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INVESTIGATION OF EFFECT OF FIBER MIGRATION AND BLEND IRREGULARITY WITHIN YARN CROSS-SECTION ON KNITTED FABRIC THERMAL COMFORT PERFORMANCE

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IN

TEXTILE ENGINEERING

BY

GÜLİSTAN CANLI

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Investigation of Effect of Fiber Migration and Blend Irregularity within Yarn Cross-Section on Knitted Fabric Thermal Comfort Performance

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Assoc. Prof. Dr. Halil İbrahim ÇELİK

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

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

Gülistan CANLI

ABSTRACT

INVESTIGATION OF EFFECT OF FIBER MIGRATION AND BLEND IRREGULARITY WITHIN YARN CROSS-SECTION ON KNITTED FABRIC THERMAL COMFORT PERFORMANCE

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In the scope of the study, cotton-acrylic yarn samples with 75-25%, %50-50%, 40-60% blending ratios were produced with three different yarn numbers; 20/1 Ne, 24/1 Ne, 30/1 Ne and three twist coefficients; 3.5 α, 4 α, 4.5 α. Knitted fabric samples were manufactured from the yarn samples with same stitch density and pattern. Half of the fabric samples were applied bleaching process other remaining part was evaluated as raw fabric. Thus, totally 27 yarn samples and 54 knitted fabric samples were obtained. The yarn cross-sectional samples were sliced with microtome. The image frames of yarn cross-sections were acquired via digital microscope. Image processing algorithm was developed to calculate yarn structural properties; fiber migration and packing density. On the other hand, fabric comfort properties; were determined by using related standards. The porosity of the fabric samples was also measured by applying image processing algorithm. The results were evaluated statistically and the effect of independent parameters; yarn number, blending ratio, twist coefficient on dependent parameters; yarn fiber migration, yarn packing density, yarn diameter. Also effect on fabric thermal comfort performance; air permeability, water vapor permeability, wickability and porosity were revealed.

Key Words: fiber blending ratio, fiber migration, fiber distribution, packing density, yarn diameter, air permeability, water vapor permeability, wicking, porosity

ÖZET

İPLİK KESİTİNDEKİ LİF GÖÇÜ VE HARMAN DÜZENSİZLİĞİNİN ÖRME KUMAŞ ISIL KONFOR PERFORMANSI ÜZERİNDE ETKİSİNİN İNCELENMESİ

CANLI, Gülistan

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Çalışma kapsamında, pamuk/akrilik iplik numuneleri 75-25%, 50-50%,40-60% karışım oranlarında, 20/1, 24/1, 30/1 olmak üzere üç farklı numarada ve 3.5 α, 4 α, 4.5 α olmak üzere üç farklı büküm katsayısında üretilmiştir. Örme kumaş numuneleri aynı desen ve sıklıkta iplik numunelerinden örülmüştür. Kumaş numunelerinin yarısı ağartma işlemi için kullanılmış ve kalan diğer kısmı ise ham kumaş olarak değerlendirilmiştir. Böylece 27 adet iplik numunesi ve 54 adet kumaş numunesi elde edilmiştir. Lif migrasyonu ve paketleme yoğunluğu gibi iplik yapısal özelliklerini hesaplamak için görüntü işleme algoritması geliştirilmiştir. Öte yandan, ilgili standartlar kullanılarak kumaş konfor özellikleri belirlenmiştir. Kumaş numunelerinin gözenekliliği, görüntü işleme algoritması uygulanarak da ölçülmüştür. Sonuçlar istatistiksel olarak iplik numarası, karışım oranı ve büküm katsayısı gibi bağımsız parametrelerin; iplik lif migrasyonu, iplik paketleme yoğunluğu, iplik çapı; ayrıca kumaşların hava geçirgenliği, su buharı geçirgenliği, kılcallık ve gözeneklilik gibi bağımlı değişkenler üzerindeki etkisi değerlendirilmiştir.

Anahtar Kelimeler: lif karışım oranı, lif migrasyonu, lif dağılımı, paketleme yoğunluğu, iplik çapı, hava geçirgenliği, su buharı geçirgenliği, kılcallık, gözeneklilik, örgü kumaş

My precious family and my husband…

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

Today, it is mentioned that yarns are made in order to take advantage of the charging properties of different fibers in the same final product. Both synthetic and natural fibers cannot be produced by adapting themselves to the area in which they are used, but by combining these synthetic and natural fibers, desired characteristic features can be acquired within the same structure.

The distribution and uniformity of the fibers in the cross-sections of blended yarns in textile materials are important in determining the structural, functional, mechanical and visual properties of the products. The outer fibers tend to show more tension as they travel a longer distance during the ring yarn production. However, the fibers in the yarn center have a lower tension because they follow a straighter path. The outer fibers try to move to the inner region because they tend to have low density, while the inner fibers tend to have the opposite direction. The tendency of the fibers to displace during yarn formation is called fiber migration. In other words, variations of the fiber placement in the yarn can be defined as fiber migration. In twisted yarns the two most important parameters to be considered in terms of cohesion and rigidity are yarn twist and fiber migration.

Yarn production line;

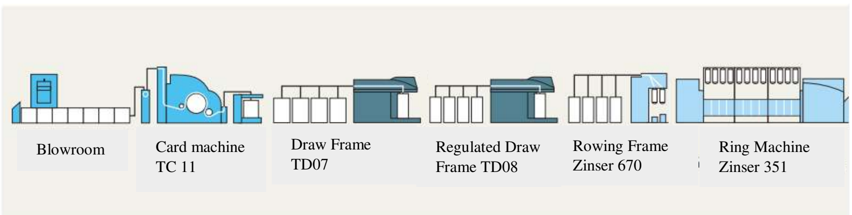


Figure 1.1 Ring Machine Park

In the scope of the study, production was performed on the machine park shown in Figure 1.1. and yarns were produced via blowroom blend.

In this study, the effects of blend ratios of yarns on yarn structure properties and fabric performance properties of blended yarns were investigated. It was stated that the location and distribution of the fibers in the yarn structure determines the porosity in the yarn structure. The porosity of fabrics has a significant influence on air permeability, water vapor permeability and capillarity productivity. Fabric porosity come out of the spaces between the connection points of the weft and warp threads forming the fabric and the spaces between the fibers in the yarn structure. [15]. Therefore, it is believed that the distribution of the fibers in the yarn structure, in other words, the fiber migration properties of the fabric, has a significant effect on the comfort properties of the fabric.

Properties of the fibers such as elasticity, rigidity, length, fineness and strength have considerable influence on the bending process and yarn properties. The rigidity and cohesion properties of the fibers are significant in the twisting process. It has been stated that as the twist factor becomes higher, yarns will have a harder structure because of holding fibers more tightly. It has been mentioned that the covering ability is reduced due to the decrease in the yarn diameter. The fabrics woven with high-twisted yarns were supposed to be thin and hard-pressed. It has been found that the fabric produced with yarns with low twist factor has soft handle, but the yarns will be weaker leading to low abrasion resistance and pilling in the fabric [38].

If the twist coefficient is high on yarn, it ensures that the fibers are held firmly. At this point, water is restricted from entering structure. Such high twisted yarns are often used where good water resistance is desired. The twist factor has significant effect on yarn diameter and softness. So, it can be stated that the twist factor affects the structural and appearance properties of the yarn.

It was concluded that wearing properties (abrasion and peeling) are improved with the increase in the twist factor. To raise level of twist helps to endure abrasion as the fibers cannot be easily pulled out of the yarn. It was stated that the similar influence preserves pilling also [38].

The characteristics of the yarns are very important in determining the properties of the fabric used in production. In this study, cotton and acrylic blended yarn was chosen. It was benefitted following properties of acrylic fiber;

Fineness of acrylic fiber is controllable. The filament yarns with acrylic fiber can made 75 to 200 denier ranges while short fibers can made 2 and 3 deniers cut in to 1,5”, 2”, 3” and 4” length. Acrylic fiber is a highly durable synthetic fiber. Its tenacity is 5 g/denier in dry state and 4,8 g/denier in wet state. Its extension at break is 15%. There is significant improvement in deformation. It has an elastic recovery of 85% after 4% extension when the load is extremely released.

Also, the reason for choosing with cotton fiber is due to these properties;

Cotton does not stress easily. It has a tenacity of 3-5 g/denier. It has an elongation at break of 5-10%. It is strong to a certain degree. The parameter that affects the strength of cotton fibers very much is moisture. The strength of the cotton increases 20% when wetted. This figure is higher than dry strength. Standard moisture recovery of cotton 8.5%.

On the yarn properties and subsequent processing, the distribution of the different yarns in the cross-section of the blend yarns has an important effect. Also, the packing density is a very significant parameter because it determines the characteristics of the yarn such as feeling, dyeing, temperature and volume. This value also determines the maximum amount of yarn that can be put in a package in packaging [5].

One of the goals of this study is to statistically determine the effects of fiber distribution properties on yarn structural and fabric comfort properties. The yarn samples were prepared in three different blending ratios- three different yarn numbers (linear density) and different twist coefficient values. Thus, it is aimed to determine the optimum blending ratio according to yarn count and twist factor in terms of fabric comfort and permeability performance.

On the other hand, by using image processing techniques it is aimed to develop powerful software for determining the yarn packing density and fabric porosity. It is aimed to easily and precisely determine the porosity characteristics of the fabric from fabric surface images with the developed algorithm. The fiber yarn packing density properties will also be determined via the developed image processing algorithms from yarn cross-section views.

The most important outputs to be achieved in the planned thesis result are;

- Statistical determination of the effects of yarn count and twist coefficient values on structural properties such as fiber migration, yarn packing density and yarn diameter at different fiber blend ratios.
- Statistical determination of the fiber comfort characteristics (air permeability, water vapor permeability, wickability) and the effects on the fabric porosity of the fiber distribution characteristics (fiber migration, yarn packing density and yarn diameter) formed in the cross section of the blended yarns with different number and twist coefficient values.
- Development of software that can determine the yarn structural characteristics (yarn packing density) from the yarn cross-sectional image and fabric porosity from knitted fabric surface images easily.

1.2.LITERATUR SURVEY

There are many studies on the structural properties of yarns and yarn performance properties. In particular, there are many papers in which different methods are proposed for measuring fiber migration, yarn packing density and yarn diameter properties. However, studies have mostly focused on yarns that made of a single fiber type. Furthermore, no study has been found on the effects of these structural features on fabric comfort performances. In addition, software that will be developed for more accurate measurement and image analysis for precise result will be used. No special software has been developed in previously studies.

Křemenáková D., et al. introduced new methods of yarn geometry assessment based on the application of software for image analysis [1]. These methods can be used for verification models and for the technical design or evaluation of yarn quality. They have used 100% ring PET fiber; round profile, 20 tex, twist 940 m^{-1} and rotor blended yarn 50-50% cotton-cottonized flax, 24 tex, twist 1260 m^{-1} for comparison of Direct method and Secant method. The selected yarns were investigated by image analysis. The images were operated via the combination of modeling and statistical treatment, depending on idealized structural regulation. The analysis results are used for assessment of textile production quality and for textile design goals.

Ghosh A. and Raihan M. presented effect of fiber blend ratio on yarn properties [2]. They have used polyester and flax 26's, 30's and 34's count yarn with different blend ratios, for example; 85/15, 80/20 and 50/50. These yarns were tested on Uster Tester and the results were examined. According to results, with the more percentage of flax in flax and polyester blend ratios yarn irregularities are higher. Polyester is better compatible with lower ratio of flax in their ratios therefore shows suitable performance.

Harwood R.J. et al. presented compression properties of yarns [3]. They have described a device which has been used to measure the effects of compression forces on the dimensions of the yarn cross-sections. According to this study; when the yarn is compressed, the density of the fiber distribution is increases. They have developed an experimental device for measuring the compression and flattening of yarns and a study made of the compression of acrylic-fiber double-rove yarns with the various levels of twist. It was state that the comparison with the experimental data shows the good predictive ability of the theory.

Kuang X. et al. presented application of finite mixture model in cotton fiber length probability distribution [4]. They used five cotton fiber samples that were collected from different spinning process (bale, card mat, carded sliver, combed sliver, finishes sliver) for this study. It was stated that based on the histograms by weight and by number of different cotton samples measured by AFIS, the probability density function with parameters of finite mixture model was used to characterize cotton fiber length distribution. They refer that the relationship between the parameters of this mixture model and some length measures can be found out, which will lay a good foundation for generating the probability density function with parameters based on length measures.

Balasubeamaian N. presented a study about yarn diameter, specific volume and packing density [5]. Relationship between yarn diameter and count by equations given by different authors is compared and discrepancies explained. A new equation is proposed taking into account the variation in specific volume with count. Packing density is found to be higher at core and decreases towards the surface with yarns manufactured by all spinning systems. Packing density in ring yarns is found to be lower than that given by open and close packing.

Ryklin D. and Silich T. presented investigation of fiber migration in cotton/polypropylene blended yarn [6]. A hypothesis states that due to fibers migration their tension in yarn becomes equal. On the basis of that hypothesis they identified the factors that affect the migration. The main factors affecting are differences in Young's modulus and density of fibers. Simulating the fibers migration, they obtained the equation for determining the proportion of fibers in the external and inner layers of blended yarn. These equations were attested via analysis of cross-section of cotton/polypropylene yarn. Result of blended yarn processing in knitting showed that migration of polypropylene fibers in direction to the yarn surface leads to substantial rise of yarn breakages due to growth of its friction coefficient.

Hussain U. et al. presented the effect of spinning variables on packing density of cotton yarn [7]. In this study, fiber dispersion along the cross-sections of ring-spun yarns and their packing density values has been researched. After the yarn production process, diameter, IPI index, uniformity index, single yarn strength, density and hairiness have been tested. The impact of TPI, spindle speed, count, hairiness and diameter has been analyzed using yarn packing density as a response variable. The aim of study was to produce a yarn with improved packing density so that the yarn properties could be predetermined. The study revealed that the raise in yarn count, TPI and spindle speed lead to increase of yarn packing density.

Zou Z. et al. presented effect of some variables on the fiber packing pattern in a yarn cross-section for vortex spun yarn [8]. This paper investigated the influence of various parameters such as fiber fineness, yarn count, distance from front roller nip point to the hollow spindle, nozzle pressure and yarn delivery speed on the fiber packing pattern in a yarn cross-section for vortex spun yarn. Cross-section images of vortex spun yarn were used to evaluate the fiber packing pattern. Results from different variables influencing the fiber packing pattern for vortex spun yarn also analyzed. The results demonstrated that the fiber fineness, yarn count, distance from the front roller nip point to the hollow spindle, nozzle pressure and yarn delivery speed are all significant parameters for yarn hairiness and fiber packing density in a vortex spun yarn cross-section.

Kilic M. et al. presented a study on comparing the packing densities of yarns spun by ring, compact and vortex spinning systems using image analysis method [9]. It was purposed in this study determining the packing densities of yarns produced by different spinning systems to examine the fiber distributions for each system. For this end, 100% Tencel LF yarns with 19.69 tex linear densities are produced on ring, compact and vortex spinning system. Cross-sections are made by hard sectioning method using a rotary microtome. Packing densities of yarns are computed by image analysis method. Result showed that compact yarns have the highest packing densities while vortex yarns have the lowest. However, differences between the packing densities of ring and compact yarns are not found statistically significant. Results show that the packing density values are parallel to yarn density values.

Taheri M. et al. presented a study on investigating the effect of yarn count twist factor on the packing density and wicking height of lyocell ring-spun yarns [10]. An image processing method was developed to define the packing density of samples. Experimental result also used to advance a regression model to predict the wicking height based on the packing density, yarn count, twist factor and rising time. The results showed that the correlation factor between the predicted and measured wicking height was 0.98 indicating the capability of the presented model to predict the wicking height of lyocell ring-spun yarns.

Kumar A. et al. presented impact of yarn extension on packing density of ring yarn [11]. It was stated that the aim is to characterize and visualize the fiber structure of the yarn using an image processing method. It was observed that the yarn packing density increased at the beginning at too high rate, then it was continuing to increase at too low rate and at the end the packing density of yarn quite slightly decreased. It was emphasized that the radial packing density of the yarn is not regular across the cross-section of the yarn. It is not maximum close the yarn axis, rather it is maximum at some length from the yarn axis. Also, it was observed that the position of maximum radial packing densities of yarn changes with the yarn elongations. The local packing density along the extent of yarn is not regular and the results are evenly applicable for all level of yarn extension.

Zheng S. et al. presented a paper of the fiber distribution in yarn cross-section for vortex spun yarn [12]. It was stated that the image processing method, based on Photoshop software, was used to analyze the fiber distribution texture in yarn cross-section for vortex-spun yarn. According to the research, it was understood that the density of fiber packing in vortex yarn is lower both in the center and on the surface than in the conventional ring yarn. In bamboo / cotton blended vortex yarns, it is stated that bamboo fibers are more easily distributed in the yarn core.

Kilic M. and Okur A. have presented the features of cotton-tencel and cotton-promodal mixed yarn spun in varied spinning systems [13]. In this study, structural, physical and mechanical features of these mixed yarn ring, compact and vortex spun yarns were analyzed. It was concluded that an incrementing ratio of regenerated cellulosic fiber content in the blend reduces diameter, unevenness, roughness and imperfections values. Besides, it increases yarn breaking force, density, elongation and shape values. Effect of blend type is also statistically significant on many yarn properties. It was stated that while cotton-promodal yarns have better physical features, cotton-tencel yarns have better mechanical features.

Lin Q. et al. have presented study on the blend disturbance in blended yarns [14]. It was stated that a new model was improved to peruse the theoretical blend disturbance of two-component blended yarn. By showing the alternatives of the number of the fibers per cross-section along the yarn, the attained statement can offer insight into the cause of blend disturbance. Two experiments show that the results from new model have essentially the same changing tendency as experimental values. It was concluded that the ratio of the blend disturbance of one component was demonstrated to diminish with the increment of its proportion and blend disturbance also diminish when it was finer fibers.

Turan R. B. et al. have presented forecasting the intra-yarn porosity via image analysis method [15]. The study aimed to suggest a new method to describe intra-yarn porosity, which has mostly been during the theoretical studies. It was concluded that in this method, at the start the cross-sectional views of the cotton yarn in the fabric were obtained, and then the intra-yarn porosity was forecasted via image processing and analysis steps. Otherwise, intra-yarn porosity was calculated theoretically based on fiber and yarn parameters.

Ishtiaque S. M. et al. presented a study on the effect of process parameters on packing density of open-end and core-sheath friction spun yarns [16]. The tendency of variance in packing density with process variances are got to be opposite to those of yarn diameter. It was stated that yarn diameter diminishes, and helix angle and packing density raise with the raise in suction air pressure of open-end and core-sheath friction spun yarns. It was concluded that core-sheath friction yarns have greater packing density but lower yarn diameter and helix angle than open-end friction yarns.

XU B. and Ma J. presented a study on the radial distribution of fibers in compact-spun flax-cotton mixed yarns [17]. This paper investigates the radial distribution of compact-spun flax-cotton mixed yarn using the Hamilton migration index, and it was compared with conventional ring-spun flax-cotton mixed yarn. It was stated that the results referred that the fiber migration of conventional ring-spun flax-cotton mixed yarn was more obvious than that of compact-spun flax-cotton mixed yarn, and the radial distribution of fibers in compact-spun flax cotton mixed yarns was more random. Therefore, the traditional migration rule does not fully apply to compact spinning technology and should be given more attention in practice.

Tyagi G.K. et al. presented a research on the effect of spinning conditions on performance and mechanical features of compact-spun and cotton-ring yarns [18]. It was concluded that an optimum spinning draft is necessary if the optimum level of structural collectivity, compressive strength, compressive energy and abrasion resistance of a yarn must be achieved for a specific end-use. It was stated that the behavior of compact-spun yarns is perceptibly better in respect of tensile strength, abrasion resistance, work of rupture, hairiness and mass irregularity.

Gharahaghaji A.A. et al. introduced cluster-spun yarn a new approach in composite yarn producing [19]. Cotton fibers and polyester multifilaments were then tested to compair their features structure variety and surface morphology of cluster and core-spun yarns were worked via electron microscopy. Image-processing and microtome have been used to examination the packing and structure of fibers in the cross-section of yarns. It was stated that the special structure of a cluster-spun yarn result in submitted improvement in the structural mechanics and yarn features. The statistical analysis conclusions indicate that the tenacity and breaking elongation of cluster-spun yarn is considerably more than in core-spun yarn. In addition, it was concluded that lower twist is required to manufacture quality yarn in cluster-spun yarns as match against with normal core-spun yarns.

Yilmaz D. et al. introduced packing density of compact yarns [20]. In this paper, fiber distribution through the cross-section of compact yarns and their packing density values were examined to ensure a better understanding of the interior structures of compact yarns produced via varied compact spinning systems through there is no information available so far concerning their interior structure. The outcomes of packing density values of compact yarns produced via three different compact yarn spinning systems, namely Rieter K44, Suessen Elite and Zinser Air-Com-Tex700, find out that there are no remarkable differences among these systems, with regard to yarn packing density values.

