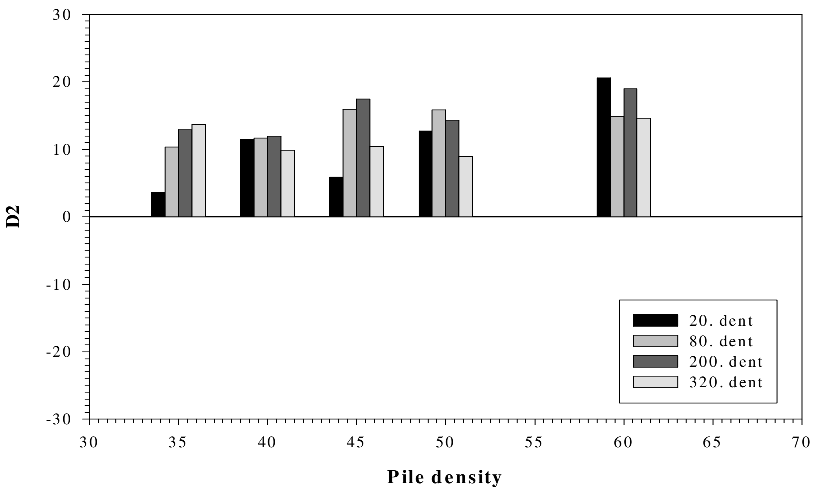


(c)

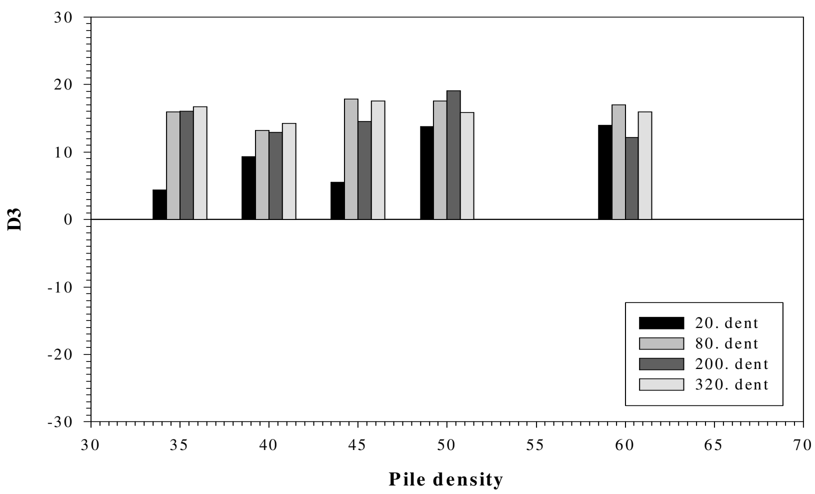
Figure 4.22 Change in tenacity of chain warp yarn versus pile density
(a) Weaving affect, (b) Latex affect, (c) Overall carpet production



(a) (b)



(b)



(c)

Figure 4.23 Change in breaking elongation of chain warp yarn versus pile density (a) Weaving affect, (b) Latex affect, (c) Overall carpet production

CHAPTER 5
CONCLUSIONS AND RECOMMEDATIONS

This research was focused on the mechanical properties of warp yarns used in woven carpet. In the first part of this research, collected stuffer and chain warp yarns from carpet industry in Gaziantep were tested. Warp trials produced with one stage production technology were tested and compared with collected warp yarns test results.

Furthermore, toughness and modulus values of the yarns were determined to estimate the energy necessary to break the yarn and initial reaction of the yarns under tension. Correlations between non-dimensional mechanical resistance of filament yarns and elongation are obtained.

In the second part, carpet samples were produced and tested to investigate the effect of weaving and latex application on mechanical properties of warp yarns. The conclusions that are draw from these experimental studies are given as follows;

THE FIRST GROUP OF THE STUDY:

Mechanical Properties

Although the raw materials, yarn production systems and after treatments are different for collected warp yarns, all of them have been used in face-to-face Wilton carpet weaving looms.

Stuffer warp yarns;

- Tenacity values of the stuffer warp yarns are changing from 21.39 cN/tex to 41 cN/tex and the breaking elongation values are changing from 13 % to 23 %, approximately.

- Toughness of the stuffer warp yarns are in the range of 189 cN/tex to 648 cN/tex and initial modulus values are between 136 cN/tex and 313 cN/tex.