Jaouadi M. et al. introduced assessment of real yarn diameter [21]. In this paper, the authors enhanced a probatory device assessment the real yarn diameter with regard to the twist variation. It was contained that the twist increases results in a free air volume lowering to a null value. So, the certain diameter tends to a limit value, the real diameter.

Kumar A. et al. introduced paper on influence of spinning operation variables on the packing density of air-jet, ring and rotor yarns using the Taguchi method [22]. The influence of lap hank, card draft, draft/doublings and drafts at ring frame, speed frame, air-jet and rotor on packing density parameters were investigated using the Taguchi method. The inclinations of alter in packing density with process variables are converse to those of the yarn diameter and helix angle of the air-jet, ring and rotor yarns studied. It was stated that the packing density was reached to be the lowest in rotor yarn the highest in air-jet yarn. It was concluded that a decrease in the rotor spinner and an increase in draft in the air-jet raises the packing density of the severally yarns.

Basal G. and Oxenham W. introduced a study about the comparison of characteristic features and structures of conventional spun and compact yarns [23]. It was interpreted that when the strength of compact yarns is compared with that of conventional yarns, the width of these yarns and the fiber migration are higher. Other important finding is; compact yarns are said to have a higher bending level in terms of drawing properties and less striking in 50/50 cotton / polyester blends.

Jiang X.Y. et al. introduced a study on the assignation the cross-sectional packing density of rotor spun yarns [24]. This paper defines an elaborated method for defining packing density. They achieved yarn cross-sectional images to ensure input data for calculating yarn cross-sectional packing density. These data contain the coordinates of each fiber center and fiber radius. It was stated that a program whose general writing algorithm is also elaborated in detail is gathered together to calculate the packing ratio zone by zone. With these different packing ratios, a curve-fitting technique yields a continued packing density function. At the same time, a study of the relationship between packing density and yarn parameters such as yarn count and twist factor involved.

Soe A.K. et al. introduced construction and features of MVS yarns in compared with ring yarns and open-end rotor spun yarns [25]. It was stated that yarn diameter, wrapper fiber pitch, wrapper fiber length, yarn helix angle, wrapper fiber crest for a one-turn twist and wrapper fiber helix angle to the yarn axis are assessed and yarn parameters such as hairiness, tenacity and evenness are assessed. The mechanical features of dry relaxed yarns were assessed with Kawabata Evaluation System instruments. Attempts are made to regard yarn structure variances in the yarn features such as bulkiness, tenacity, hairiness, evenness pressure features and mixing properties can be clarified by the observed variances in the yarn structure.

Najar S.S. et al. introduced analysis of mixing irregularities and fiber migration index wool/acrylic mixed worsted yarns by using and image-analysis technique [26]. In this paper, wool/acrylic mixed combed yarns were used. It was indicated that the digital images of yarn cross-sections with before dying fibers were got up using an optical microscope and a digital image capturing system. Via performing a mathematical technique on bitmap data, the index of blend irregularities, size of fiber clusters and prior fiber migration were gauged. It was stated that the experimental results referred a good correlation between the suggested image processing technique and that of the visual method. It was concluded that the index of blend irregularities and sizes of fiber clusters for wool/acrylic mixed yarns were shown to range from

1.97 to 2.2 and from 3.87 to 4.88, in regular turn. Besides, the acrylic fibers in blended yarns were by choice positioned in outer layers of the yarn cross-section.

Cheng K.P.S. and Yu C. introduced a study of compact spun yarns [27]. This study examines the working principle of compact spinning and the structure variances between Com4® yarns spun by a Rieter ComfortSpin® K40 compact spinning machine and traditional ring spun yarns. Variances in yarn quality are examined. It was stated that the higher tensile strengths and lower hairiness of the Com4 yarns are the key acquisitions of the compact spinning. However, it was concluded that limitations of the new technology are also found out by examining the quality of yarns with different counts.

Tyagi G.K. and Kaushik R.C.D. introduced radial packing density and related features of polyester DEF-3 yarns [28]. The effect of yarn linear density, core content and friction ratio on radial packing density and mechanical properties of polyester DEF-3 yarns has been studied. It was observed that the packing density is max. at the core it decreases against are surface. It was stated that packing density of a thin yarn is less than that of a coarse yarn, regardless of the process parameters. It was concluded that the higher the core substance and the friction ratio, the higher is the packing density. A raise in core content and friction ratio results in large raise in tenacity, flexural rigidity, breaking extension, abrasion resistance and initial modulus of yarns.

Grishanov S.S. et al. introduced the simulation of the geometry of two-component yarns part I: the mechanics of stand pressure: simulating yarn cross-section mold [29]. The geometry of two-components yarns is examined, and a new attitude is introduced which addresses some of the limitations of other models. The model takes account of the compressional deformation of the individual strands bring about transverse forces generated during the twisting process. The change in the cross-section pay regard to the mechanical features of the strands and the observed changes in cross-section mold caused by lateral pressure. It was stated that he outcome is a methodology and conjectural equations for modeling the pressured mold of strands in two-component yarns; the model has been successfully used in CAD systems to simulate yarn aspect.

Grishanov S.S. et al. introduced the simulation of the geometry of a two-component yarn part II: fiber divisionis in the yarn cross-section [30]. This study examines the divisionis of fibers in yarns and discusses the development of a model for the simulation of fiber divisionis; the concept of 'virtual location' within the cross-section domain, which may contain a fiber, is introduced. The divisionis of fibers in real yarns is match against with computer-generated divisionis. The distributions estimated by using the model indicate all of the features of the yarns considered. The change in the fiber distribution bring about pressure forces is considered, and a model to define the behavior of real yarns is proposed.

Sengupta A.K. et al. presented studies on fiber migration in blended yarns [31]. The effect of fiber and process factor on preferential migration of components in binary blended yarns has been studied. It observed that fiber type, blend composition and yarn twist have strong influences on the segregation behavior of the components. The drafting system employed on the ring frame also influences the extend of migration.

Chao N.P.C. presented blending cotton and polyester fibers effects of processing methods on fiber distribution and yarn properties [32]. This research was carried out statistically peruse the influence of the speed of drawing frame and the number of drawing operations on the fiber divisionis, in terms of fiber migration index, and other physical features of the blended yarns made from the slivers mixed at the drawing frame. It was concluded that the number of drawing operations had a remarkable influence, in a statistical sense, on the regularity of slivers, rovings, and yarns. A raise in the number of drawing operations had developed the regularity of the product. It was stated that speed of the drawing frame was found to have but little influence on the product regularity.

Ogulata R.T. introduced air permeability of woven fabrics [33]. Air permeability is a significant feature for woven and it depends on many parameters of the fabric. Thereby, a theoretical definition is highly complex and hard in relating the parameters to the air perm. For this reason, constitute of the air permeability is mostly made experimentally. In this paper, it has been attempted to install a simple theoretical model for the air permeability of woven fabrics. For the objective, a capillary model of porous systems on **D2'Arcy's** law was used, and theoretical values were examined.

Mansor A et al. presented knitted fabric parameters in relation to comfort properties [34]. This study reports on a research of physical features on some of the clothing comfort features of knitting fabrics. Fabric parameters such as weight, thickness and density have been provided for to be correlated to air and water vapor permeability, and also moistness management features which involves accumulative one-way transport index and overall humidity management capacity. It was stated that this is significant in order to designate the overall thermophysiological comfort performance of knitted fabrics. The results proposed that all the fabric parameters stated before be cleared to affect the fabric comfort features.

Chatterjee A. and Singh P. introduced studies on wicking of polyester fabric [35]. This paper purposed to investigate vertical wicking features of polyester fabric depended on change in tension and change in sample direction. Also, experimental results are matched against with theoretical results. It was stated that according to results the max. height acquired empirically in both warp way and weft way is more than that theoretical values. The max. height acquired by fabric empirically in weft is more as matched against to warp way. It was concluded that vertical wicking increases with increase in tension. This study is focused on wicking which plays a crucial role in specifying comfort and moisture transport behavior of fabric.

Jakšić D. and Jakšić N. presented porosity of flat textiles [36]. J-method of porosity assessment of the flat textiles is presented here. It enables us to compute maximal and average hydraulic diameter of pores and relative divisionis of pore's diameters regardless of the type of the flat textile by using both procedures. The results are in good agreement with those obtained by the microscope. Considering the results obtained when testing woven fabric, they have concluded that method could be used to determine the porosity parameters of knitted fabrics and thinner non-woven fabrics.

Regab A. et al. introduced specify of pore size, porosity and pore size divisionis of woven structures by image analysis techniques [37]. In this paper, it has been tried to set up a theoretical model for both the pore size and porosity of woven textiles. The image analysis method could be used to examine the surface porosity, vug size and size divisionis in single layer woven fabrics. The analysis shows that the gaps between warp and weft threads are exorbitant irregular with respect to size and shape. It was concluded that a comparison of the peaks of the pore distributions with air perm. data refers a correlation between the inter-fiber pore gaps and the air permeability. Besides, the inter-yarn porosity may sometimes be an important factor

Subhasis D. and Kothari V.K. presented moisture absorption properties of cotton fabrics were tested [43]. Apart from the weft density and the covering factor of woven fabrics, water vapor transfers increase with wind speed. In these fabrics the relationship of the moisture vapor transmission over time was tested. It has been found that the phenomena of swelling of hygroscopic fibers play an important role on the moisture vapor permeability properties of cotton fabrics.

Tanveer H. et al. presented liquid moisture management in knitted textiles – a review [44]. Controlled release of liquid moisture and water vapor from the skin surface to the atmosphere by the wearer's clothes is defined as moisture management. Liquid moisture management is vital in sports knitwear and summer clothes, evaporative cooling and sweat management are important for maintaining thermophysiological comfort. In the study, reviews some basis principles and main mechanisms contained in liquid moisture management, coupled with some last developments in fiber, yarn, knitting and topical finishing for improving the moisture management features of knitted fabrics.

Demiroz Gun A. and Bodur A. presented water vapor permeability of fabrics [46]. The ability of clothing to transmit perspiration in its vapor form is water vapor permeability which is one of the important parameters providing comfort to clothing. In this study, based on the literature review, the general information about the water vapor permeability of fabrics is given.

Kumar Sinha S. et al. presented a paper about the packing density of modified ring spun yarn [48]. In this study, polyester/PVA blended yarn was modified via resolution of the next component. It was stated that the resultant alteration in structural regulating on resolution was evaluated by the change in radial packing distribution of fibers. Migration index, aided in describing the location that was affected more in the redistribution.

Hamilton J. B. presented the radial distribution of fibers in blend yarns [49]. It was stated that in this study a method is represented by way of any preferential radial distribution of a specific fiber component in a blended yarn, relative to the yarn axis, may be measured and described by a single numerical parameter, termed the Migration Index.

1.3.LAYOUT OF THE THESIS

The thesis consists of 4 Chapters. In chapter 1 the aim of the thesis was explained and a detailed literature survey was given. The material properties and the methods for measurements of yarn and fabric properties were given in chapter 2**.** The test results and statistical analyzes were given in Chapter 3. Conclusion of the study was given in the Chapter 4.

CHAPTER 2

MATERIAL AND METHODS

2. MATERIAL AND METHOD

2.1. MATERIAL

In this study, it is aimed to investigate the effect of bending ratio, twist factor and yarn number on some yarn performance values (fiber migration, packing density and yarn diameter) and fabric comfort performance values (air permeability, water vapor permeability, wickability and porosity). For this purpose, ring yarns were produced with 3 different blend ratios, 3 different twist factors and 3 different yarn numbers. The blend ratios were determined as 75/25%, 50/50%, 40/60% cotton/acrylic. The twist factors were determined as α=3.5, 4, 4.5 and the yarn numbers were chosen as Ne 20/1, Ne 24/1, Ne 30/1. Thus, totally 27 yarn samples were produced by using conventional ring spinning machine (Zinser 351). These yarns were provided by Bulut Tekstil San. ve Tic. Ltd. Şti. in Gaziantep, Turkey. The fiber properties used in yarn sample production are submitted in Table 2.1. The physical properties of yarn samples are given in Table 2.2.

Table 2.1 Fiber Properties

Fiber Properties	Cotton (American)	Acrylic (Dralon)
Fiber Fineness	2.05 dtex	1.3 dtex
Fiber Length	28.72 mm	37 mm
Breaking Elongation	5.10%	23 %
Strength	30.6 g/tex	26 cN/tex
Radiance	76.6	Bright
Moisture	6.60%	-
C-Grade	31-1	898
U Index	81.8	-
SF-Value	8.4	2.4

Table 2.2 Yarn Physical Properties

S. No	Blend Ratio % (Co/Acry)	Ne	Twist Factor α_e	U%	CVm %	Thin -50%	Thick +50%	Neps +200%	Elong. (%)	Strng. (cN/tex)	H.	Dia. (mm)	Density (g/cm³)
1	40/60%	30/1	3.5	11.99	15.53	16.30	268.8	580.0	8.08	13.18	8.86	0.24	0.43
2	40/60%	30/1	4	12.13	15.59	11.30	303.8	665.0	7.31	12.59	7.86	0.23	0.47
3	40/60%	30/1	4.5	11.96	15.33	10.00	245.0	617.5	7.74	13.86	7.02	0.22	0.52
4	40/60%	24/1	3.5	10.99	14.08	1.30	176.3	246.3	8.62	13.69	9.19	0.27	0.43
5	40/60%	24/1	4	10.50	13.45	1.30	120.0	227.5	8.62	13.70	8.36	0.26	0.47
6	40/60%	24/1	4.5	10.91	13.95	1.30	121.3	232.5	8.98	12.3	10.62	0.25	0.51
7	40/60%	20/1	3.5	9.86	12.57	0.00	58.8	168.8	9.31	14.62	9.58	0.30	0.42
8	40/60%	20/1	4	9.72	12.47	0.00	78.8	206.3	9.00	14.50	8.48	0.28	0.47
9	40/60%	20/1	4.5	9.72	12.67	2.50	91.3	211.3	9.07	13.10	10.74	0.27	0.51
10	50/50%	30/1	3.5	11.20	14.35	2.50	168.8	372.5	13.32	5.77	8.29	0.24	0.43
11	50/50%	30/1	4	11.07	14.12	2.50	146.3	385.0	6.85	13.45	7.19	0.23	0.48
12	50/50%	30/1	4.5	12.01	15.40	8.80	278.8	518.8	7.29	13.69	6.66	0.22	0.52
13	50/50%	24/1	3.5	10.14	12.92	1.30	88.8	202.5	7.55	13.90	7.30	0.30	0.42
14	50/50%	24/1	4	9.90	12.67	0.00	95.0	142.5	7.47	13.39	8.29	0.28	0.47
15	50/50%	24/1	4.5	10.05	12.82	0.00	100.0	148.8	7.62	13.16	10.35	0.27	0.50
16	50/50%	20/1	3.5	9.40	12.00	0.00	38.8	135.0	7.70	13.63	9.64	0.28	0.41
17	50/50%	20/1	4	9.29	11.83	0.00	47.5	132.5	8.17	14.88	8.14	0.26	0.46
18	50/50%	20/1	4.5	9.14	11.65	0.00	46.3	168.8	8.95	15.84	7.74	0.25	0.52
19	75/25%	30/1	3.5	13.12	17.03	12.50	475.0	738.8	5.68	9.99	8.95	0.26	0.37
20	75/25%	30/1	4	13.52	17.41	11.30	470.0	792.5	6.05	13.30	8.13	0.24	0.43
21	75/25%	30/1	4.5	13.42	17.31	23.80	515.0	833.8	6.28	14.03	7.18	0.23	0.48
22	75/25%	24/1	3.5	12.21	15.64	2.50	258.8	283.8	5.93	12.35	9.19	0.31	0.38
23	75/25%	24/1	4	11.74	15.15	1.30	260.0	262.5	6.27	13.40	8.91	0.30	0.41
24	75/25%	24/1	4.5	12.05	15.48	2.50	271.3	246.3	6.58	14.97	7.90	0.28	0.47
25	75/25%	20/1	3.5	11.61	14.83	0.00	157.5	165.0	6.10	11.58	10.56	0.29	0.38
26	75/25%	20/1	4	10.65	13.63	0.00	96.3	142.5	7.30	14.66	9.16	0.27	0.43
27	75/25%	20/1	4.5	11.22	14.39	0.00	160.0	203.8	7.64	15.60	7.83	0.26	0.46

In order to determine the effects of yarn properties on fabric performances, knitted fabric samples are produced from the yarn samples. Circular sample knitting machine (Figure 2.1) was used for production of fabrics. The properties of knitting machine are given in Table 2.3. These knitted fabrics were provided by Bulut Tekstil San. ve Tic. Ltd. Şti. in Gaziantep, Turkey.

Table 2.3 Sample Knitting Machine Properties

Sample Knitting Machine Properties	
Diameter	3½" (inch)
Fineness	28
Number of Needles	300

Figure 2.1 Sample Knitting Machine

All knitted fabrics were produced with the same loop density and same knit type (single jersey). Each fabric sample was produced in 10-meter length. These samples separated into two parts so that one part will be used for raw fabric tests and the other part will be used for bleached fabric tests. The purpose of which is to observe the effect of the differences between the raw fabric and the bleached fabric on the fabric comfort performance values. In addition to performance tests; thickness, weight, loop density and loop length were also determined. The course and wale densities were measured according to TS EN 14971:2006 [50]. The fabric thickness and fabric mass were determined in accordance with the standards TS 7128 EN ISO 5048:1998 [51], TS EN 12127:1999 [52], respectively. The yarn loop lengths were measured according to the standard TS EN 14970:2006 [53]. The physical properties of raw and bleached fabric samples were given in Table 2.4 and Table 2.5 respectively.

Table 2.4 Raw Fabrics Physical Properties

Raw Fabric Properties					
Sample Code	**Thickness, mm**	**Fabric mass, g/m²**	**Fabric Density, Loop/cm**		**Loop length, mm**
			Wale	**Course**	
R.S.1	0.47	78.9	11	9	4.60
R.S.2	0.54	101.33	11	9	4.40
R.S.3	0.61	127.5	11	9	4.10
R.S.4	0.50	89.88	10	9	4.75
R.S.5	0.56	114.21	11	10	4.30
R.S.6	0.61	135.74	12	9	4.30
R.S.7	0.51	84.77	11	9	4.65
R.S.8	0.57	113.65	11	10	4.45
R.S.9	0.63	142.26	12	9	4.30
R.S.10	0.46	70.8	11	9	4.40
R.S.11	0.53	101.67	11	10	4.20
R.S.12	0.58	131.44	11	9	4.15
R.S.13	0.51	83.61	11	9	4.40
R.S.14	0.54	110.37	11	9	4.30
R.S.15	0.56	134.52	11	9	4.50
R.S.16	0.55	93.87	11	9	4.60
R.S.17	0.59	104.82	11	9	4.40
R.S.18	0.66	137.96	11	9	4.15
R.S.19	0.48	80.5	11	9	4.10
R.S.20	0.55	103.8	12	10	4.20
R.S.21	0.60	124.78	12	10	4.25
R.S.22	0.51	89.95	11	9	4.05
R.S.23	0.57	106.67	11	9	4.35
R.S.24	0.64	144.37	12	10	4.45
R.S.25	0.54	92.34	11	10	4.10
R.S.26	0.61	115.33	11	10	4.30
R.S.27	0.66	141.26	11	9	4.35

Table 2.5 Bleached Fabric Physical Properties

Bleached Fabric Properties					
Sample Code	**Thickness, mm**	**Fabric mass, g/m²**	**Fabric Density, Loop/cm**		**Loop length, mm**
			Wale	**Course**	
B.S.1	0.44	97.58	11	10	4.15
B.S.2	0.52	114.51	10	11	4.20
B.S.3	0.61	137.70	11	10	4.20
B.S.4	0.50	98.08	10	10	4.25
B.S.5	0.55	123.55	10	10	4.30
B.S.6	0.62	146.02	11	10	4.10
B.S.7	0.57	103.47	11	11	4.35
B.S.8	0.59	123.46	11	11	4.40
B.S.9	0.66	151.90	11	10	4.50
B.S.10	0.50	93.48	10	11	4.25
B.S.11	0.60	114.29	11	11	3.95
B.S.12	0.68	138.33	11	10	4.40
B.S.13	0.57	90.20	11	11	4.35
B.S.14	0.62	112.35	11	11	4.20
B.S.15	0.69	148.31	11	10	4.30
B.S.16	0.58	101.34	11	10	4.25
B.S.17	0.68	136.2	12	11	4.30
B.S.18	0.72	161.45	12	10	4.40
B.S.19	0.54	87.89	11	11	4.10
B.S.20	0.57	116.62	11	11	4.15
B.S.21	0.66	139.05	12	10	4.25
B.S.22	0.59	108.11	11	11	4.15
B.S.23	0.67	122.87	12	10	4.35
B.S.24	0.71	154.48	12	11	4.10
B.S.25	0.56	112.38	12	11	3.85
B.S.26	0.62	128.09	11	10	4.15
B.S.27	0.73	159.59	12	11	4.25

2.2.METHODS

Prior to the physical measurements and performance tests applied to yarns and fabrics, samples were conditioned according to related standards “TS EN ISO 139:2008 Textile- Standard environments for conditioning and testing” [54]. Then measurements and tests were carried out. This is a necessary parameter to make measurements more accurate and reliable. In this section, the methods used for yarn and fabrics measurements were investigated separately.