- Shrinkage behaviors of short staple fibers are found to be in the range of – 3.1% to – 1.5 %. Shrinkage values of filament yarns are higher than short staple fibers. Their values are changing between – 8.06 % and – 4.38 %.

Chain warp yarns;

- Tenacity values of chain warp yarns are between 33.31 cN/tex to 38.32 cN/tex except one sample. Breaking elongation values are in the range of 12.96 %- 21.54 %.

- The minimum and maximum toughness values for chain warp yarns are found to be 249 cN/tex and 531 cN/tex, respectively. Initial modulus values are changing from 182 cN/tex-429 cN/tex.

- The minimum and maximum shrinkage values of chain warp yarns are found as – 4.71 % and – 8.42 %, respectively.

Warp trials;

- Tenacity values of warp trials are between 23.53 cN/tex and 34.12 cN/tex, while breaking elongation are changing from 16.31 % to 24.68 %.

- Toughness values are between 312 cN/tex-400 cN/tex and initial modulus are between 133 cN/tex-250 cN/tex. Shrinkage values of CF warp trials which are approximately – 14% are higher than the conventional warp yarns. However for BCF warp trials; shrinkage values are changing from – 3.10 % to – 5.01 %.

- The economical properties of BCF warp trials having 202 tex and 209 tex linear densities are seem to be similar mechanical behavior with conventional warp yarns. If the basic mechanical requirements of warp yarns acceptable for carpet weaving loom could be combined with other advantages of BCF yarn, this yarn be a new choice as warp yarn.

Dimensional analysis

Stuffer warp filaments;

- As a result of regression analysis, it can probably say that there is a linear relationship between Π_{x3} and Π_{x2} for stuffer warp filaments that are commonly used in Gaziantep carpet industry. This relationship is given in equation 4.2 which expressed as;

  $\sigma_y * t^2 * \rho_y / T_f^2 = 8613.80 * (\Delta L/L) - 838.87.$

Chain warp yarns;

- There is a linear relationship between Π_{x1} (non-dimensional mechanical resistance of filament yarns) and Π_{x2} (elongation) for different values of linear density of chain warp yarns. When the linear density of chain warp yarns decreases from 122 tex to 67 tex the slope of Π_{x1} with Π_{x2} increases.

- The linear relationship between non-dimensional mechanical resistance of chain warp filaments and breaking elongation can be approximated with following empirical equation;

  $\sigma_y * t^2 * \rho_y / T_f^2 = 5339 * (\Delta L/L) - 295.84$

THE SECOND GROUP OF THE STUDY:

Stuffer warp yarn;

- In general, the change in tenacity values of the stuffer warp yarns after weaving decrease. The latex application raises the tenacity of all raveled yarns for all pile densities.

- The elongation changes of the stuffer warp yarns for all pile densities and dent numbers decrease during weaving operation. Since latex makes yarn stiffer, the elongation value continues to decrease for all pile densities. For overall carpet production the elasticity of the stuffer warp yarns decrease from 35 pile density to 45 pile density. Between 45 pile density to 60 pile density, this trend is not continued.

- ***As a result, it is determined that the tenacity at the end of the carpet production of the stuffer warp yarns increases and elongation at break of yarns decreases.***

Chain warp yarn;

- Weaving has a deduction effect on tenacity of chain warp yarns. Tenacity of the chain warp yarn raise after latex process. Change in tenacity of the chain warp yarns decrease from 35 pile density to 60 pile density for overall carpet production. There is no significant tenacity change for overall carpet production.

- Weaving has not an important influence on the elongation of the chain warp yarns. Latex has a positive effect on the elongation approximately in the range of 4-21 %. The breaking elongation of the chain warp yarn is affected positively for overall carpet production

- ***As a result, it is determined that the tenacity of the chain warp yarns has not important changes and in the view of overall carpet production elongation increases.***

RECOMMENDATIONS:

- Warp yarns can be produced with one stage according to the determined ranges such as; tenacity, breaking elongation, shrinkage value etc. More economical yarns can be produced and tested.

- Cost analysis of the yarn production system that is two and one stage could be determined Cost analysis of the carpet production stages can also be performed. The carpet production with conventional warp yarns can be compared with that of carpet produced with warp yarns produced with one stage system.

- There are a lot of studies about the performance of the carpet produced from the different pile yarns. Besides this, effect of the warp yarns on carpet performance can be studied. The characteristics of the warp yarns which give the best results in the carpet could be determined systematically.