2.2.1. Yarn Structural Properties

In the scope of study, the yarn structural properties; fiber migration, yarn diameter, yarn packing density were measured. The yarn diameter measurement was achieved by means of Uster Testing device. Other two properties; fiber migration and yarn density were determined from the yarn cross-sectional views. The images of the yarn cross section are needed. So, we prepare the yarn slices to obtain yarn cross-sectional images. A microtome device was used to obtain yarn slices.

2.2.1.1.Fiber Migration

The distribution of fibers in the yarn and indirectly the yarn structure has a significant effect on the yarn physical character and the performance characteristics of both the fabric and the yarn. In order to determine the visual, mechanical and functional properties, especially in the blended yarns, the fiber distribution and the fiber blend irregularity in the cross-section are vital.

Most common method used for the dispersion analysis of fibers in blend yarns is the Hamilton fiber migration index [12]. The Hamilton Migration Method analyzes the fiber distribution and orientation in yarn cross-section and explains it as an index. This index is predicated on the specific first moments of the fibers around the center of the yarn cross-section. The migration index is predicated on specific first moments of a constituent about the center of yarn cross-section and relates the moment (FM_a) corresponding to the actual distribution to moments ((FM_u), (FM_I) and (FM_0)) corresponding to three hypothetical distributions; uniform distribution and maximum inward and maximum outward migrations respectively. Thereby the migration index is given by allied to whether the migration is outward or inward.

First of all, the yarn cross-section is divided into 5 equal parts as shown on the Figure 2.2. The different fibers in the mixture are identified by a separate letter. In this study, for acrylic "a" and for cotton "c" letters were used [49].

a_i= Acrylic fibers quantity

c_i= Cotton fibers quantity

i = Sectional ring number

For all rings, the fibers in the mixture are counted separately. For example;

a_1 means number of acrylic fibers in layer 1, c_1 means number of acrylic fibers in layer 1, a_2 means number of acrylic fibers in layer 1, c_2 means number of acrylic fibers in layer 2 and the same for other layers [49]. It was shown in the Table 2.6.

Table 2.6 Fibre Frequency Distribution

Area No	**1 (core)**	**2**	**3**	**4**	**5 (surface)**	**Fiber Totals**
Area Bias Value	**-2**	**-1**	**0**	**1**	**2**	
Fiber A **Fiber B** **Fiber C** **etc.**	a_1 b_1 c_1	a_2 b_2 c_2	a_3 b_3 c_3	a_4 b_4 c_4	a_5 b_5 c_5	A B C
Area Totals	t_1	t_2	t_3	t_4	t_5	T

Because the densities of the acrylic fibres and cotton fibres are different, the fibre cross-section areas are not the same for the acrylic fibres and cotton fibres with the same linear densities [49]. Thus, the ratio of fibre numbers for each layer should be converted into a ratio of the fibre volume as follows (2.1):

V_A *= the volume of white acrylic fibers,*

V_C *= the volume of cotton fibers,*

T_A *= the linear density of the acrylic fiber (dtex)*

T_C *=the linear density of the cotton fiber (dtex)*

ρ_A *= the density of the acrylic fiber (g/cm*^{3}*),*

ρ_C *= the density of the cotton fiber (g/cm*^{3}*),*

C *= ratio between the volume of the acrylic fibers,*

$$C = \frac{\mathrm{VA}}{\mathrm{VC}} = \frac{\mathrm{TA}\,.\rho\mathrm{C}}{\mathrm{TC}\,.\rho\mathrm{A}} \qquad (2.1)$$

Table 2.7 Volume Fibre Distribution

Area No	**1 (core)**	**2**	**3**	**4**	**5 (surface)**	**Fiber Totals**
Area Bias Value	**-2**	**-1**	**0**	**1**	**2**	
Fiber A **Fiber B** **Fiber C** **etc.**	a'_1 b'_1 c'_1	a'_2 b'_2 c'_2	a'_3 b'_3 c'_3	a'_4 b'_4 c'_4	a'_5 b'_5 c'_5	A' B' C'
Area Totals	t'_1	t'_2	t'_3	t'_4	t'_5	T'

The relative volume of the acrylic fibers, a_i, is equal to the number of the acrylic fibers, a_i, multiplying the coefficient C. The relative volume of cotton fibers, c_i, is the same as the number of cotton fibers, c_i. The relative volume of fibers of each layer, t_i, is the sum of a_i and c_i (Table 2.7).

FM_u = uniform distribution of the component through the section

FM_a = the fibre moment of the actual distribution

FM_o = maximum possible outward migration of the component

FM_i = maximum possible inward migration

Calculation of FM_u, FM_i, FM_o and FM_a;

$$FMa = (-2a'1) + (-1a'2) + (Oa'3) + (1a'4) + (2a'5) \tag{2.2}$$

or

$$FMa = 2(a'5 - a'1) + (a'4 - a'2) \tag{2.3}$$

$$FMu = \frac{A\prime}{T\prime}[\, 2(t'5 - t'1) + (t'4 - t'2)] \tag{2.4}$$

Table 2.8 Volume Fibre Distribution (If distribution is uniform)

Area No	**1 (core)**	**2**	**3**	**4**	**5 (surface)**	**Fiber Totals**
Area Bias Value	**-2**	**-1**	**0**	**1**	**2**	
Volume Values	$\boldsymbol{\frac{A't'1}{T'}}$	$\boldsymbol{\frac{A't'2}{T'}}$	$\boldsymbol{\frac{A't'3}{T'}}$	$\boldsymbol{\frac{A't'4}{T'}}$	$\boldsymbol{\frac{A't'5}{T'}}$	$\boldsymbol{A'}$

Table 2.9 Maximum Inward Migration

1	2	3	4	5	Total	FM_i, (alternative forms)
t'1	**t'2**	**t'3**	**t'4**	**t'5**	**T'**	
A'	-	-	-	-	A'	-2A'
t'_1	x	-	-	-	A'	$-x-2\ t'_1$
t'_1	t'_2	x'	-	-	A'	$-\ t'_2-2\ t'_1$
t'_1	t'_2	t'_3	x^n	-	A'	$x^{'n}-\ t'_2-2\ t'_1$
t'_1	t'_2	t'_3	t'_4	x'^n	A'	$2x^{'n}+t'_4-\ t'_2-2\ t'_1$

Table 2.10 Maximum Outward Migration

1	2	3	4	5	Total	FM_o, (alternative forms)
t'1	**t'2**	**t'3**	**t'4**	**t'5**	**T'**	
-	-	-	-	A'	A'	2A'
-	-	-	y	$t^{'5}$	A'	$2t'_5+y$
-	-	y'	$t^{'4}$	$t^{'5}$	A'	$2t'_5+t'_4$
-	y^n	$t^{'3}$	$t^{'4}$	$t^{'5}$	A'	$2t'_5+t'_4$-y^n
y'^n	$t^{'2}$	$t^{'3}$	$t^{'4}$	$t^{'5}$	A'	$2t'_5+t'_4-t'_2-2y^{'n}$

FM_i and FMo were determined according to the above tables (Table 2.8, Table 2.9, Table 2.10) and according to acuations respectively (2.2), (2.3), (2.4), (2.5), (2.6).

When $[FM_a] < [FM_u]$,

$$M = \frac{FM_a - FM_u}{FM_o - FM_u} \times 100\% \qquad (2.5)$$

When $[FM_a] > FM_u]$,

$$M = \frac{FM_a - FM_u}{FM_u - FM_I} \times 100\% \qquad (2.6)$$

The migration index is assigned a positive or a negative mark predicated on whether the migration has been outward or inward. In a binary blend, the index for the two constituents is in identical, but bears converse sign. Zero migration index performs absolute and homogeneous blending [31].

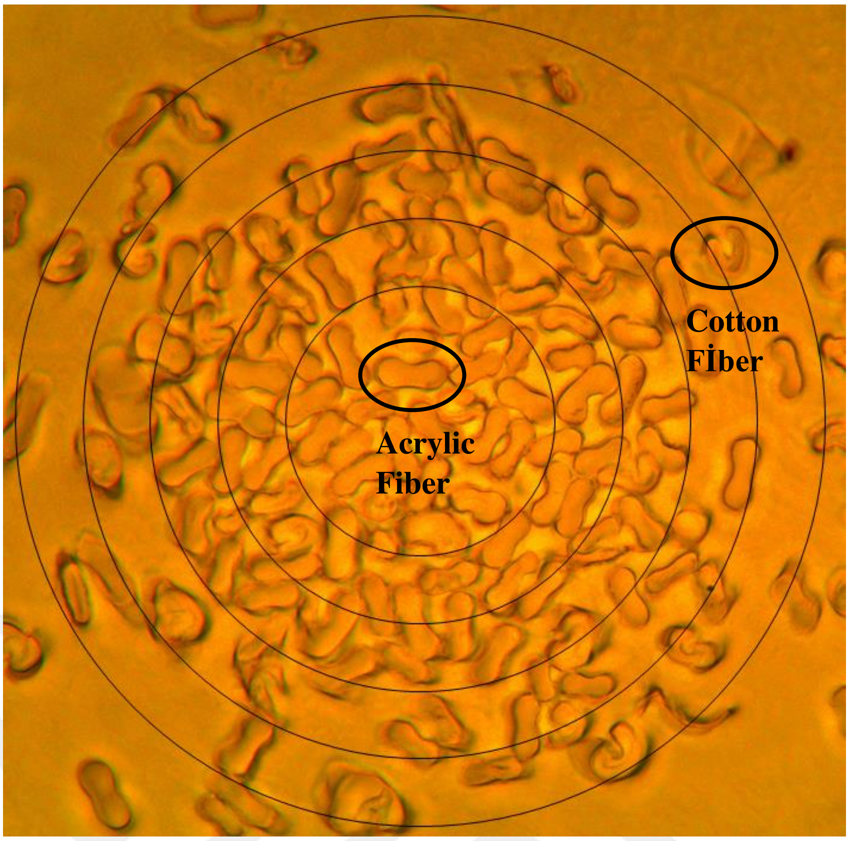


Figure 2.2 Dividing 5 equal areas of the yarn cross-section

2.2.1.2.Yarn Diameter

In this study, yarn diameter measured by Uster Tester 5. The measurement for each sample was repeated 5 times and at 400m/min speed. It was stated that the number of fibers in cross-section, twist, density, surface structure and fiber fineness are the factors that determine the yarn diameter. Surface fiber distribution and density greatly affect the yarn diameter at 8 mm. Short surface defects (neps), seed coating parts, wrapped fibers etc. significantly changes the diameter of the yarn at 0.3 mm length [47].

2.2.1.3.Yarn Packing Density

Packing density is accepted as an important feature in yarn because it has a significant effect on properties such as yarn feel, temperature, volume, dyeing. Besides this, it has been seen that the amount of maximum yarn that can be put on a package is also affected.

There are several methods to determine the packing density. The yarn packing density can be determined by using three different methods; direct method, secant method and tracer fiber method.

i. Direct Method

In this method, the yarn is fixed to take the cross-side section of the yarn and the thin sections are taken without deteriorating the fiber settling. During cross-sectioning, a chemical that provides fixing, such as PVA, is used to prevent fiber distribution. The yarns fixed and dried with chemical are placed on the device called microtome together with the molds in which they are placed and sectioned at the desired micron. Yarn cross-sections are examined under a microscope. The yarn cross-section image is equally divided into rings with certain areas. All yarn and fiber areas are identified through a program. The yarn area is derived from the diameter of the ring [5].

$$Packing\ Density = \frac{Fiber\ Area}{Yarn\ Area} \tag{2.7}$$

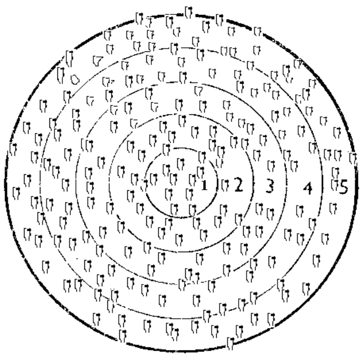


Figure 2.3 Yarn cross-section divided in number of radial zones [5].

With this method, radial packing density can also be calculated by determining rings evenly on the cross-section view. The cross-sectional view is divided into 5 regions most frequently and the packing density is checked as given in Figure 2.3. However, if you want to examine it in more detail, it can be divided into 20 regions. During splitting, there will be some fibers hanging in both regions. In order to reach the correct packing density, an average of 50 sections should be examined statistically [5].

ii. Secant Method

This method is preferred to determine the packing density of non-regular fibers such as trilobal polyester, viscose. After determining the center of gravity of the yarn, the fiber diameter is regenerated around after the selection of the equivalent fiber diameter. Fiber diameter is predicted from the linear density and bulk density of fiber supposing the cross-section to be annular and fiber cross-sectional area predicted from the following equations (2.8) [5].

$$d_{\mathrm{f}} = \frac{1}{5}\sqrt{\frac{t(f)}{\pi\rho(f)}} \quad \text{and} \quad S_{\mathrm{f}} = \frac{\pi d(f)2}{4} \tag{2.8}$$

d(f) =Fiber diameter in mm

t(f) =Fiber linear density in Decitex

ρ(f) =Fiber mass density in g/cm³

Sf = Fiber cross-sectional area

As the fibers track helical path, fiber cross-sectional area is reformed as per yarn twist and distance of circular ring from center of yarn by multiplying by secant of helix angle [5].

iii. Tracer Fiber Technique

A small quantity of (0.1%) of colored fiber is introduced in the blend. Yarn is optically resolved in a fluid of same fracture index as fiber so that path of colored fiber can be follow up under microscope. Image of yarn in 2 vertical directions via use of a mirror placed at 450 will result in proper mapping of tracer fiber profile [5].

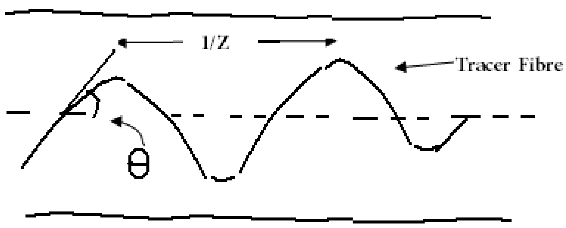


Figure 2.4 Path of tracer fiber [5]

As given in Figure 2.4 number of turns per unit length made via a fiber can be figured out and the length contributed via fiber to varied annular zones of yarn can be estimated. Image obtaining software can be used to get a proper mapping of tracer fiber. To get % fiber contributing to every zone, length is corrected for helix angle in the zone by multiplying by secant tan-1(2πr/z), where r is area radius (.1r, .2r …) and z is turns per unit extent [5].
Ishtiaque has developed the following formula for estimating packing density from tracer fiber examination (2.9), (2.10).

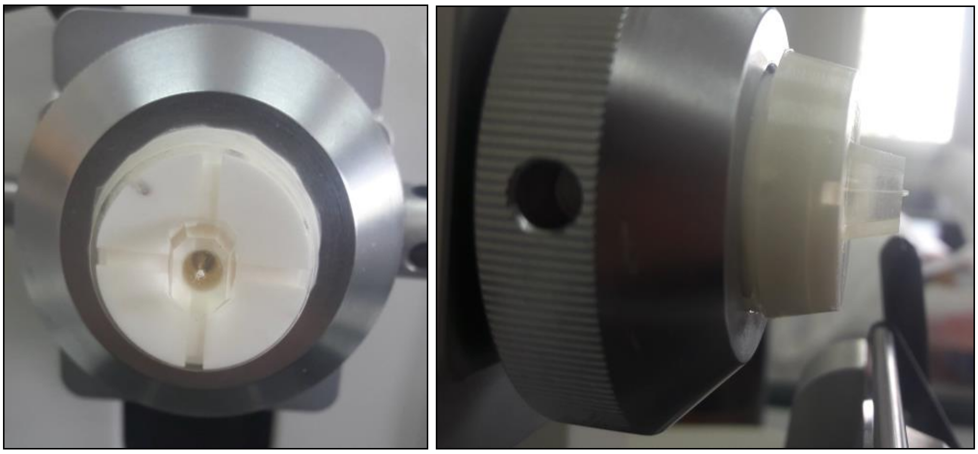
$$\text{Packing Density} = \frac{2\,\pi\, n\, F\, Z2}{((\sqrt{1+(\pi\, D\, Z)2}))-1} \tag{2.9}$$

Where
n = number of fibres in cross-section
F= Fibre cross-sectional area, mm^2
Z = Average number turns of helix in tracer fibre (turns/mm)
D = yarn diameter in mm
Dogu gives the following equation for radial packing density of with filaments migration [5].

$$V_r = \frac{n\frac{dx}{dr}}{\pi r\, cos\theta} \tag{2.10}$$

Where v_r *= packing density at radius r*
n = number of starting points at axis
Θ = twist angle of fiber at radius r
dr/dx = Rate of migration

Direct method was used in this study. In the method, all samples were placed into a resin solidified separately. Some special molds were used to solidify the samples. Microtome mold holders were placed on the parts of the molds. The yarns were fixed both side with adhesive tapes by passing through the center of the specimen holders and molds with a certain tension. After that the yarns were ready for the resin process. 9 samples were prepared form each sample mold.



(a) (b)

Figure 2.5 Yarn sample mold views on microtome device

(a) front view (b) yarn sample mold side view

Following the preparation of the yarns, the resin was prepared according to certain parameters and injected from the empty parts of the samples with the injector into the mold. In this study, 9 samples were prepared for each of 27 yarn samples. As a chemical adhesive, the historesin was prepared in 2 steps. In step 1, the infiltration solution was prepared. To prepare the infiltration solution, the mixture of 50 ml 2-hydroxyethyl methacrylate as basic resin/liquid and 0,5g dicyclohexyl phthalate and benzoyl peroxide as activator was mixed in a magnetic stirrer until completely dissolved. In step 2, the embedding medium was prepared. To prepare embedding medium 15 ml infiltration solution and 1 ml methyl methacrylate as hardener was mixed. After each 3x3 mold was prepared, the historesin was allowed to stand for 16 hours to achieve sufficient hardness for cutting. The ready molds were placed on the microtome device and fixed as shown in the Figure 2.5. Therefore, 1 sample was tested daily. After 24 hours the samples were ready to get cross-section slice. The samples were removed from the mold after they reached the sufficient hardness and placed in the sample holder of the microtome. To obtain more reliable results, 20 cross-section slices were prepared from each of 9 molds to ensure reliability of data. Thus, 180 cross-section slices were taken for each yarn sample. 16 μm thick sections were taken from the samples. Sections taken were placed between the glass slide and cover glass then examined under a microscope and images were taken. The yarn cross-sectional images were acquired through the cross-section slice with a microscope equipped with a camera.

Figure 2.6 Microtome Device

Determination of the yarn and fiber structural properties (fiber migration, yarn packing density, fiber distribution and yarn diameter) requires a digital camera, personal computer, as well as MATLAB program for automatic measurement as shown in Figure 2.7.

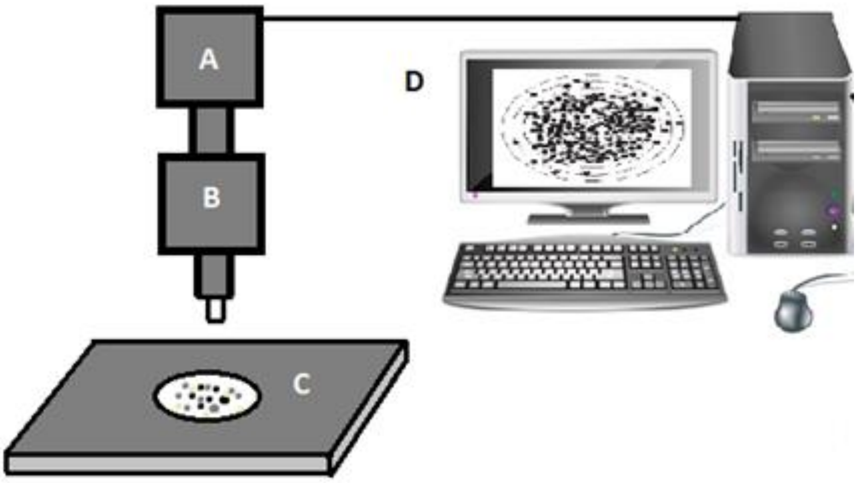


Figure 2.7 Schematic diagram of the image-processing system (A) Camera (Leica DM1000), (B)Optical Microscope, (C) Yarn Cross-Section Sample, (D) Computer,

Leica RM2125 RTS Rotary Microtome was used for yarn cross-section study. The device is given as in Figure 2.6. In order to analyze the yarn structure properties such as; fiber migration, packing density and yarn diameter, the yarn cross-section view must be investigated. For this aim, the yarn cross-section slices were got by using microtome device. Then, the yarn cross-section image was acquired by using Leica DM1000 camera microscope. In order to determine the desired yarn structure properties from cross-section views image processing method was developed.

2.2.2. Fabric Performance Properties

The comfort performances of the fabric samples were evaluated in terms of their permeability and liquid transmission capacity. The fabric samples were tested in two forms; raw fabric and bleached fabric.