- Carpets with different construction can be produced by using warp yarns produced with one stage production system and carpet performance tests can be made. Thus, the most suitable carpet construction can be determined for these warp yarns.

- If the carpet is completely composed of synthetic yarns, it could be recycled. For this purpose, it is necessary to find the alternatives of the jute used as weft yarn. For the further works, studies can be about the PES carpets i.e. carpet comprises PES completely.

APPENDICES

A1)

Table 1 Mechanical properties of stuffer warp yarns

	Code	Tenacity (cN/tex)	Breaking Elongation (%)	Time (s)	Density (gr/m^3)	Linear Density (tex)	Twist (folded) (Turns/meter)	Number of filament
1	**$SSPCB_5T_{211}$-1**	25.91	18.46	10.91	1.44	211	87	-
2	**$SSPCB_5T_{211}$-2**	27.20	16.54	10.23	1.44	211	107	-
3	**$SSPCB_5T_{211}$-3**	21.39	17.22	10.12	1.44	211	93	-
4	**$SSPCB_5T_{197}$**	29.36	15.88	9.30	1.44	197	201	-
5	**$SSPCB_6T_{197}$-1**	30.30	17.34	10.12	1.44	197	202	-
6	**$SSPCB_6T_{197}$-2**	29.30	16.46	9.63	1.44	197	199	-
7	**$SSPCB_4T_{197}$-1**	39.78	17.34	10.13	1.43	197	141	-
8	**$SSPCB_4T_{197}$-2**	28.86	19.68	11.47	1.43	197	191	-
9	**$SSPCB_4T_{197}$-3**	26.61	18.98	11.12	1.43	197	71	-
10	**$SSPCB_4T_{197}$-4**	32.75	18.31	10.69	1.43	197	135	-
11	**$SSPCB_4T_{197}$-5**	37.14	18.41	10.77	1.43	197	148	-
12	**$SSPCB_2T_{197}$-1**	38.81	19.27	11.23	1.40	197	165	-
13	**$SSPCB_2T_{197}$-2**	37.07	18.41	10.71	1.40	197	169	-
14	**$SSPVB_5T_{197}$-1**	30.32	18.27	10.65	1.44	197	137	-
15	**$SSPVB_5T_{197}$-2**	32.91	16.93	9.87	1.44	197	151	-
16	**$SSPVB_4T_{197}$**	37.94	17.06	9.99	1.43	197	151	-
17	**$SSPVB_3T_{197}$-1**	35.72	19.57	11.39	1.41	197	135	-
18	**$SSPVB_3T_{197}$-2**	40.62	20.64	12.02	1.41	197	92	-
19	**$SSPVB_2T_{197}$-1**	35.78	21.67	12.64	1.40	197	175	-
20	**$SSPVB_2T_{197}$-2**	37.50	21.63	12.57	1.40	197	126	-
21	**$SFPB_1T_{178}$-1**	31.32	15.43	9.06	1.38	178	-	576
22	**$SFPB_1T_{178}$-2**	37.41	15.96	9.41	1.38	178	-	576
23	**$SFPB_1T_{167}$**	31.71	13.46	8.14	1.38	167	-	576
24	**$SFPB_1T_{150}$**	33.75	12.96	7.60	1.38	150	-	384
25	**$SFPB_1T_{122}$-1**	30.02	14.00	8.20	1.38	122	-	384
26	**$SFPB_1T_{122}$-2**	39.36	23.00	13.51	1.38	122	-	384
27	**$SFPB_1T_{122}$-3**	35.13	19.42	11.34	1.38	122	-	384
28	**$SFPB_1T_{100}$**	32.64	17.07	10.01	1.38	100	-	294

A2)

Table 2 Mechanical properties of chain warp yarns

	Code	Tenacity (cN/tex)	Breaking Elongation (%)	Time (s)	Density (gr/m_3)	Linear density (tex)	Number of filament
1	**$CFPB_1T_{122}$-1**	34.18	14.73	8.64	1.38	122	384
2	**$CFPB_1T_{122}$-2**	33.97	15.53	9.19	1.38	122	384
3	**$CFPB_1T_{122}$-3**	36.27	18.05	10.53	1.38	122	384
4	**$CFPB_1T_{122}$-4**	34.32	19.98	12.26	1.38	122	384
5	**$CFPB_1T_{122}$-5**	35.18	12.96	8.76	1.38	122	384
6	**$CFPB_1T_{122}$-6**	34.54	21.54	12.56	1.38	122	384
7	**$CFPB_1T_{122}$-7**	36.94	17.10	10.18	1.38	122	384
8	**$CFPB_1T_{122}$-8**	36.35	17.14	10.03	1.38	122	384
9	**$CFPB_1T_{122}$-9**	38.32	14.58	9.00	1.38	122	384
10	**$CFPB_1T_{122}$-10**	35.75	13.48	8.32	1.38	122	384
11	**$CFPB_1T_{122}$-11**	35.31	13.58	7.99	1.38	122	384
12	**$CFPB_1T_{122}$-12**	35.48	14.80	8.67	1.38	122	384
13	**$CFPB_1T_{122}$-13**	34.08	13.14	7.74	1.38	122	384
14	**$CFPB_1T_{116}$**	37.98	13.91	9.15	1.38	116	384
15	**$CFPB_1T_{100}$**	33.31	18.82	11.00	1.38	100	294
16	**$CFPB_1T_{89}$-1**	50.43	16.68	9.83	1.38	89	288
17	**$CFPB_1T_{89}$-2**	36.66	15.21	9.36	1.38	89	288
18	**$CFPB_1T_{89}$-3**	38.02	15.71	9.23	1.38	89	288
19	**$CFPB_1T_{89}$-4**	37.60	18.24	10.79	1.38	89	288
20	**$CFPB_1T_{69}$**	33.50	19.42	11.98	1.38	69	196
21	**$CFPB_1T_{67}$-1**	37.66	17.57	10.29	1.38	67	196
22	**$CFPB_1T_{67}$-2**	35.51	21.43	12.73	1.38	67	196
23	**$CFPB_1T_{67}$-3**	36.46	20.68	12.03	1.38	67	196
24	**$CFPB_1T_{67}$-4**	34.34	21.29	12.43	1.38	67	196
25	**$CFPB_1T_{67}$-5**	36.33	18.22	11.69	1.38	67	196
26	**$CFPB_1T_{67}$-6**	35.62	16.65	9.66	1.38	67	196
27	**$CFPB_1T_{67}$-7**	36.15	16.03	9.46	1.38	67	196
28	**$CFPB_1T_{67}$-8**	34.27	15.45	9.29	1.38	67	196

B)

Table 3 Shrinkage values of the stuffer and chain warp yarns

Stuffer Warp Yarn	Shrinkage (%)	Chain Warp Yarn	Shrinkage (%)
$SSPCB_5T_{211}$	-2.48	$CFPB_1T_{122}$	-8.42
$SSPCB_5T_{197}$	-2.39	$CFPB_1T_{116}$	-7.54
$SSPCB_6T_{197}$	-2.38	$CFPB_1T_{100}$	-4.71
$SSPCB_4T_{197}$	-3.00	$CFPB_1T_{89}$	-7.53
$SSPCB_2T_{197}$	-2.58	$CFPB_1T_{69}$	-6.14
$SSPVB_5T_{197}$	-1.51	$CFPB_1T_{67}$	-5.26
$SSPVB_4T_{197}$	-3.14		
$SSPVB_3T_{197}$	-1.48		
$SSPVB_2T_{197}$	-2.18		
$SFPB_1T_{178}$	-8.06		
$SFPB_1T_{167}$	-5.43		
$SFPB_1T_{122}$	-4.74		
$SFPB_1T_{100}$	-4.38		

C1)

Table 4 Toughness- initial modulus values of stuffer warp yarns

Code	Initial Modulus (cN/tex)	Toughness (cN/tex)
$SSPCB_5T_{211}$-1	149	252
$SSPCB_5T_{211}$-2	152	246
$SSPCB_5T_{211}$-3	136	189
$SSPCB_5T_{197}$	181	248
$SSPCB_6T_{197}$-1	189	287
$SSPCB_6T_{197}$-2	167	255
$SSPCB_4T_{197}$-1	302	342
$SSPCB_4T_{197}$-2	158	306
$SSPCB_4T_{197}$-3	171	271
$SSPCB_4T_{197}$-4	189	287
$SSPCB_4T_{197}$-5	243	400
$SSPCB_2T_{197}$-1	237	343
$SSPCB_2T_{197}$-2	235	335
$SSPVB_5T_{197}$-1	200	284
$SSPVB_5T_{197}$-2	208	320
$SSPVB_4T_{197}$	247	318
$SSPVB_3T_{197}$-1	235	389
$SSPVB_3T_{197}$-2	244	402
$SSPVB_2T_{197}$-1	196	385
$SSPVB_2T_{197}$-2	250	423
$SFPB_1T_{178}$-1	240	307
$SFPB_1T_{178}$-2	329	408
$SFPB_1T_{167}$	291	245
$SFPB_1T_{150}$	313	328
$SFPB_1T_{122}$-1	250	248
$SFPB_1T_{122}$-2	280	648
$SFPB_1T_{122}$-3	220	407
$SFPB_1T_{100}$	228	316