Cotton fibers are physically swollen during treatment with a strong alkaline solution. A more uniform structure occurs among the cellulose molecules encountered with a strong alkaline solution. This new construction leads to increased strength and to improved dying ability. Bleaching can be done in every step of the pre-treatment in finishing halls as well as painted product. The physical density of the fabric and yarn also increases.

In this study, half of the fabric samples were bleached to observe changes in the physical and thermal performance characteristics of the fabric after bleaching.

The bleaching process was made with ATAC laboratory Dyeing Machine Figure 2.8. The applied pre-treatment process is summarized in Figure 2.9. The fabric sample was applied with NaOH and wetting agent by increasing temperature to in 50 minutes. Then the fabrics were treated with H_2O_2 for 40 minutes at constant temperature of 90 ^oC. The temperature of the solution was gradually decreased to 30 ^oC Finally, the samples were rinsed 2 times with 5minute periods.

Figure 2.8 ATAC Dying Machine

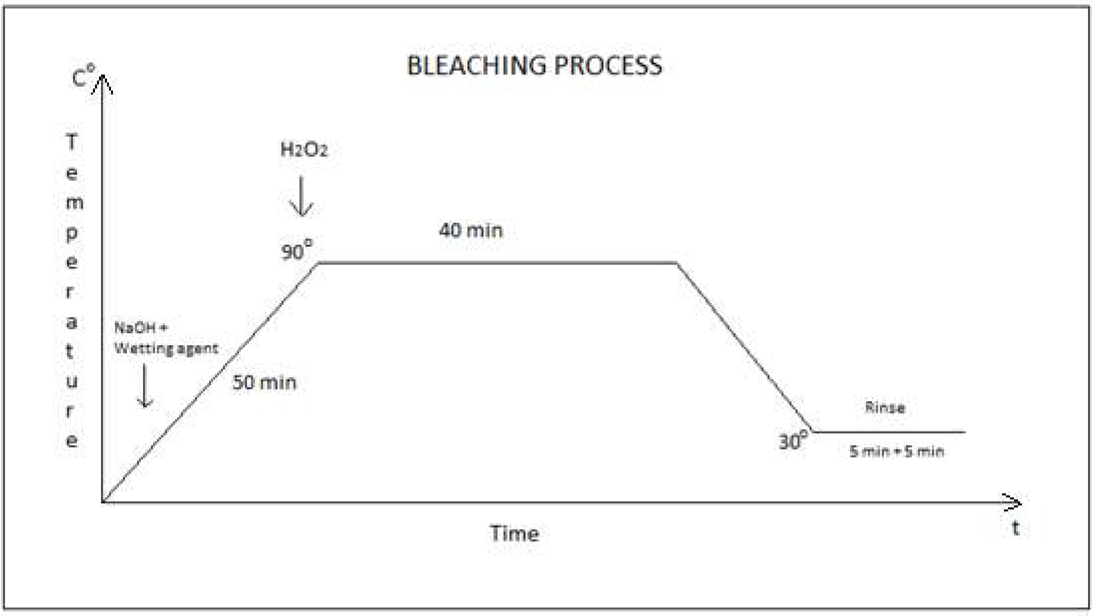


Figure 2.9 Bleaching Process

2.2.2.1.Air Permeability

The air permeability is the ratio of air flow passing perpendicular through the two surfaces of textile fabrics by way of a known area under a foreseen air [34]. The air permeability is a so significant factor with regard to comfort performance and barrier effects of textile materials. It is taken into assessment particularly for clothing, sails, parachutes, air bag fabrics, vacuum cleaners and industrial filter fabrics. The air permeability is primary dependent upon the fabric weight porosity and thickness. [33]. The air permeability of a fabric is influenced via a lot of factors; the design of a woven, the type of fabric structure, the count of warp and weft yarns per centimeter (or inch), the dimension of the yarns, the quantity of twist in yarns and the type of yarn structure. [33]

SDL ATLAS M021A Air Permeability Tester was used for this test (Figure 2.10). Air permeability test was performed in accordance with ASTM D737-04/2008 standard [39]. The test area is 20 cm^2 and the pressure drop is adjusted as 100 Pa. The fabric sample is placed over the air flow tube and it is sequenced with a test head. By means of a pressure difference between two sides of the fabric, air flow is supplied through the fabric structure. Air flow will occur from the side with higher air pressure, through the fabric, to the side with the lower air pressure. The air permeability value is determined as the air flow speed per meter square of the fabric surface in $mm/s/m^2$. For each sample, 10 different measurements were achieved. And the average of the measurements is taken, and the results are determined. This test was applied for both raw and bleached fabric samples.

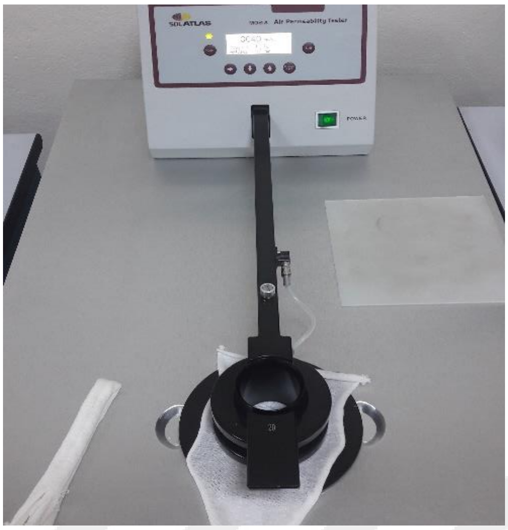


Figure 2.10 SDL Atlas Air Permeability Tester

2.2.2.2.Water Vapor Permeability (WVP)

Water vapor permeability (WVP) tests were made by using SDL Atlas Water Vapor Permeability Tester as shown in Figure 2.11 according to BS 7209:1990 [55]. There are two methods for water vapor diffuses through the air spaces between fibers and yarns. The method chosen in this study is the forward one, containing the assessment of weight loss within vaporization time of water involved in a cup. The method matches against the rate of water mass transfer via fabric from eight cups, two of them covered with reference fabric and the other six with test samples [34].

Figure 2.11 SDL Atlas Water Vapor Permeability Tester

Three specimens were taken from different region of each of samples. Then, the sample cups were filled with 46 ml of distilled water. The reason for filling 46 ml is to keep the distance between water and fabric surface constant (Figure 2.12). After filling the water, the samples are placed properly on the container and glued. The ring of cup is placed over the fabric sample so that it does not slip. Then, the gap between the ring and cup is closed with the help of band to prevent air passage. In this way, 3 specimens for each sample were placed on turn table. A reference fabric is needed to compare the results. In this study, instead of the reference fabric, one of the cups filled with water without fabric was taken as reference. Ambient temperature and humidity were noted at the beginning. After the samples were placed, the turn table is rotate for 1 hour.

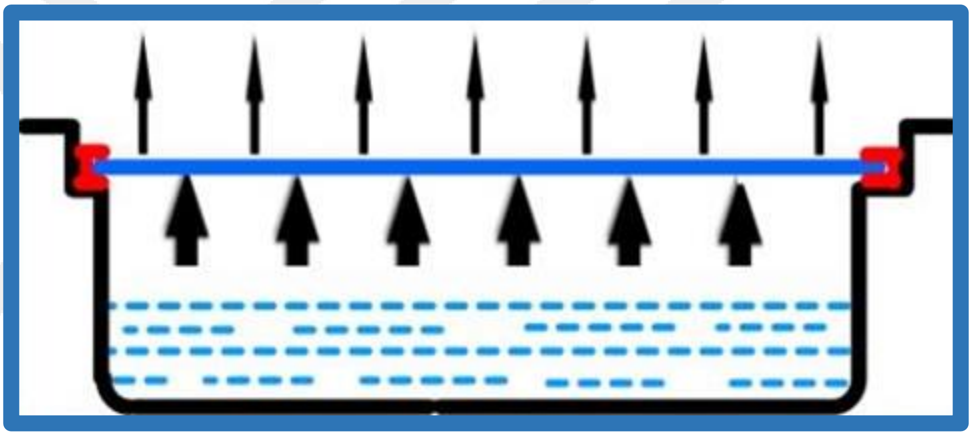


Figure 2.12 Water vapor permeability container water methods [45]

The weight of each cup is measured after 1-hour rotation. The cups are weighed on a precision scale. After the first measurement, turn table is rotated for 5 hours. And then second weight measurement was taken at the end of the 5 hours. The difference between the two measurements is calculated after the test is finished. According the results, the water vapor permeability index is found with the equations given below (2.11), (2.12).

The water vapor permeability index calculated by expressing water vapor permeability (WVP) of the reference;

$$WVP = \frac{24M}{At} \tag{2.11}$$

Were, M is the loss in mass (g), t is the time interval (h), and A is the area of the test cup (m²). Water vapor permeability index (L) was calculated by;

$$L = \frac{WVP_{test}}{WVP_{reference}} \times 100 \qquad (2.12)$$

2.2.2.3.Wicking

'Wicking ability' is the "ability to continue capillary flow of fluid" via inter-fiber or inter-yarn spaces in a fabric. The general moisture management features of a fabric are affected via its wettability and wicking ability [44].

It was stated that transfer of water via textiles plays a very significant role in deciding dyeing, comfort and finishing properties of textile fabrics, fluid filtration, and etc. Transfer of water takes place via the phenomenon of capillarity. It was concluded that capillarity is the ability of liquids to penetrate into fine pores with wettable was and be displeased from those with non-wettable. Capillary wetting is because of the meniscus formed via fibers and yarn in wale and course directions, especially in the interstitial area [35]. Wicking can only happen when a fluid wets fiber aggregated with capillary gaps between them. The resulting capillary forces between them. The resulting capillary forces that be found out from the wetting of the fabric surface in so far as pressure difference generated by surface tension of the fluid across the curved fluid/vapor interface drive the fluid into the capillary gaps. By the reason of capillary forces are occasioned by dampening, wicking is a result of spontaneous wetting in a capillary system [35].

In this study 54 fabric (27 raw fabric samples and 27 bleached fabric samples) samples were applied vertical wicking-tests. The test was made according to DIN 53924 [56]. The schematic diagram of experimental setup for measurement of vertical wicking is shown in Figure 2.14. Since the standard necessitates the application of the test procedure to at least five specimens, a vertical wicking apparatus was designed and manufactured (Figure 2.13). Thus, five specimens of each sample were tested at the same time. The water was colored with food dye to facilitate visual tracking of the movement of water on fabric sample.

Specimens with the size of 220 mm × 25 mm were prepared from fabrics. The specimens were suspended vertically with their bottom ends dipped in a reservoir of distilled water. In order to ensure that the bottom ends of the specimens immersed vertically at a depth of 20 mm into the water, the bottom end of each specimen was clamped with a 3g clip. For kinetics of wicking heights, distance traveled by water on vertical strip was measured after 1-3 and 5 minutes and then the readings were taken after every 5 minutes up to 30 minutes.

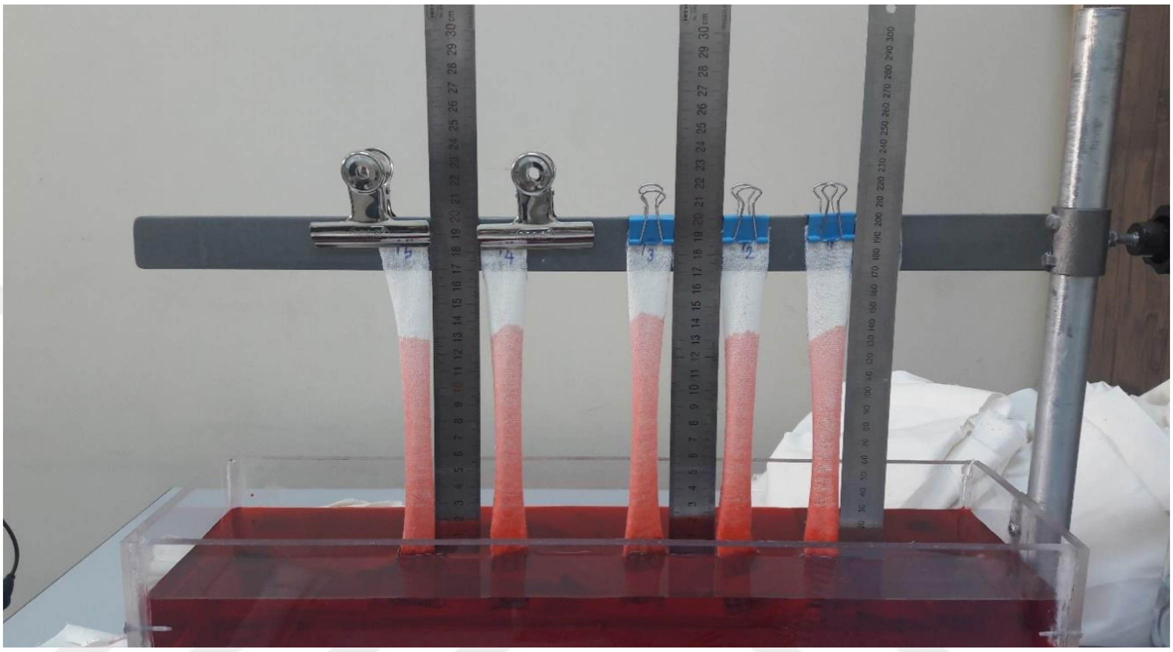


Figure 2.13 Vertical Wicking Testing Apparatus (bleached fabric samples)

2.2.2.4.Porosity

Thermal comfort of garment and textiles is much related to fabrics permeability, waterproofness and water-vapor permeability. In other respect, these three characteristics are dependent on the internal structure and porosity [37].

Porosity is described as the rate of the total blank area to the total area or as the rate of the total blank volume to the total volume. The fabric's porosity was presented as having three varied components, which were the inter yarn and inter-fiber porosities; and the influential porosity of the flow that occurred in the fabric was defined as a function of the inter-yarn and inter-fiber porosities [15,36].

In this study, porosity was measured with image analysis method.

CHAPTER 3

RESULT AND DISCUSSION

3. RESULT AND DISCUSSION

3.1.Development of Image Processing Algorithms

3.1.1. Yarn Packing Density Algorithm

In order to determine the desired yarn structure properties from cross-section views, an image processing algorithm was developed in MATLAB environment. Since the spaces between fibers in yarn cross-section will be determine, it was thought that these spaces can be detected in accordance with the light intensity value differences at fibers and spaces. For this aim, an image processing algorithm based on noise removing filters, low pass filters and binarization was developed (Figure3.1).

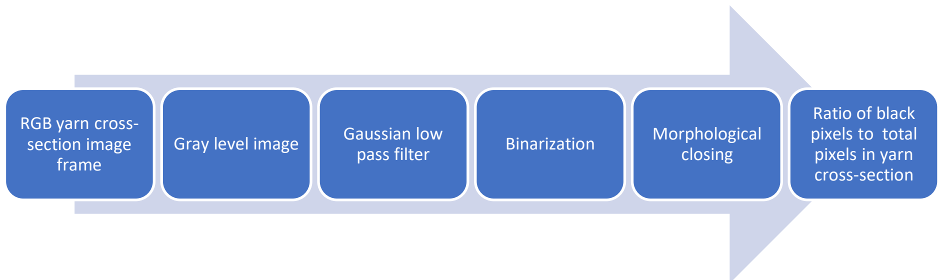


Figure 3.1 Yarn packing density algorithm

First of all, the size adjustments for image processing on MATLAB were made on the yarn cross-section images. Thus, the background of the images was eliminated. The image frame in RGB (Figure 3.2.a) form was converted to gray level. The noising removing operation was achieved by using Gaussian filter. The Gaussian filter was used for image smoothing as low-pass filter. Then, the image frame was converted to binary form (Figure 3.2.b). In order to determine the yarn packing denstity exactly, morphological closing was applied to fill in the spaces in fiber lines

(Figure 3.2.c). Closing is the name given to the morphological operation of dilation followed by erosion with the same structuring element. The yarn total cross-section area is calculated by selecting the maximum axis of the binary image size as the diameter of the yarn (Figure 3.2.c). Finally, the ratio of total black pixes to total pixels in yarn cross-section was calculated as yarn packing density.

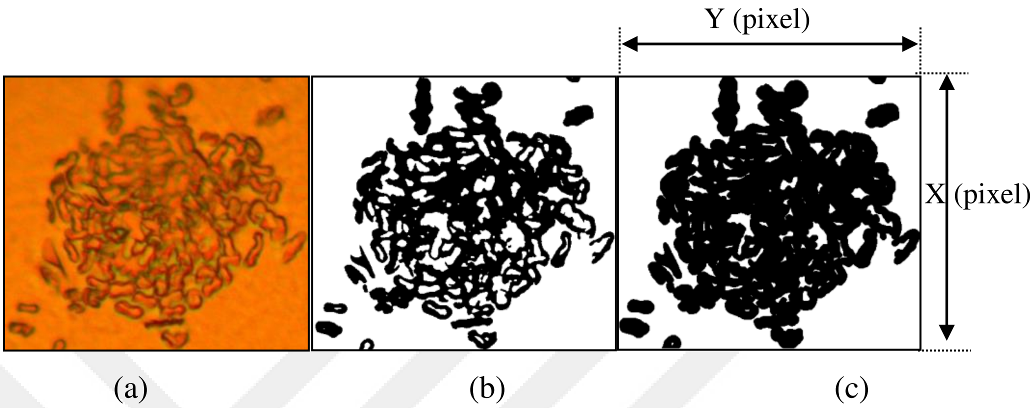


Figure 3.2 Packing Density Matlab Views of Yarn Cross-sections, (a) Microscope view, (b) Binary view, (c) Closed view

3.1.2. Fabric Porosity Algorithm

A simple machine vision system was built to acquire fabric images. The system consists of microscope camera, led light source and computer (Figure 2.15). The algorithm developed for porosity ratio measurement was generating in MATLAB environment. The fabric surface images were acquired from 10 different locations of each fabric samples. These images were transferred to MATLAB. With software that was developed via MATLAB, the ratio of the pores on fabric image to the total image size was found as a percentage (%). The porosity measurement of the algorithm is based on the light transmission intensity thorough the fabric. When the light source is submitted to the fabric back side, the light intensity of values of the pixels corresponds to pores will be higher than that of pixels corresponds to fibes and yarns (Figure 3.3). By using this principle, the image processing algorithm was developed. The same algorithm with yarn packing density was used except binarization method. The image frames get in RGB format were convert to 8-bit gray level images (Figure 3.4(a)). The image frames were applied the low pass Gaussian filter (Figure 3.4(b)). The filtered image is then applied binarization process (Figure 3.4(c)). Each pixel of the image frame is converted to black or white color according to being below or above threshold level. The threshold level is calculated by using Otsu method [57]. If the pixel value of the image frame is below threshold level, the gray level value of that pixel is allocated as “0”. Otherwise, it is set as “1”. The pixel value “1” corresponds to white and “0” corresponds to black. In the binary image frame, the white regions indicate the pores and the black regions indicate the fibers [58]. The porosity of the fabric sample is calculated as the ratio of white pixels to total pixels of the image frame. The image frames were acquired from 3×3 cm fabric areas with the size of 748 x 748 pixels.

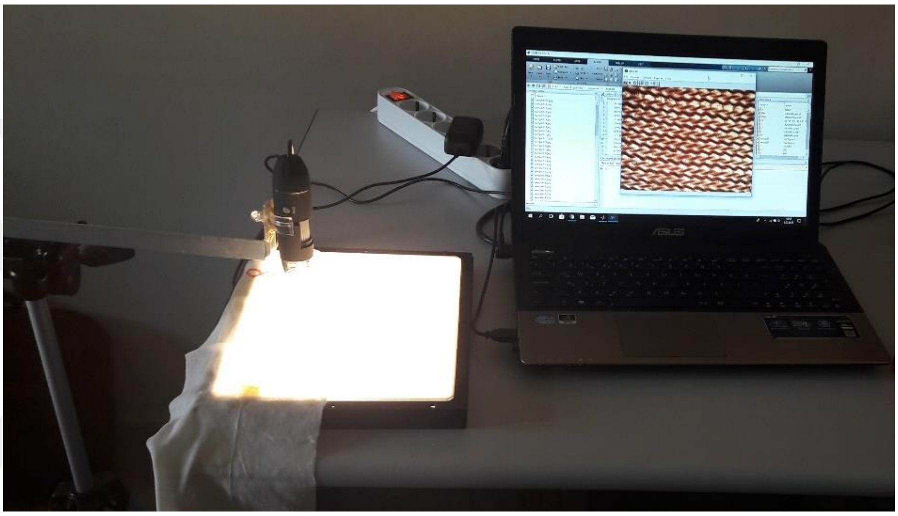
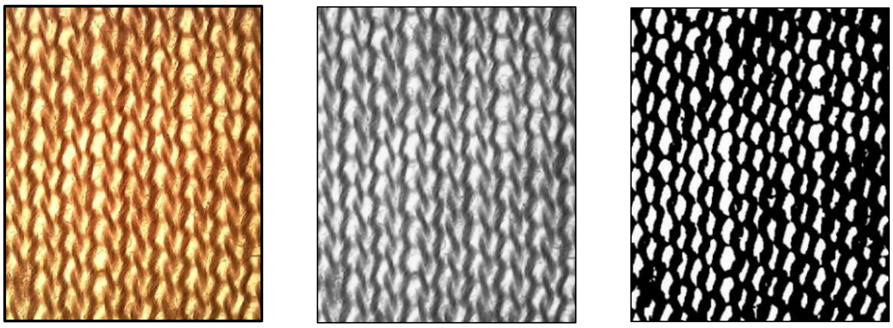


Figure 3.3 Porosity Testing Appartus



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

Figure 3.4 Porosity algorithm application. RGB format (a), Gaussian filter (b), Binary image (c).