C2)

Table 5 Toughness- initial modulus values of chain warp yarns

Code	Initial Modulus (cN/tex)	Toughness (cN/tex)
$CFPB_1T_{122}$-1	313	254
$CFPB_1T_{122}$-2	311	335
$CFPB_1T_{122}$-3	261	363
$CFPB_1T_{122}$-4	250	501
$CFPB_1T_{122}$-5	326	250
$CFPB_1T_{122}$-6	236	531
$CFPB_1T_{122}$-7	277	513
$CFPB_1T_{122}$-8	293	383
$CFPB_1T_{122}$-9	333	384
$CFPB_1T_{122}$-10	318	267
$CFPB_1T_{122}$-11	333	312
$CFPB_1T_{122}$-12	333	367
$CFPB_1T_{122}$-13	306	249
$CFPB_1T_{116}$	350	294
$CFPB_1T_{100}$	201	363
$CFPB_1T_{89}$-1	429	501
$CFPB_1T_{89}$-2	342	358
$CFPB_1T_{89}$-3	294	398
$CFPB_1T_{89}$-4	210	387
$CFPB_1T_{69}$	191	385
$CFPB_1T_{67}$-1	278	400
$CFPB_1T_{67}$-2	184	514
$CFPB_1T_{67}$-3	182	436
$CFPB_1T_{67}$-4	191	465
$CFPB_1T_{67}$-5	220	397
$CFPB_1T_{67}$-6	240	368
$CFPB_1T_{67}$-7	227	332
$CFPB_1T_{67}$-8	250	320

D1)

Table 6 Non-dimensional parameters of the stuffer warp filament yarns

Code	Π_1	Π_2	Π_3
$SFPB_1T_{178}$-1	0.112	0.154	460
$SFPB_1T_{178}$-2	0.144	0.160	592
$SFPB_1T_{167}$	0.104	0.135	428
$SFPB_1T_{150}$	0.120	0.130	218
$SFPB_1T_{122}$-1	0.187	0.140	339
$SFPB_1T_{122}$-2	0.666	0.230	1,208
$SFPB_1T_{122}$-3	0.419	0.194	760
$SFPB_1T_{100}$	0.451	0.171	482

D2)

Table 7 Non-dimensional parameters of the chain warp filament yarns

Code	Π_{x1}	Π_{x2}	Π_{x3}
$CFPB_1T_{122}$-1	0.237	0.147	429
$CFPB_1T_{122}$-2	0.266	0.155	482
$CFPB_1T_{122}$-3	0.373	0.181	676
$CFPB_1T_{122}$-4	0.478	0.200	868
$CFPB_1T_{122}$-5	0.250	0.130	454
$CFPB_1T_{122}$-6	0.505	0.215	916
$CFPB_1T_{122}$-7	0.355	0.171	644
$CFPB_1T_{122}$-8	0.339	0.171	615
$CFPB_1T_{122}$-9	0.288	0.146	522
$CFPB_1T_{122}$-10	0.229	0.135	416
$CFPB_1T_{122}$-11	0.209	0.136	379
$CFPB_1T_{122}$-12	0.247	0.148	449
$CFPB_1T_{122}$-13	0.189	0.131	343
$CFPB_1T_{116}$	0.326	0.139	598
$CFPB_1T_{100}$	0.556	0.188	594
$CFPB_1T_{89}$-1	0.849	0.167	872
$CFPB_1T_{89}$-2	0.560	0.152	574
$CFPB_1T_{89}$-3	0.564	0.157	579
$CFPB_1T_{89}$-4	0.780	0.182	783
$CFPB_1T_{69}$	1.394	0.194	653
$CFPB_1T_{67}$-1	1.226	0.176	587
$CFPB_1T_{67}$-2	1.769	0.214	847
$CFPB_1T_{67}$-3	1.622	0.207	777
$CFPB_1T_{67}$-4	1.631	0.213	781
$CFPB_1T_{67}$-5	1.526	0.182	731
$CFPB_1T_{67}$-6	1.022	0.167	489
$CFPB_1T_{67}$-7	0.995	0.160	476
$CFPB_1T_{67}$-8	0.909	0.155	436

E1)

Table 8 Tenacity- breaking elongation changes of stuffer warp yarn raveled out from the carpet samples

	Tenacity (%)			Breaking Elongation (%)		
Code	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**
S35-20	- 0.82	4.78	3.93	-18.41	6.18	-13.36
S35-80	0.82	1.10	1.92	-16.18	-1.89	-17.76
S35-200	- 0.69	4.78	4.06	-17.23	-3.33	-19.99
S35-320	2.24	1.57	3.85	-16.82	-1.34	-17.94
S40-20	- 1.19	6.62	5.35	-20.05	1.39	-18.93
S40-80	-0.05	5.88	5.82	-18.70	-0.29	-18.93
S40-200	1.24	5.13	6.43	-17.70	-4.77	-21.63
S40-320	-6.40	8.22	1.29	-22.27	-0.30	-22.51
S45-20	-4.11	5.77	1.42	-23.15	-4.65	-26.73
S45-80	-1.71	8.45	6.59	-20.46	-4.72	-24.21
S45-200	1.48	1.27	2.77	-20.34	-7.14	-26.03
S45-320	-5.22	6.87	1.29	-21.34	-6.86	-26.73
S50-20	-1.66	7.10	5.32	-21.51	-6.65	-26.73
S50-80	-1.03	6.52	5.43	-20.69	-7.46	-26.61
S50-200	-2.66	7.64	4.77	-23.27	-3.74	-26.14
S50-320	-3.35	10.04	6.35	-22.04	-3.53	-24.79
S60-20	-0.50	4.19	3.66	-21.28	-5.06	-25.26
S60-80	-0.87	5.61	4.69	-22.10	-5.19	-26.14
S60-200	0.00	4.59	4.59	-22.10	-7.67	-28.08
S60-320	-2.27	5.07	2.69	-21.69	-4.64	-25.32

E2)

Table 9 Tenacity- breaking elongation changes of chain warp yarn raveled out from the carpet samples

	Tenacity (%)			Breaking Elongation (%)		
Code	**C1**	**C2**	**C3**	**D1**	**D2**	**D3**
C35-20	-3.92	4.51	0.41	0.76	3.57	4.35
C35-80	-3.54	6.44	2.67	5.11	10.32	15.96
C35-200	-2.97	7.75	4.55	2.78	12.95	16.09
C35-320	-2.34	6.56	4.06	2.65	13.71	16.72
C40-20	-4.47	8.19	3.35	-2.02	11.53	9.27
C40-80	-4.36	5.04	0.46	1.39	11.64	13.19
C40-200	-3.73	6.96	2.97	0.88	11.94	12.93
C40-320	-2.37	5.58	3.08	3.97	9.89	14.26
C45-20	-2.13	1.92	-0.25	-0.38	5.89	5.49
C45-80	-3.32	4.09	0.63	1.64	15.95	17.85
C45-200	-5.07	7.12	1.69	-2.46	17.46	14.57
C45-320	-1.66	3.80	2.07	6.44	10.49	17.60
C50-20	-2.62	3.58	0.87	0.95	12.69	13.75
C50-80	-3.00	2.56	-0.52	1.45	15.86	17.54
C50-200	-1.63	3.91	2.21	4.10	14.36	19.05
C50-320	-2.72	1.01	-1.74	6.37	8.96	15.90
C60-20	-4.22	4.38	-0.03	-5.55	20.64	13.94
C60-80	-1.50	-0.64	-2.13	1.77	14.94	16.97
C60-200	-3.05	2.22	-0.90	-5.74	19.01	12.18
C60-320	-0.22	0.05	-0.16	1.20	14.59	15.96

F1)

Table 10 Coefficient of variation (CV%) of the stuffer warp yarn raveled out from the carpet samples