3.2.Yarn Structural Properties

3.2.1. Fiber Migration

The fiber migration index is calculated to determine the distribution of constituent fibers in yarn cross-section. When the migration index is zero, it designates that fiber components are evenly distributed. In this case, the fiber components are uniformly distributed among the inward and outward of yarn cross-section.

The migration index is either positive or negative depending on whether it is outward or inward [49].

$$M = \frac{FM_a - FM_u}{FM_o - FM_u} \times 100\% \quad , \quad M = \frac{FM_a - FM_u}{FM_u - FM_I} \times 100\% \tag{3.1}$$

In the yarns consisting of a mixture of two different fibers, the migration index takes the same value for each fiber component but in the opposite sign. Therefore, the sum of the migration index of the two fibers is equal to zero. The migration index of yarn constituting fibers; acrylic and cotton are calculated by using Hamilton method (3.1) given in Chapter 2. The fiber migration index results of acrylic and cotton fibers are given in Table 3.1.

Table 3.1 Fiber Migration Index %

Avarage of Fiber Migration Index %																											
Sample Properties	40/60 % Cotton/Acrylic									50/50 % Cotton/Acrylic									75/25 % Cotton/Acrylic								
	3,5 α			4 α			4,5 α			3,5 α			4 α			4,5 α			3,5 α			4 α			4,5 α		
	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1	30/1	24/1	20/1
Sample No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Acrylic	7	9	10	8	10	8	10	11	12	4	6	7	6	7	9	7	8	9	-10	-11	-12	-11	-12	-14	-12	-13	-14
Cotton	-7	-9	-10	-8	-10	-8	-10	-11	-12	-4	-6	-7	-6	-7	-9	-7	-8	-9	10	11	12	11	12	14	12	13	14

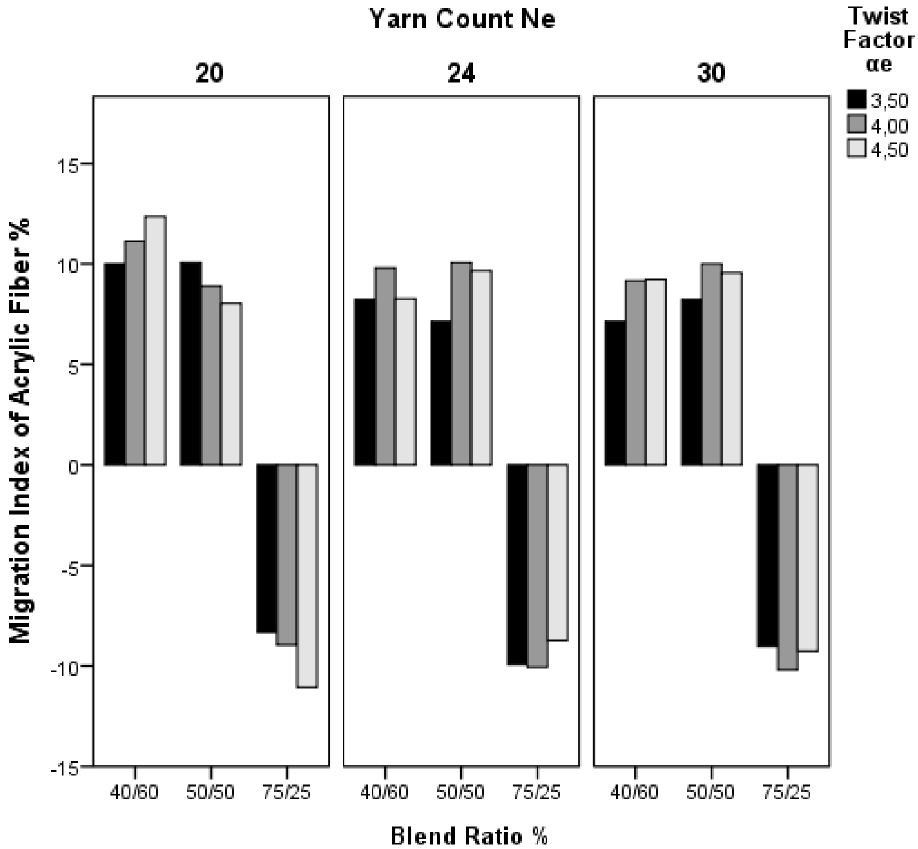


Figure 3.5 Acrylic Fiber Migration Index %

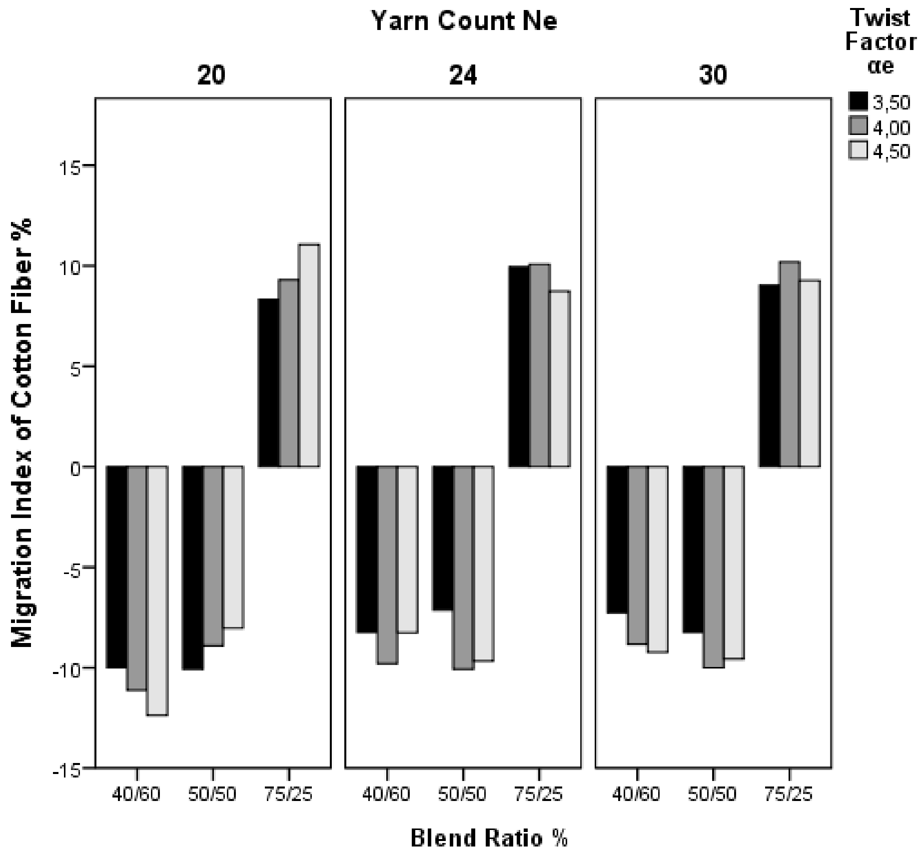


Figure 3.6 Cotton Fiber Migration Index %

The migration index results of acrylic and cotton component are given in Table 3.1 and Figure 3.5 and Figure 3.6 respectively. As examined from Figure 3.5, acrylic fibers are distributed to outward (positive (+) sign) of the yarn diameter for all samples except 75-25% cotton / acrylic blend ratio samples. It means that for all yarn linear densities and twist coefficients expect 75-25% cotton / acrylic blend ratio, the acrylic component of the blended yarn samples are generally distributed near to the yarn surface. When the cotton fiber occupies the very great proportion of yarn cross-section, the acrylic fibers are oriented toward the yarn core and so they have the minus migration index values for 75-25% cotton / acrylic blend ratio.

When the general trend of acrylic migration index with respect to the cotton blend ratio is investigated, it can be said that as the acrylic ratio increases, the cotton fibers migrate to the core and the acrylic fiber migrates to the outward of the yarn cross-section.

According to the yarn linear density, as the yarn becomes thicker, the migration indexes od components increases in all mixtures.

As seen from Figure 3.5 and Figure 3.6 there is no consistency between twist coefficient and migration index values. For the yarn samples with Ne 20/1 count and 50-50% cotton/acrylic blend ratio, the migration index increases with twist coefficient increase. On the other hand, the migration index of acrylic fiber decreases with the increase in twist coefficient for Ne 20/1 count and 50-50 cotton/acrylic blend ratio.

Variance analysis is performed to evaluate effects of independent parameters; blend ratio, twist factor, yarn count on fiber migration index property.

Table 3.2 Acrylic fibers migration ANOVA results

Tests of Between-Subjects Effects						
Dependent Variable:	**Acrylic Migration**					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	64619.356[a]	26	2485.360	67.476	0.000	0.691
Intercept	7362.178	1	7362.178	199.878	0.000	0.203
Blend Ratio	63566.430	2	31783.215	**862.894**	**0.000**	0.688
Twist Factor	71.207	2	35.604	0.967	0.381	0.002
Yarn Count	125.267	2	62.633	1.700	0.183	0.004
Blend Ratio * Twist Factor	156.563	4	39.141	1.063	0.374	0.005
Blend Ratio * Yarn Count	266.837	4	66.709	1.811	0.125	0.009
Twist Factor * Yarn Count	129.859	4	32.465	0.881	0.475	0.004
Blend Ratio * Twist Factor * Yarn Count	303.193	8	37.899	1.029	0.412	0.010
Error	28840.467	783	36.833			
Total	100822.000	810				
Corrected Total	93459.822	809				
a. R Squared = 0.691 (Adjusted R Squared = 0.681)						

According to the results of variance analysis (Table 3.2); only the fiber blend ratio has statistically significant effect on fiber migration index vales (p= 0.000) at 95% confidence interval.

Table 3.3 Tukey test table showing the effect of blend ratio on acrylic fiber migration

Blend Ratio %	**N**	**Subset**	
		1	**2**
75/25	270	-9.51	
50/50	270		9.07
40/60	270		9.48

Tukey test was applied to compare the acrylic migration values of the different blend ratios (Table 3.3). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 75/25 blend ratio and other two blend ratios; 40/60% and 50/50%. However, there is no difference between the acrylic migration values of the yarn samples with 40/60% and 50/50% blend ratios. The migration index values are near to each other for all three blend ratios. Since the sign of migration index value only designates the orientation of fiber component according to being inward (-) or outward (+) of yarn cross-section, it can say that the highest and lowest migration index values are obtained with 75/25% and 50/50% cotton/acrylic blend ratios respectively.

3.2.2. Yarn Diameter

The fibers are considered as the main factor in the yarn structure. In other respects, another factor is the air gap caused by spinning technology. More efficient estimation of the fabric properties is achieved by knowing the volume of fibers in the yarn formation. One of the parameters used in the analysis of fabric structural properties such as width, covering, comfort is the yarn diameter. The fabric cover factor will have large change even with a small change in the diameter of the yarns forming the fabric structure. The diameter measurement results of yarn samples are given in Table 3.4.

Table 3.4 Yarn Diameter Values

S. No	Blend Ratio % (Co/Acry)	Ne	Twist Factor αe	Dia. (mm)	Density (g/cm³)
Y.S.1	**40/60%**	**30/1**	**3.5**	0.24	0.43
Y.S.2	**40/60%**	**30/1**	**4**	0.23	0.47
Y.S.3	**40/60%**	**30/1**	**4.5**	0.22	0.52
Y.S.4	**40/60%**	**24/1**	**3.5**	0.27	0.43
Y.S.5	**40/60%**	**24/1**	**4**	0.26	0.47
Y.S.6	**40/60%**	**24/1**	**4.5**	0.25	0.51
Y.S.7	**40/60%**	**20/1**	**3.5**	0.30	0.42
Y.S.8	**40/60%**	**20/1**	**4**	0.28	0.47
Y.S.9	**40/60%**	**20/1**	**4.5**	0.27	0.51
Y.S.10	**50/50%**	**30/1**	**3.5**	0.24	0.43
Y.S.11	**50/50%**	**30/1**	**4**	0.23	0.48
Y.S.12	**50/50%**	**30/1**	**4.5**	0.22	0.52
Y.S.13	**50/50%**	**24/1**	**3.5**	0.28	0.42
Y.S.14	**50/50%**	**24/1**	**4**	0.26	0.47
Y.S.15	**50/50%**	**24/1**	**4.5**	0.25	0.50
Y.S.16	**50/50%**	**20/1**	**3.5**	0.30	0.41
Y.S.17	**50/50%**	**20/1**	**4**	0.28	0.46
Y.S.18	**50/50%**	**20/1**	**4.5**	0.27	0.52
Y.S.19	**75/25%**	**30/1**	**3.5**	0.26	0.37
Y.S.20	**75/25%**	**30/1**	**4**	0.24	0.43
Y.S.21	**75/25%**	**30/1**	**4.5**	0.23	0.48
Y.S.22	**75/25%**	**24/1**	**3.5**	0.29	0.38
Y.S.23	**75/25%**	**24/1**	**4**	0.27	0.41
Y.S.24	**75/25%**	**24/1**	**4.5**	0.26	0.47
Y.S.25	**75/25%**	**20/1**	**3.5**	0.31	0.38
Y.S.26	**75/25%**	**20/1**	**4**	0.30	0.43
Y.S.27	**75/25%**	**20/1**	**4.5**	0.28	0.46

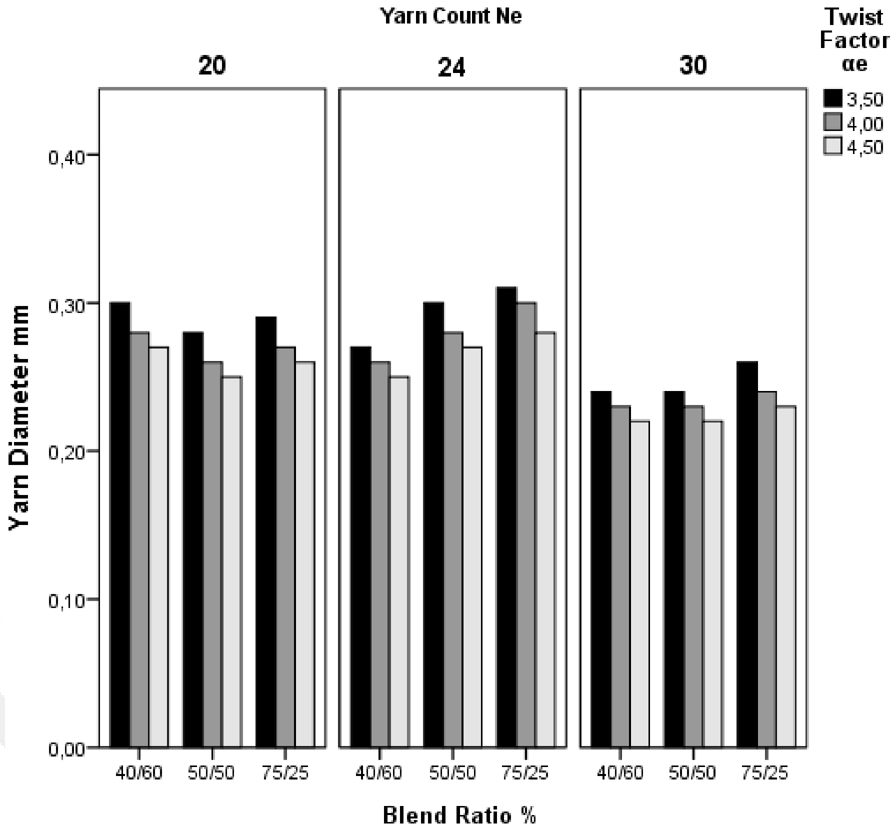


Figure 3.7 Yarn Diameter Values

The diameters of the samples were compared according to the blend ratio, yarn count and twist factor (Table3.4). It can be obviously seen from Figure 3.7. that the increase in twist factor has decreasing effect on yarn diameter for all yarn counts and blend ratios. Yarn diameter values was measured according to 400m/min speed by Uster Tester 5. The measurement for each sample was repeated 5 times. In the yarn samples with blend ratio of 40/60%, it was seen that the yarn diameter values increase as the yarns get coarse. For other blend ratios;50/50% and 75/25% cotton/acrylic, there is an ascending and descending trend for three yarn linear densities and three twist coefficients. As observed from Figure 3.3 the yarn diameter increases from Ne 20/1 to Ne 24/1 and it decreases from Ne 24/1 to Ne 30/1. Since each fiber type have different cohesion characteristics and physical property, it cannot be said that the yarn diameter decreases for all blend ratios and twist coefficients as the yarn get thinner with higher yarn count. Ne 20 and Ne24 values of 50/50% and 75/25% blend ratios were increased contrary to the expected. This is thought to be due to the production process and mass variation due to the blend ratio. The Tukey result shows that the diameter decreases as the number increases (as the yarn becomes thinner) as expected, according to the overall average diameter values of the yarns. A decrease in diameter was observed as the twist increased in the same blend ratio. When the yarn diameter values are investigated with respect to the blend ratio within the same yarn count, it can be seen that the yarn diameter increases as the cotton content increases for all twist factors except the samples with Ne 20/1. The effect of the twist angle on the number of twists on the yarn and thus on the yarn density and the packing was explained by the following figures and equations (Figure 3.8).

$$\tan\theta = \frac{\pi D}{L} \tag{3.3}$$

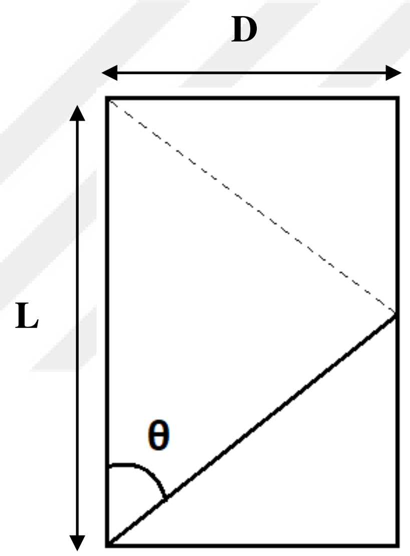


Figure 3.8 Twist angle

The greater the diameter of the yarn, the larger is the angle produced by one turn of twist. As 1/L is equivalent to turns per unit length then:

$$\tan\theta \infty D\ x\ turns/\ unit\ length \tag{3.4}$$

In the indirect system for measuring linear density the diameter is proportional to l/√count. Therefore

$$\tan\theta \infty\ \frac{turns/unit\ lenght}{\sqrt{count}} \tag{3.5}$$

A twist factor is defined using this relationship:

$$K = \frac{turns/unit\ length}{\sqrt{count}} \tag{3.6}$$

where K is the twist factor.

Table 3.5 Yarn diameter ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Diameter**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	0.052[a]	26	.002	20.034	0.000	0.906
Intercept	5.601	1	5.601	56011.111	0.000	0.999
Blend Ratio	0.003	2	.002	17.444	**0.000**	0.392
Twist Factor	0.011	2	.005	52.778	**0.000**	0.662
Yarn Count	0.037	2	.019	**185.444**	**0.000**	0.873
Blend Ratio * Twist Factor	0.000	4	6.111E-05	0.611	0.656	0.043
Blend Ratio * Yarn Count	0.000	4	2.778E-05	0.278	0.891	0.020
Twist Factor * Yarn Count	4.444E-05	4	1.111E-05	0.111	0.978	0.008
Blend Ratio * Twist Factor * Yarn Count	0.001	8	6.944E-05	0.694	0.695	0.093
Error	0.005	54	.000			
Total	5.659	81				
Corrected Total	0.057	80				
a. R Squared = .906 (Adjusted R Squared = .861)						

According to the results of analysis of variance (Table 3.5.), all of three independent factors; yarn count, (p= 0.000), twist factor (p= 0.000) and blend ratio (p= 0.000) have statistically significant effect of yarn diameter values, 95% confidence interval. When F values are examined, it is seen that the yarn count (F = 185.444) has highest effect on the yarn diameter.

Table 3.6 Tukey test table showing the effect of blend ratio on yarn diameter

Blend Ratio %	N	Subset	
		1	2
40/60	27	0.2578	
50/50	27	0.2589	
75/25	27		0.2722

Tukey test was applied to compare the yarn diameter values of the blend ratio groups (Table 3.6). It can be understood that there is a significant difference between the values of 40/60%, 50/50% blend ratio samples with 75/25% blend ratio. However, there is no difference between the yarn diameter values of the yarn samples with the blend ratio of 40/60% and 50/50%. The lowest yarn diameter was obtained in the 40/60% blend ratio, while the highest yarn diameter was obtained in the blend ratio of 75/25%. In addition, according to result in Table 3.6, the ratio of cotton content in the yarn constituent fibers increases the yarn diameter value also increased.