Stuffer warp yarn	After weaving (CV %)		After latex (CV%)	
Code	**Tenacity**	**Breaking elongation**	**Tenacity**	**Breaking elongation**
S35-20	3.85	4.27	4.76	4.95
S35-80	5.21	5.17	6.41	9.27
S35-200	6.80	5.02	7.07	5.53
S35-320	6.88	3.50	5.88	3.27
S40-20	5.16	5.54	5.71	4.59
S40-80	3.42	6.98	6.41	4.62
S40-200	5.83	4.77	4.94	3.36
S40-320	8.41	6.21	7.01	3.89
S45-20	6.58	6.40	8.26	7.02
S45-80	4.42	4.35	4.34	3.42
S45-200	3.74	3.55	5.47	5.08
S45-320	7.85	5.72	8.04	4.57
S50-20	4.64	4.96	7.27	6.08
S50-80	5.08	6.16	5.02	5.11
S50-200	7.56	5.74	5.58	4.77
S50-320	6.94	5.23	6.79	4.15
S60-20	6.46	5.59	4.90	4.45
S60-80	4.67	4.63	4.49	4.84
S60-200	4.67	4.89	4.78	6.13
S60-320	5.41	3.63	5.03	3.94

F2)

Table 11 Coefficient of variation (CV%) of the chain warp yarn raveled out from the carpet samples

Chain warp yarn	After weaving (CV %)		After latex (CV%)	
Code	**Tenacity**	**Breaking elongation**	**Tenacity**	**Breaking elongation**
C35-20	9.69	12.22	5.10	10.26
C35-80	2.38	6.74	4.86	6.82
C35-200	3.49	7.09	2.22	4.56
C35-320	3.58	7.79	3.34	6.21
C40-20	3.68	5.22	2.33	4.89
C40-80	4.79	5.82	5.02	6.90
C40-200	4.52	6.95	3.14	6.48
C40-320	3.26	6.73	2.43	5.82
C45-20	2.98	5.80	4.22	9.17
C45-80	3.58	6.45	2.63	9.28
C45-200	6.76	10.30	4.92	8.67
C45-320	3.63	5.50	2.88	5.49
C50-20	5.34	7.90	3.41	6.63
C50-80	3.33	7.86	3.42	8.52
C50-200	4.38	8.54	3.33	7.62
C50-320	2.88	7.59	10.91	13.95
C60-20	5.83	8.20	3.96	8.20
C60-80	4.15	6.72	8.02	11.30
C60-200	4.61	7.11	3.51	7.31
C60-320	3.50	6.77	2.74	6.65

G1)

Table 12 Machine settings of the CF production on POLYSPIN BCF8 machine

SETTINGS	VALUE
Raw Material	PES Granule BG820 Intrinsic viscosity (I.V.) = 0.8 gr/dl
Extruder Temperature	240°C
Cooling Temperature	15 °C
Temperature and speed of the slow godet	70 °C and 800 m/min
Temperatures and speeds of the fast godets	110 °C and 1500 m/min 130 °C and 2800 m/min
Draw ratio	3- 3.5
Speed of the winder	2750 m/min

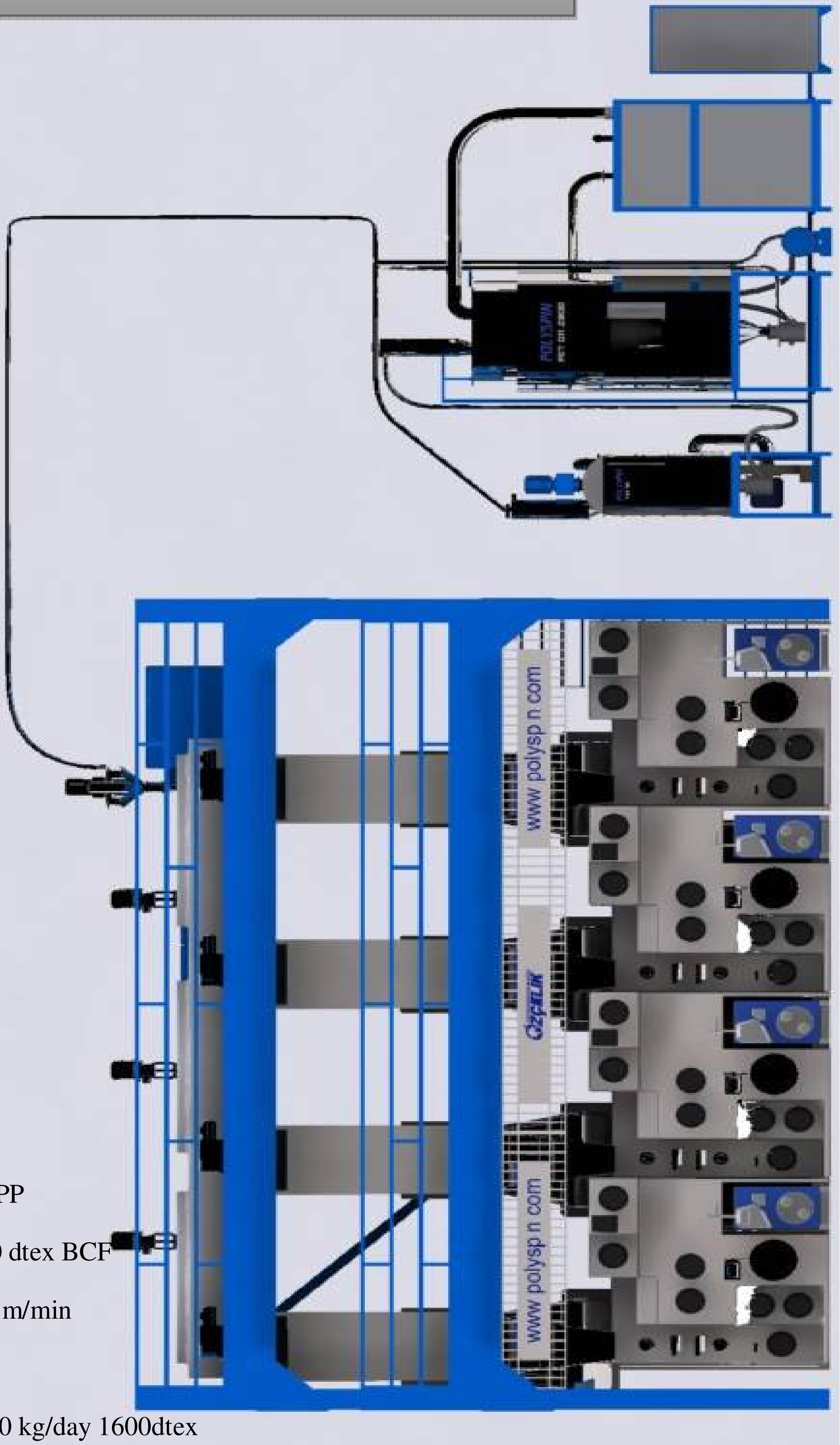
G2)

Table 13 Machine settings of the BCF production on POLYSPIN BCF8 machine

SETTINGS	VALUE
Raw Material	PES Granule BG820 Intrinsic viscosity (I.V.) = 0.8 gr/dl
Extruder Temperature	240°C
Cooling Temperature	15 °C
Temperature and speed of the slow godet	70 °C and 800 m/min
Temperatures and speeds of the fast godets	110 °C and 1400 m/min 130 °C and 2800 m/min
Draw ratio	3
Temperature and pressure of texturation	170 °C and 7 bar
Speed of the winder	2400 m/min

H)

Photograph 1 POLYSPIN BCF8 with dryer and crystallizator



POLYSPIN BCF8

Raw materials: PES, PA, PP

Product range: 600- 4000 dtex BCF

Production speed: > 3000 m/min

Number of bobbin: 8

Production capacity: 4500 kg/day 1600dtex

5300 kg/day 2000dtex

5500 kg/day 2600dtex

Maximum power ≈ 450 kW with all accessories

I)

Table 14 Mechanical properties of warp trials

Code	Breaking strength (cN/tex)	Breaking Elongation (%)	Time (s)	Density (gr/m^3)	Linear density (tex)	Initial Modulus (cN/tex)	Toughness (cN/tex)	Shrinkage (%)
$WBFPB_1T_{209}$	31.15	20.31	12.22	1.38	209	224	418	-4.93
$WBFPB_1T_{202}$	34.12	19.32	12.73	1.38	202	220	449	-5.01
$WBFPB_1T_{183}$	23.53	24.68	19.55	1.38	183	108	403	-3.19
$WCFPB_1T_{139}$	24.24	16.31	16.31	1.38	139	250	312	-13.11
$WCFPB_1T_{119}$	27.07	20.10	21.56	1.38	119	133	552	-14.95

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