Table 3.7 Tukey test table showing the effect of twist factor on yarn diameter

Twist Factor α_e	N	Subset		
		1	2	3
4.50	27	0.2500		
4.00	27		0.2611	
3.50	27			0.2778

Tukey comparison test was applied to determine the differences between twist factor groups. According to the Tukey comparison in Table 3.7, there is a significant difference between the yarn diameter values of the samples with three twist factors $\alpha_e = 3.5$, $\alpha_e = 4$ and $\alpha_e = 4.5$. The lowest yarn diameter value was obtained in with $\alpha_e = 4.5$ twist factor, and the highest yarn diameter was obtained in the α_e=3.5 twist factor. Also, it is seen that the yarn diameter values decrease as the twist factor increases.

Table 3.8 Tukey test table showing the effect of yarn count on yarn diameter

Yarn Count Ne	N	Subset		
		1	**2**	**3**
30	27	0.2356		
24	27		0.2656	
20	27			0.2878

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.8). There is a significant difference between the yarn diameter values of the samples with each yarn count. The lowest and highest yarn diameter values were obtained in the Ne 30/1 yarn count, while the highest yarn diameter was with samples and Ne 20/1 respectively. It can also reveal that the yarn diameter values decrease as the yarn count increases (as the yarn gets thinner).

3.2.3. Yarn Packing Density

Table 3.9 shows the packing density values of yarn samples. The yarn packing density were compared according to blend ratio, twist factor and yarn count (Figure 3.10). The packing density of all yarn samples increases for the coarser yarns i.e. lower yarn count This result can be attributed to the fact that there will be less space between the fibers in lower yarn diameter. It is obviously seen from Table 3.12 that as the twist factor increases, the packing density also increases for all blend ratios and yarn counts. There is a consistency between cotton content and packing density of the yarn samples. In general trend, higher packing density values are obtained with higher cotton content values. This is because of lower bending rigidity. Packing density increases with higher yarn number. Because number of turns increases (3.2). It can be seen bending shape of the fibers in Figure 3.9 and Figure 3.10.

$$T\ /\ " = \alpha e. \sqrt{Ne} \tag{3.2}$$

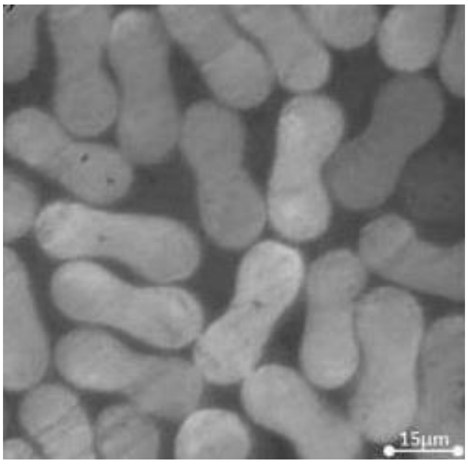


Figure 3.9 Acrylic fibers view

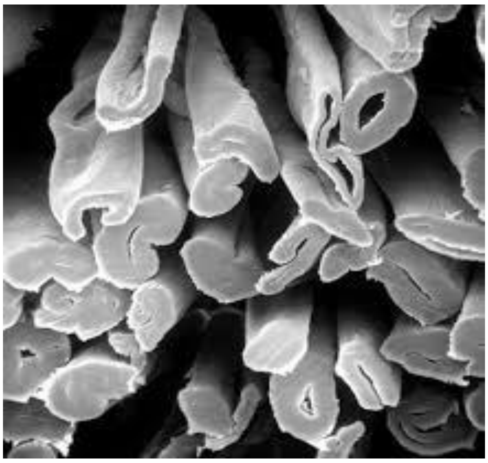


Figure 3.10 Cotton fibers view

Table 3.9 Packing density values of yarn samples

PACKING DENSITY VALUES OF YARN SAMPLES									
Sample Properties	**40/60 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	Y.S.1	Y.S.2	Y.S.3	Y.S.4	Y.S.5	Y.S.6	Y.S.7	Y.S.8	Y.S.9
Mean	0.61	0.60	0.58	0.63	0.61	0.60	0.65	0.64	0.63
Sample Properties	**50/50 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	Y.S.10	Y.S.11	Y.S.12	Y.S.13	Y.S.14	Y.S.15	Y.S.16	Y.S.17	Y.S.18
Mean	0.64	0.61	0.59	0.65	0.63	0.61	0.66	0.64	0.62
Sample Properties	**75/25 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	Y.S.19	Y.S.20	Y.S.21	Y.S.22	Y.S.123	Y.S.24	Y.S.25	Y.S.26	Y.S.27
Mean	0.66	0.64	0.63	0.67	0.65	0.64	0.69	0.66	0.65

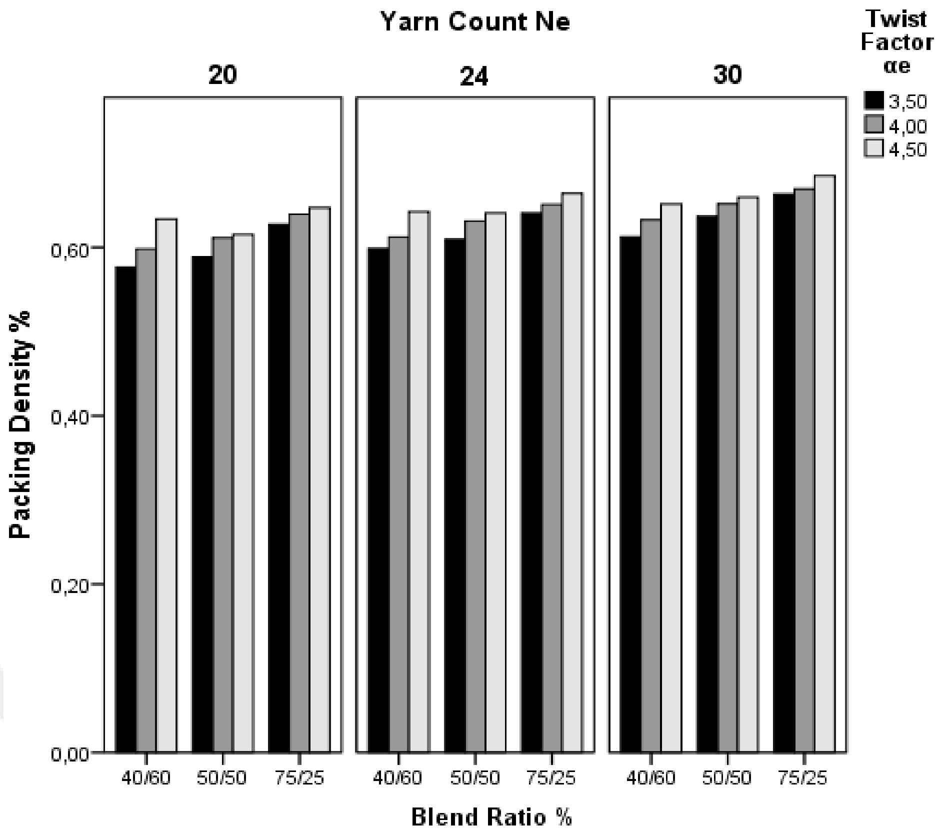


Figure 3.11 Packing density of yarn samples

As given in Table 3.10 all three of independent parameters; yarn count (p= 0.000), twist factor (p= 0.000) and blend ratio (p= 0.000) has statistically significant effect on yarn packing density values, in 95% confidence interval. The highest effect is with blend ratio (F = 17.840) and the lowest effect is obtained with twist factor. However, there is affected by the yarn packing density value.

Table 3.10 Yarn packing density ANOVA results

Tests of Between-Subjects Effects						
Dependent Variable:	**Packing_Density**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	0.536[a]	26	0.021	3.770	0.000	0.111
Intercept	324.368	1	324.368	59285.142	0.000	0.987
Blend Ratio	0.195	2	0.098	**17.840**	**0.000**	0.044
Twist Factor	0.136	2	0.068	12.400	**0.000**	0.031
Yarn Count	0.176	2	0.088	16.040	**0.000**	0.039
Blend Ratio * Twist Factor	0.019	4	0.005	0.884	0.473	0.004
Blend Ratio * Yarn Count	0.005	4	0.001	0.249	0.910	0.001
Twist Factor * Yarn Count	0.001	4	0.000	0.065	0.992	0.000
Blend Ratio * Twist Factor * Yarn Count	0.004	8	0.000	0.084	1.000	0.001
Error	4.284	783	0.005			
Total	329.189	810				
Corrected Total	4.820	809				
a. R Squared = .111 (Adjusted R Squared = .082)						

Table 3.11 Tukey test table showing the effect of blend ratio on packing density

Blend Ratio %	**N**	**Subset**	
		1	**2**
40/60	270	0.6173	
50/50	270	0.6271	
75/25	270		0.6540

Tukey test was applied to compare the yarn packing density values of the blend ratio groups (Table 3.11). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 40/60%, 50/50% blend ratio samples with 75/25% blend ratio samples. However, it is seen that there is no difference between the yarn packing density values of the yarn samples with the blend ratio of 40/60% and 50/50%. The lowest yarn packing density value was obtained in the blend ratio of 40/60%, while the highest yarn packing density value was obtained in the blend ratio of 75/25%. In addition, it can also be concluded that the ratio of cotton in constituent fibers increases, the yarn packing density value also increases.

Table 3.12 Tukey test table showing the effect of twist factor on packing density

Twist Factor α_e	N	Subset		
		1	2	3
3.50	270	0.6170		
4.00	270		0.6328	
4.50	270			0.6487

Tukey comparison test was applied to determine the differences between twist factor groups (Table 3.12). There is a significant difference between the yarn packing density values of the samples with three twist factors α_e = 3.5, α_e = 4 and α_e = 4.5. The lowest yarn packing density value was obtained in the α_e = 4.5 twist factor, and the highest yarn packing density was obtained in the α_e=3.5 twist factor. It is revealed that the yarn packing density values decrease as the twist factor increases. This result can be explained with the radial force effect of twist turns on fibers. The twist turns are formed via the ring rotation during the spinning process. When the number of turns per unit length of yarn increases, the force applied on the fibers also increases. So, the higher packing density results with higher twist factor can be attributed to this increasing force due to higher twist factors [8]

Table 3.13 Tukey test table showing the effect of yarn count on packing density

Yarn_Count Ne	N	Subset		
		1	2	3
20	270	0.6151		
24	270		0.6321	
30	270			0.6512

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.13). Significant difference is obtained between each yarn count group. While the highest yarn packing density value was obtained with Ne 30/1 yarn count, the lowest yarn packing density was obtained in the Ne 20/1 yarn count. It can also be seen that the packing density increases when the yarn get courser. This result can be linked to higher diameter of courser yarns.

3.3.Fabrics Performance Properties

3.3.1. Air Permeability

Fabric air permeability is a character of air passing through fabric, generally under the state that two sides of fabric exist pressure variation, that is to say, it is speed that airflow perpendicular goes via fabric in a predicted test zone, pressure drop and time, whose unit is “”mm/s” or “m/s”. A device often used to measure this is the air permeability device. The principle is that in a predicted pressure difference, quantity of airflow passing via a definite area of fabric in a certain time is measured, so that air permeability is calculated [40].

It was stated that air permeability is a significant factor in the productivity of textile materials such as fabrics air bags, gas filter, clothing, mosquito netting, sails, vacuum cleaners’ parachutes and tent. It can also be used to ensure a sign of the breathability of rainproof fabrics and weather-resistant [39].

Under normal conditions, as the yarns twist factor increases, the amount of air passing through the yarn increases. However, this increase stops and decreases after certain twist factor (Figure 3.12). The twist factor significantly influences the air permeability performance on the yarn and therefore on the fabric.

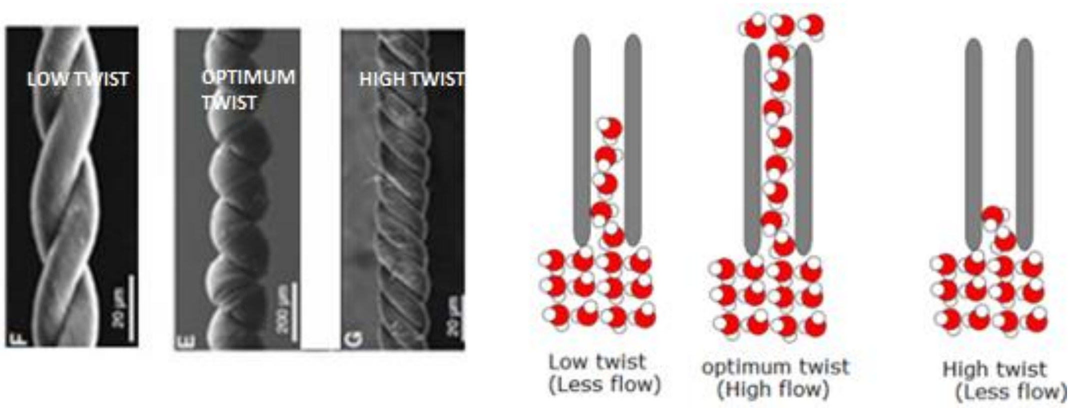


Figure 3.12 Effect of twist factor on air permeability [42]

Table 3.14 Air permeability test result of raw fabric samples

RAW FABRICS AIR PERMEABILITY (mm/s)									
Sample Properties	**40/60 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	R.S.1	R.S.2	R.S.3	R.S.4	R.S.5	R.S.6	R.S.7	R.S.8	R.S.9
Mean	3392	2438	1757	3796	2471	1895	4071	2627	1959
Sample Properties	**50/50 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	R.S.10	R.S.11	R.S.12	R.S.13	R.S.14	R.S.15	R.S.16	R.S.17	R.S.18
Mean	3293	2128	1627	3559	2594	1863	3795	2795	1874
Sample Properties	**75/25 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	R.S.19	R.S.20	R.S.21	R.S.22	R.S.23	R.S.24	R.S.25	R.S.26	R.S.27
Mean	2756	1905	1360	3252	2102	1474	3373	2445	1786

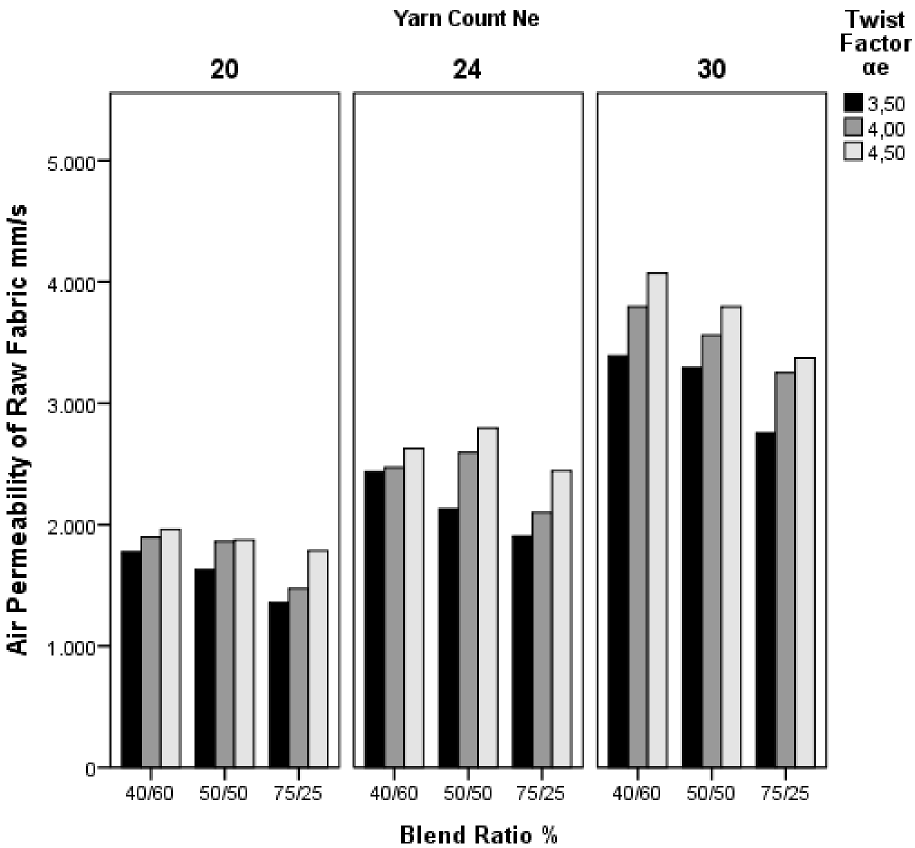


Figure 3.13 Air permeability of raw fabric samples

Air permeability results can be evaluated within two main group; raw and bleached fabrics. Initially, the test values of raw fabrics were examined as shown in Table 3.14 and they designated versus yarn count, blend ratio and twist factor in Figure 3.13.

When the air permeability test values are examined for raw fabric samples, it can be seen that air permeability value increases as the yarn count becomes thinner. This is an expected result. Since all fabrics are produced with same pattern (single jersey) and stitch density, the space between the yarns and loops will increase with thinner yarns. Within the same yarn count, air permeability values increase as the twist factor increases. This result coincides with literature [42]. As seen from Figure 3.3, the yarn diameter decreases with increase in twist factor and so the spaces between the stitch yarns increase. Thus, the higher pores are submitted for higher pores air flow. When we evaluate the results according to blend ratio (40/60%, 50/50% and 75/25% Cotton/Acrylic), a decrease in the air permeability of the fabric sample was observed as the cotton ratio increased. This result can be attributed to the fact that as the cotton content of the yarn fiber constituent increase, both the yarn diameter and packing density increase. The higher diameter and packing density provide less spaces for air passage through the fabric structure.

While the effects of independent parameters; yarn count, twist factor and blend ratio are analyzed, Covariance analysis is performed to take into account the yarn dependent properties such as fiber migration and packing density. According to the results of analysis (Table 3.15); yarn count ($p= 0.000$), twist factor ($p= 0.000$) and blend ratio ($p= 0.000$) have significant effect on air permeability performance of raw fabric 95% confidence interval. However, acrylic fiber migration ($p= 0.122$) and yarn packing density ($p= 0.103$) have no significant. When F values are examined, it is seen that the maximum effect comes from yarn count ($F = 4936.269$) and the minimum one comes from fiber blend ratio.

Table 3.15 Raw fabric air permeability ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Raw_Air_Perm**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	161175562.943[a]	28	5756270.105	420.143	0.000	0.980
Intercept	17325644.122	1	17325644.122	1264.579	0.000	0.840
Packing Density	36692.674	1	36692.674	2.678	0.103	0.011
Acrylic Fiber Migration	33044.636	1	33044.636	2.412	0.122	0.010
Blend Ratio	3988221.785	2	1994110.893	145.548	**0.000**	0.547
Twist Factor	9211804.373	2	4605902.186	336.179	**0.000**	0.736
Yarn Count	135260921.901	2	67630460.951	**4936.269**	**0.000**	0.976
Blend Ratio * Twist Factor	285011.498	4	71252.874	5.201	0.000	0.079
Blend Ratio * Yarn Count	837578.390	4	209394.597	15.283	0.000	0.202
Twist Factor * Yarn Count	860944.460	4	215236.115	15.710	0.000	0.207
Blend Ratio * Twist Factor * Yarn Count	978327.247	8	122290.906	8.926	0.000	0.229
Error	3301874.542	241	13700.724			
Total	1897515579.000	270				
Corrected Total	164477437.485	269				
a. R Squared = .980 (Adjusted R Squared = .978)						

Table 3.16 Tukey test table showing the effect of blend ratio on raw fabric air permeability

Blend Ratio %	**N**	**Subset**		
		1	**2**	**3**
75/25	90	2272.50		
50/50	90		2614.22	
40/60	90			2713.80

Tukey test was applied to compare the raw fabric air permeability values of the blend ratio groups (Table 3.16). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 40/60%, 50/50% and 75/25%

blend ratio samples. The highest raw fabric air permeability value was obtained in the blend ratio of 40/60%, while the lowest raw fabric air permeability was obtained in the blend ratio of 75/25%. The air permeability of the fabric samples increases with the decrease in yarn cotton content. The result can be explained with the effects of cotton content to yarn diameter and packing density properties. As the cotton ratio in yarn cross-section increases, yarn packing density and diameter properties increase. This situation provides less space for air flow.

Table 3.17 Tukey test table showing the effect of twist factor on raw fabric air permeability

Twist Factor α_e	**N**	**Subset**		
		1	**2**	**3**
3.50	90	2297.11		
4.00	90		2556.19	
4.50	90			2747.22

Tukey comparison test was applied to determine the differences between twist factor groups (Table 3.17). According to the Tukey table, there is a significant difference between air permeability values of raw fabric samples with different twist factors α_e = 3.5 and α_e = 4 and α_e = 4.5. The lowest raw fabric air permeability value was obtained in the α_e = 3.5, while the highest raw fabric air permeability was obtained in the α_e =4.5. Also, it is seen that the raw fabric air permeability values increase as the twist factor increases. The effects of twist factor on air permeability and yarn diameter have consistency. As the yarn twist factor increases, the yarn diameter decreases and so the air gapes between the yarns increases.

Table 3.18 Tukey test table showing the effect of yarn count on raw fabric air permeability

Yarn Count Ne	N	Subset		
		1	2	3
20	90	1734.80		
24	90		2389.39	
30	90			3476.33

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.18). According to the Tukey table, there is a significant difference between the raw fabric air permeability values with the yarn count Ne 30/1 and Ne 24/1 and Ne 20/1. The lowest raw fabric air permeability value was obtained in Ne 20/1 yarn count, and the highest raw fabric air permeability was obtained with Ne 30/1 yarn count. Since all fabric samples are produced with constant stitch density, it is seen that the raw fabric air permeability values increase as the yarn count increases (as the yarn gets thinner).

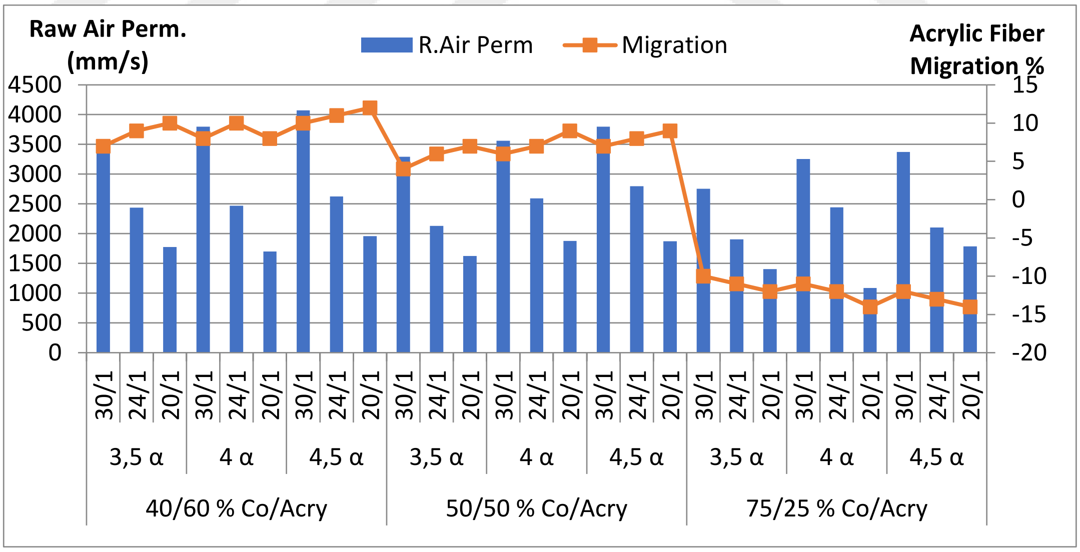


Figure 3.14 Relation between raw air permeability and fiber migration

The relationship between raw fabric air permeability and acrylic fiber migration was investigated in Figure 3.14. The migration value and the air permeability generally progress opposite to each other. In other words, fiber migration is increased while raw fabric air permeability is decreased. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value. The decrease comes from the negative sign because of the change in direction of migration value. The acrylic fibers in the yarn structure are oriented to the outer layer of the yarn and the cotton fibers to the core. It is thought that air pockets are reduced by the combination of acrylic fibers in the outer layer and cotton fibers filling the core. Thus, the air permeability decreases as the migration increases. As the cotton content in the structure increased, the migration became homogenous and so it was a negative effect on air permeability.

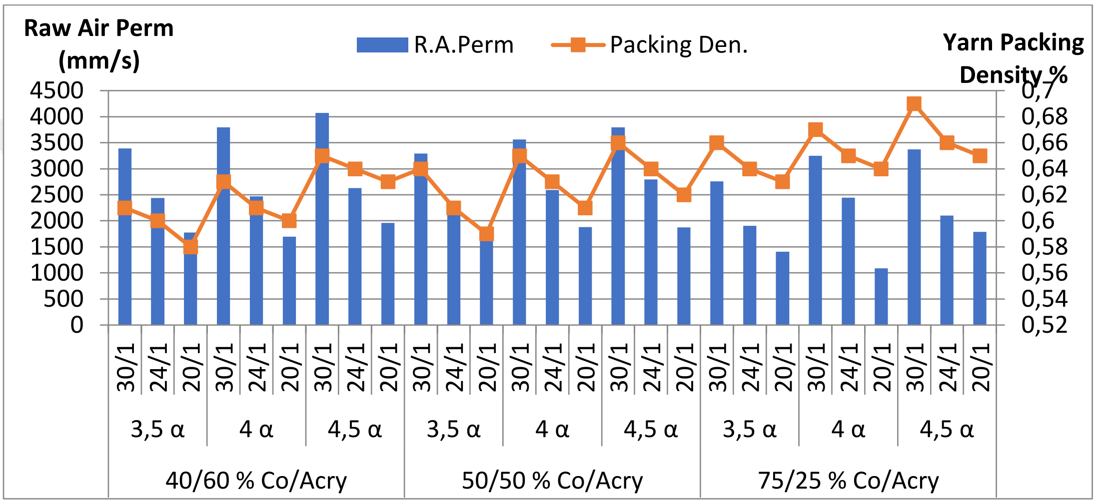


Figure 3.15 Relation between raw air permeability and packing density

The relationship between raw fabric air permeability and yarn packing density was examined in Figure 3.15 While the raw fabric air permeability values are decreasing, the yarn packing density value decreases at the same time. A positive correlation between air permeability and yarn packing density is seen. It is thought that the amount of air passing through the yarn structure will decrease as the packing density decreases.

The air permeability reults of bleached fabrics are given in Table 3.19. The air permeability results are investigated with regard to yarn count, twist factor and blend ratio in Figure 3.16.

Table 3.19 Air permeability test result of bleached fabric samples

BLEACHED FABRICS AIR PERMEABILITY (mm/s)									
Sample Properties	**40/60 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	B.S.1	B.S.2	B.S.3	B.S.4	B.S.5	B.S.6	B.S.7	B.S.8	B.S.9
Mean	2037	1441	1058	2234	1402	912	2158	1737	1207
Sample Properties	**50/50 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	B.S.10	B.S.11	B.S.12	B.S.13	B.S.14	B.S.15	B.S.16	B.S.17	B.S.18
Mean	1867	1409	851	2012	1466	910	2574	1467	965
Sample Properties	**75/25 % Cotton/Acrylic**								
	3,5 α			**4 α**			**4,5 α**		
	30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
Sample No	B.S.19	B.S.20	B.S.21	B.S.22	B.S.23	B.S.24	B.S.25	B.S.26	B.S.27
Mean	1659	1103	788	1394	1053	672	1537	1269	648

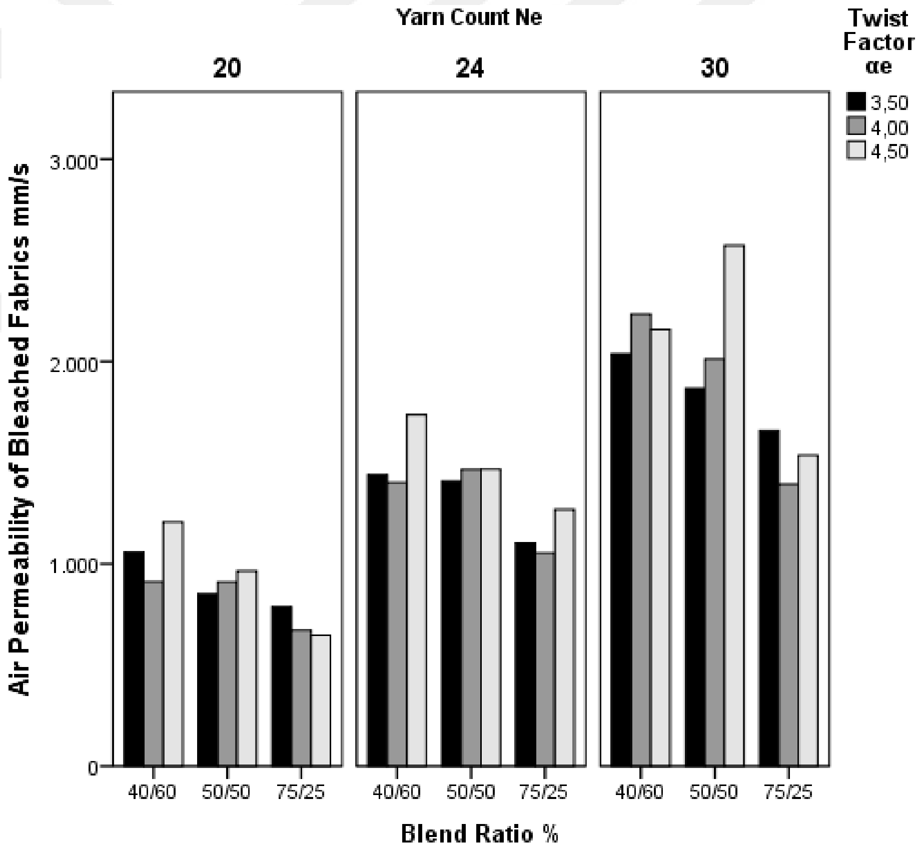


Figure 3.16 Air permeability of bleached fabric samples

When the bleached fabric air permeability values are examined (Table 3.19 and Figure 3.16), it can be seen that air permeability value increases as the yarn count becomes thinner as in raw fabric samples. On the other hand, it can be seen that the consistency between twist factor and air permeability values of the raw fabric was vanished in bleached fabrics. This result can be explained with the chemical and physical effect of the bleaching process on yarn and fabric structure. When we evaluate the results according to blend ratio (40/60%, 50/50% and 75/25% Cotton/Acrylic), a decrease in the air permeability of the fabric sample was observed as the cotton ratio increases.

In addition, when compared to the raw and bleached fabric samples, it has been observed that the air permeability values of the raw fabric samples are higher than the bleached fabric samples. This result can be attributed to the swelling effect of bleaching process on cotton fiber.

Table 3.20 Bleached fabric air permeability ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Bleached Air_Perm**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	66769787.104[a]	28	2384635.254	425.683	0.000	0.980
Intercept	4717820.385	1	4717820.385	842.181	0.000	0.778
Packing Density	586.399	1	586.399	0.105	0.747	0.000
Acrylic Fiber Migration	9106.952	1	9106.952	1.626	0.204	0.007
Blend Ratio	3942541.853	2	1971270.926	351.893	**0.000**	0.745
Twist Factor	1513402.132	2	756701.066	135.079	**0.000**	0.529
Yarn Count	48018479.622	2	24009239.811	**4285.905**	**0.000**	0.973
Blend Ratio * Twist Factor	851299.216	4	212824.804	37.991	0.000	0.387
Blend Ratio * Yarn Count	1448053.252	4	362013.313	64.623	0.000	0.518
Twist Factor * Yarn Count	301754.829	4	75438.707	13.467	0.000	0.183
Blend Ratio * Twist Factor * Yarn Count	2197092.359	8	274636.545	49.026	0.000	0.619
Error	1350059.415	241	5601.906			
Total	598132158.000	270				
Corrected Total	68119846.519	269				
a. R Squared = 0.980 (Adjusted R Squared = 0.978)						

The effects of dependent; yarn packing density and fiber migration and independent parameters; yarn count, twist factor and blend ratio were investigated statistically in covariance analysis (Table 3.20). According to the results of (presented in Table 3.20); three of independent parameters have statistically significant effect ($p<0.05$) on air permeability of bleached fabrics. On the other hand, the dependent parameters come from the yarn structure properties; yarn packing density and fiber migration have no significant effect ($p>0.05$). When F values are examined, it is seen that the highest and lowest effects are obtained with yarn count ($F = 4285.905$) and twist factor ($F=135.079$) respectively.

Table 3.21 Tukey test table showing the effect of blend ratio on bleached fabric air permeability

Blend Ratio%	N	Subset		
		1	2	3
75/25	90	1124.70		
50/50	90		1502. 33	
40/60	90			1576.19

Tukey test was applied to compare the bleached fabric air permeability values of the blend ratio groups (Table 3.21). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 40/60%, 50/50% and 75/25% blend ratio samples. The highest air permeability value of bleached fabric was obtained in the blend ratio of 40/60%, and the lowest air permeability was obtained with 75/25% blend ratio. In addition, according to Table 3.21 results, as the ratio of cotton component in the blend yarn decreases, the air permeability of bleached fabric increases.

Table 3.22 Tukey test table showing the effect of twist factor on bleached fabric air permeability

Twist Factor α_e	N	Subset	
		1	2
3.50	90	1339.39	
4.00	90	1357.00	
4.50	90		1506.83

Tukey comparison test was applied to determine the differences between twist factor groups (Table 3.22). According to the Tukey table, there is a significant difference between the air permeability values of bleached fabric with the twist factor α_e= 4.5 and other two twist factors; α_e = 3.5 and α_e= 4.0. However, it is seen that there is no difference between the bleached fabric air permeability values of the yarn samples with the twist factor of α_e = 3.5 and α_e = 4,0. The lowest bleached fabric air permeability value was obtained in the α_e = 3.5 twist factor, while the highest bleached fabric air permeability was obtained in the α_e=4.5 twist factor. Also, it is seen that the bleached fabric air permeability values increase as the twist factor increases. As discussed for air permeability results of raw fabrics, this result can be explained with decreasing effect of twist factor on yarn diameter and so proving higher space for air flow.

Table 3.23 Tukey test table showing the effect of yarn count on bleached fabric air permeability

Yarn Count Ne	N	Subset		
		1	2	3
20	90	890.08		
24	90		1371.87	
30	90			1941.28

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.23). According to the Tukey table, there is a significant difference between the air permeability values of bleached fabric with three yarn counts; Ne 30/1, Ne 24/1 and Ne 20/1. The lowest air permeability value was obtained with Ne

20/, while the highest air permeability was obtained with Ne 30/1. As seen from Table 3.23 the air permeability of bleached fabrics increases with the yarn count increasei.e. the yarn gets thinner.

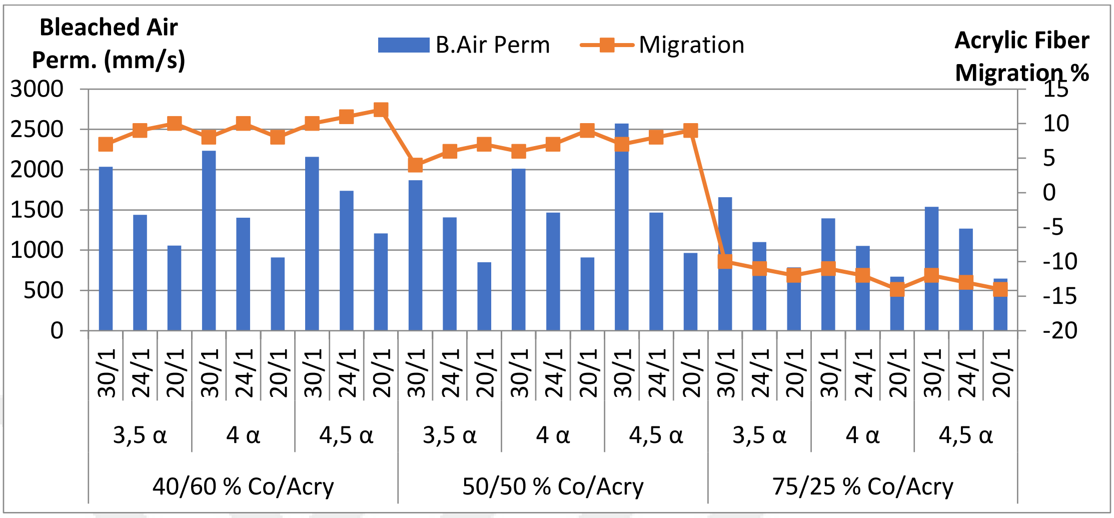


Figure 3.17 Relation between bleached air permeability and fiber migration

The relationship between bleached fabric air permeability and acrylic fiber migration was examined in Figure 3.17. The migration value and the bleached fabric air permeability generally progressed to the opposite of each other. In other words, fiber migration is increased while air permeability of bleached fabric decreases. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value, but because of the change the direction of migration value. The same results and relationships were obtained with raw fabrics. The difference between raw and bleached fabrics is the decline in air permeability values. This is expected to due to swelling in cotton after bleaching and decreasing the air pockets.

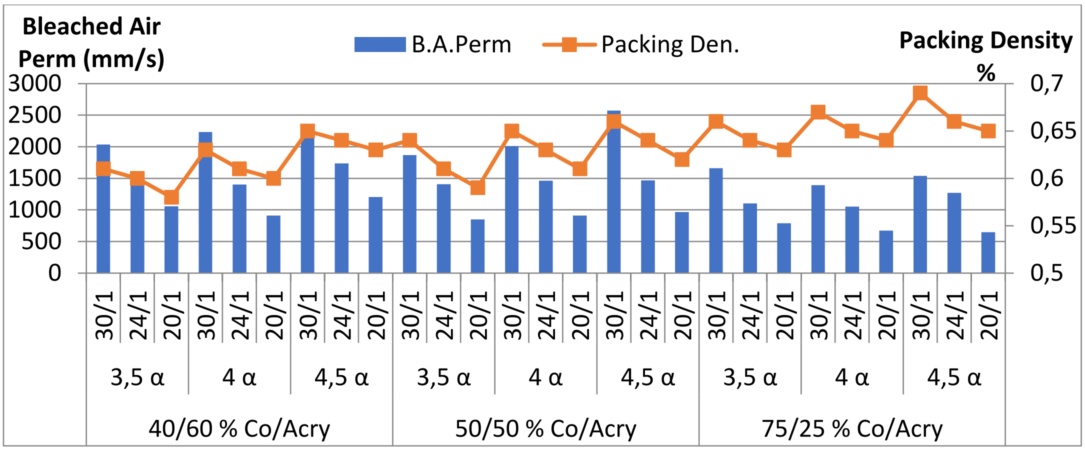


Figure 3.18 Relation between bleached air permeability and packing density

The relationship between bleached fabric air permeability and yarn packing density was examined in Figure 3.18. The consistency between yarn packing density and air permeability results can be clearly seen. While the bleached fabric air permeability values are decreasing, the yarn packing density value decreases at the same time. It is thought that the amount of air passing within the yarn structure decreases as the packing density decreases and so air gaps in the yarn cross-section decrease.

3.3.2. Water Vapor Permeability

Cloth is designed to continue a comfortable and hygienic area for the human body in which one feels good, even if inner or outer affects change immediately. The area in which the warmth, humidity and air circulation are correctly coupled is called the "comfort zone". It was stated that the three basic parameters of garment (temperature, moisture and air circulation) must be adapted to the different internal and external affects, like rest or body exertion and to the changes in outside climate. The main duty of cloth is thus temperature arrangement for the body and thus relief of the circulatory organs, maintaining body and mental performance and imparting a sense of comfort, even under the least favorable climatic conditions. Since water vapor permeability is one of the principal factors that come to mind about sweating, there is a significant effect on the comfort features of garment fabrics.

It was stated that garment materials with high water vapor permeability permits the human body to take advantage of its ability to supply cooling due to sweat production and vaporization. When sweating takes place to cool the body, the water exuded through skin appears initially as liquid which vaporizes at once (in comfortable situations) and forms moisture vapor. This vapor is then detracted from the surrounding of the body, either by convection or through the clothing worn on the person, carrying heat away with it [44].

The water vapor permeability (WVP) results of the fabric samples are analyzed in two groups such as raw fabrics and bleached fabrics. WVP results of raw fabric samples are presented in Table 3.24 and Figure 3.12.

Table 3.24 Water vapor permeability test results of raw fabric samples

WATER WAPOR PERMEABILITY VALUES OF RAW FABRICS								
40/60% Co/Acry Samples			**50/50% Co/Acry Samples**			**75/25% Co/Acry Samples**		
Sample No	**Mean**	**WVP Index**	**Sample No**	**Mean**	**WVP Index**	**Sample No**	**Mean**	**WVP Index**
R.S.1	860.81	0.47	**R.S.10**	808.82	0.44	**R.S.19**	886.81	0.48
R.S.2	840.59	0.46	**R.S.11**	797.26	0.43	**R.S.20**	875.25	0.47
R.S.3	820.37	0.44	**R.S.12**	803.04	0.44	**R.S.21**	808.82	0.44
R.S.4	820.37	0.44	**R.S.13**	829.04	0.45	**R.S.22**	823.26	0.45
R.S.5	826.15	0.45	**R.S.14**	788.60	0.43	**R.S.23**	808.82	0.44
R.S.6	817.48	0.44	**R.S.15**	791.48	0.43	**R.S.24**	803.04	0.44
R.S.7	846.37	0.46	**R.S.16**	779.93	0.42	**R.S.25**	831.93	0.45
R.S.8	840.59	0.46	**R.S.17**	834.81	0.45	**R.S.26**	805.93	0.44
R.S.9	800.15	0.43	**R.S.18**	808.82	0.44	**R.S.27**	846.37	0.46

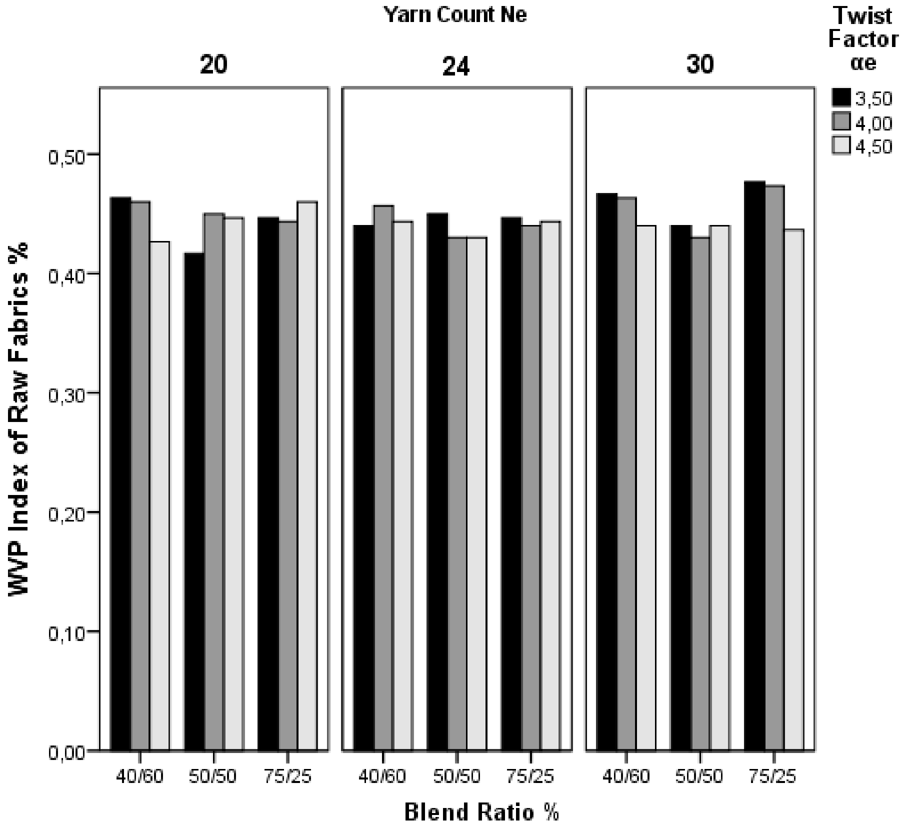


Figure 3.19 Water vapor permeability test results of raw fabric samples

According to Figure 3.19, the results are close to each other. So, it can be said that there is no significant difference between all raw fabric results and any general trend cannot be seen for an independent parameter.

According to the results of analysis of variance (Table 3.25); all of three independent yarn count (p= 0.896), twist factor (p= 0.884) and blend ratio (p= 0.723) and two dependents; fiber migration and packing density have no significant effect on WVP performance of the raw fabric samples within 95% confidence interval. Therefore, Tukey test was not applied for any of the dependent variables.

Table 3.25 Raw fabric WVP permeability ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Raw_WVP**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	0.019[a]	28	0.001	0.114	1.000	0.058
Intercept	0.099	1	0.099	16.596	0.000	0.242
Packing Density	0.000	1	0.000	0.074	0.786	0.001
Acrylic Fiber Migration	0.002	1	0.002	0.294	0.590	0.006
Blend Ratio	0.006	2	0.003	0.482	0.620	0.018
Twist Factor	0.002	2	0.001	0.164	0.850	0.006
Yarn Count	0.002	2	0.001	0.170	0.844	0.006
Blend Ratio * Twist Factor	0.003	4	0.001	0.119	0.975	0.009
Blend Ratio * Yarn Count	0.002	4	0.000	0.068	0.991	0.005
Twist Factor * Yarn Count	0.002	4	0.001	0.086	0.987	0.007
Blend Ratio * Twist Factor * Yarn Count	0.006	8	0.001	0.116	0.998	0.018
Error	0.309	52	0.006			
Total	16.489	81				
Corrected Total	0.328	80				
a. R Squared = 0.058 (Adjusted R Squared = -0.450)						

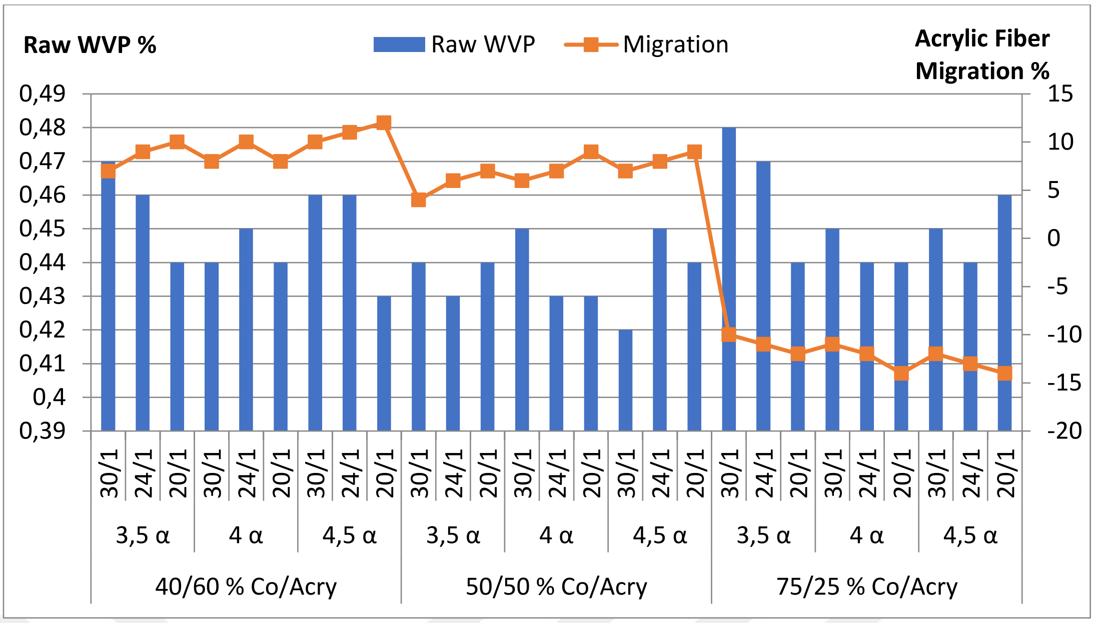


Figure 3.20 Relation between raw WVP and fiber migration

The relationship between WVP values of raw fabric samples and acrylic fiber migration was examined in Figure 3.20. The migration value and the raw fabric water vapor permeability generally progressed opposite to each other. In other words, fiber migration increases while raw fabric water vapor permeability decreases. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value, but because of the change in direction of migration value.

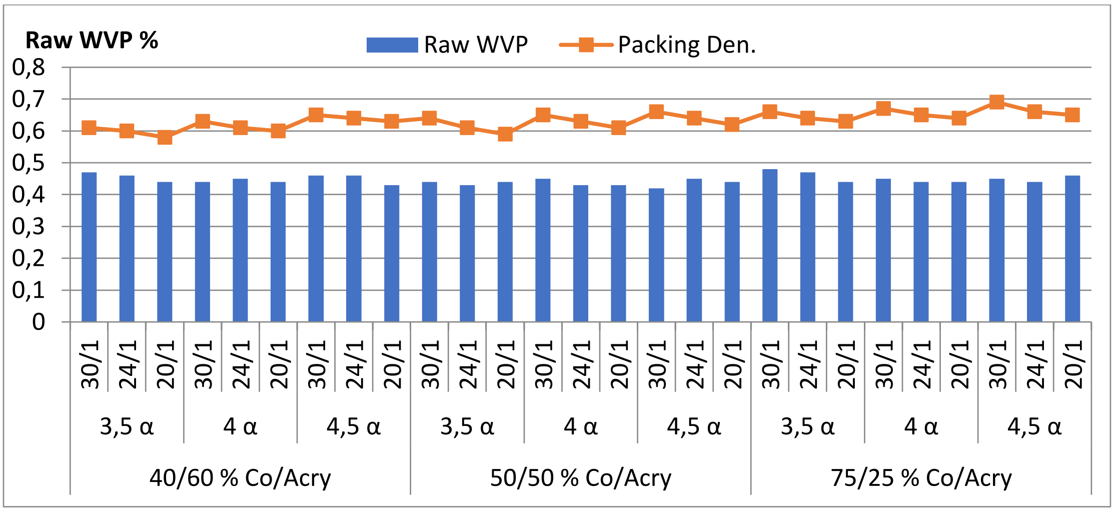


Figure 3.21 Relation between raw WVP and packing density

The relationship between raw fabric water vapor permeability and packing density was examined in Figure 3.21. The packing density value and the raw fabric water vapor permeability generally progressed parallel to each other. Other literally, yarn packing density increases while raw fabric water vapor permeability increases.

Table 3.26 Water vapor permeability test results of bleached fabric samples

WATER WAPORPERMEABILITY VALUES OF BLEACHED FABRICS								
40/60% Co/Acry Samples			50/50% Co/Acry Samples			75/25% Co/Acry Samples		
Sample No	Mean	WVP Index	Sample No	Mean	WVP Index	Sample No	Mean	WVP Index
B.S.1	896.12	0.47	**B.S.10**	899.08	0.47	**B.S.19**	890.20	0.47
B.S.2	970.06	0.51	**B.S.11**	890.20	0.47	**B.S.20**	872.46	0.46
B.S.3	946.40	0.50	**B.S.12**	866.54	0.45	**B.S.21**	866.54	0.45
B.S.4	955.27	0.50	**B.S.13**	854.71	0.45	**B.S.22**	860.63	0.45
B.S.5	881.33	0.46	**B.S.14**	854.71	0.45	**B.S.23**	1017.38	0.53
B.S.6	851.76	0.45	**B.S.15**	777.82	0.41	**B.S.24**	1023.29	0.54
B.S.7	884.29	0.46	**B.S.16**	786.69	0.41	**B.S.25**	1023.29	0.54
B.S.8	866.54	0.45	**B.S.17**	825.14	0.43	**B.S.26**	872.46	0.46
B.S.9	851.76	0.45	**B.S.18**	887.25	0.47	**B.S.27**	831.05	0.44

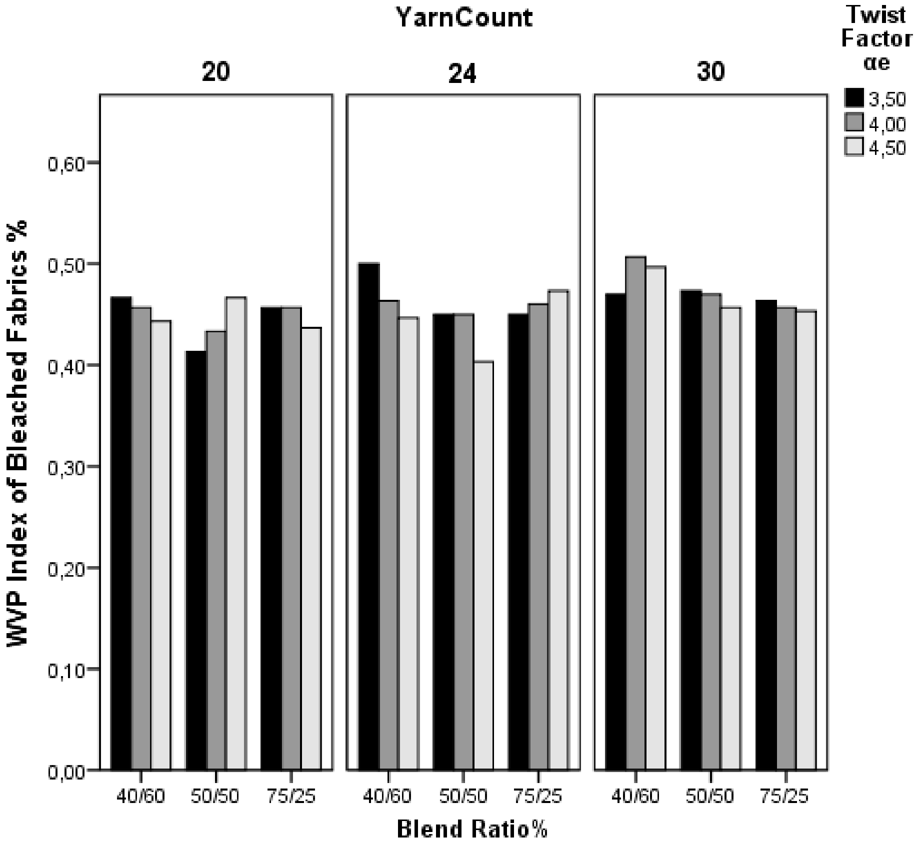


Figure 3.22 Water vapor permeability test results of bleached fabric samples

Relying on the results in Table 3.26 and Figure 3.22, as obtained for raw fabric samples there is no significant difference between all raw fabric results and any general trend cannot be seen for an independent parameter.

According to the results of analysis of variance (Table 3.27); yarn count (p= 0.004) and blend ratio (p= 0.002) have significant effects on WVP results of bleached fabric in 95% confidence interval. However, acrylic migration (p= 0.641), packing density (p= 0.618) and twist factor (p=0.423) parameters have no significant effects. When F values was examined, it is seen that the effects of blend ratio (F = 6.841) and yarn count (F=6.127) are close to each other.

Table 3.27 Bleached fabric WVP permeability ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Bleached WVP**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	0.040[a]	28	0.001	2.053	0.012	0.525
Intercept	0.099	1	0.099	142.885	0.000	0.733
Packing Density	0.000	1	0.000	0.252	0.618	0.005
Acrylic Fiber Migration	0.000	1	0.000	0.220	0.641	0.004
Blend Ratio	0.010	2	0.005	**6.841**	**0.002**	0.208
Twist Factor	0.001	2	0.001	0.874	0.423	0.033
Yarn Count	0.009	2	0.004	6.127	**0.004**	0.191
Blend Ratio * Twist Factor	0.001	4	0.000	0.282	0.888	0.021
Blend Ratio * Yarn Count	0.003	4	0.001	1.185	0.328	0.084
Twist Factor * Yarn Count	0.002	4	0.001	0.779	0.544	0.057
Blend Ratio * Twist Factor * Yarn Count	0.012	8	0.001	2.119	0.050	0.246
Error	0.036	52	0.001			
Total	17.087	81				
Corrected Total	0.076	80				
a. R Squared = 0.525 (Adjusted R Squared = 0.269)						

Tukey test was applied to compare the bleached fabric WVP permeability values of the blend ratio groups (Table 3.28). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 75/25%, 50/50%

blend ratio samples with 40/60% blend ratio samples. However, it is seen that there is no difference between the WVP permeability values of bleached fabric samples with the blend ratio of 75/25% and 50/50%. The lowest WVP value of bleached fabrics was obtained in the blend ratio of 50/50%, and the highest WVP value of bleached was obtained in the blend ratio of 40/60%.

Table 3.28 Tukey test table showing the effect of blend ratio on WVP of bleached fabric

Blend Ratio %	N	Subset	
		1	2
50/50	27	0.4463	
75/25	27	0.4563	
40/60	27		0.4722

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.29). There is a significant difference between WVP values of Ne 30/1 and other two yarn count groups; Ne 20/1 and Ne 24/1. There is no significant difference between Ne 20/1 and Ne 24/1 groups. The lowest WVP value is obtained with Ne 20/1 yarn count, while the highest WVP value was obtained in Ne 30/1.

Table 3.29 Tukey test table showing the effect of yarn count on WVP of bleached fabric

Yarn Count Ne	N	Subset	
		1	2
20	27	0.4478	
24	27	0.4552	
30	27		0.4719

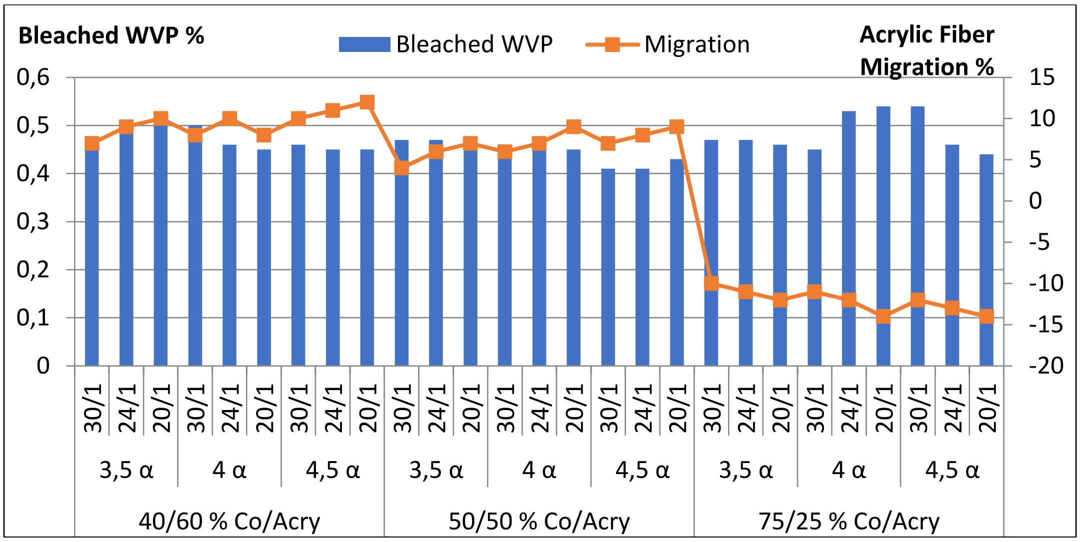


Figure 3.23 Relation between bleached WVP and fiber migration

The relationship between WVP values of raw fabric samples and acrylic fiber migration was examined in Figure 3.23. General trend of acrylic fiber migration index is similar to that of WVP values of the bleached fabric. There is a decrease in the negative direction of migration between samples 18-27. The change is caused from the change in the direction of migration value.

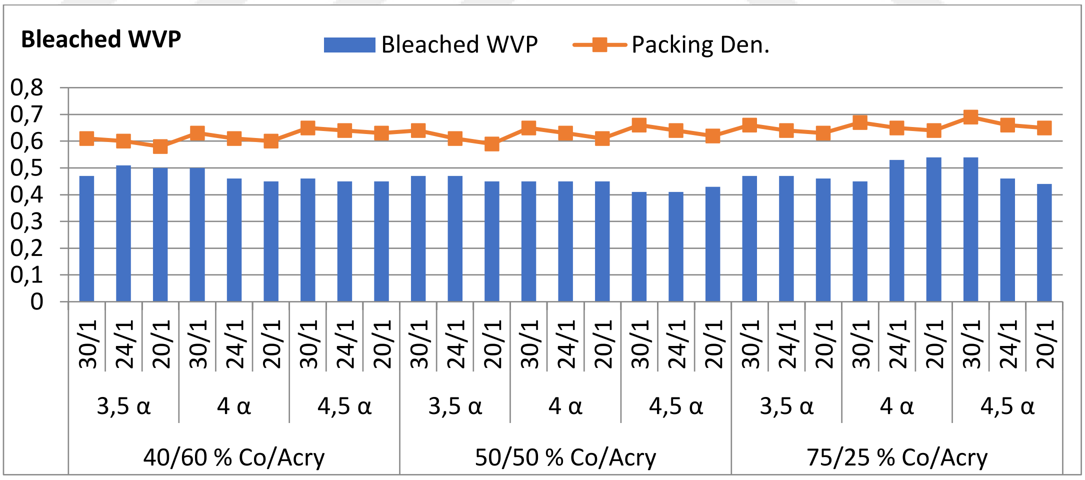


Figure 3.24 Relation between bleached WVP and packing density

The packing density values and the water vapor permeability values of bleached fabric were observed together in Figure 3.24. It can be said that general trends of both two parameters; WVP and acrylic fiber migration are very close to each other.

3.3.3. Wicking

The moisture transfer predicated with wicking is one of the most significant aspects in clothing science and strongly effects on the quality of clothes. Wicking is an autogenous transfer of fluid driven into a porous system via capillary forces. Additionally, the packing density has a direct connected with the yarn structure [10]. In general, fluid moisture transfer in textile materials are principal affected by the moisture absorbency of the fiber content and wicking ability which are specified via the capillary action, pathways and surface tension [34]. Low twisted yarn has lower wicking ability because of more free space and high twisted yarn also lower wicking ability because of no more free space. Hence optimum twist is needed for better wicking ability [42]. It was emphasized that the wicking, moisture management and wetting are significant features influencing the thermo-physiological comfort of a cloth [44].

Figure 3.25 Vertical Wicking Testing Apparatus (raw fabric samples)

In the scope of the study, wickability test was made on raw and bleached fabrics as previously mentioned. The device which the test was made consists of water tank, ruler, sample holder and paperclip materials and has been developed in accordance with the standards. As shown in Figure 3.25, there was no visible liquid increase after 30 minutes in the tests on raw fabrics samples. These results are due to oil and wax on the cotton and hydrophilic structure of the acrylic fiber. Since no visible result was obtained for the raw fabric in the wickability test, the result table could not be formed. Thus, it can be said that capillarity in raw fabric has failed.

The wickablility of bleached fabric samples are evaluated as vertical liquid rise within 30 minutes duration. The height of liquid rise is measured after 1, 3, 5, 10, 15, 20, 25 and 30 minutes the fabric samples dipped in liquid tank. The results are given in Table 3.30. The liquid heights in predetermined time periods are presented in Table 3.30 and Figure 3.26.

Table 3.30 Wicking test results of bleached fabric samples according to time

WICKING TEST RESULTS OF BLEACHED FABRICS (MIN)								
	1'	**3'**	**5'**	**10'**	**15'**	**20'**	**25'**	**30'**
B.S.1	5.5	7.9	9.4	12.1	13.3	14.3	15.0	15.7
B.S.2	6.0	8.9	10.0	12.4	13.9	15.1	15.8	16.6
B.S.3	6.1	8.6	10.4	13.1	14.7	16.1	16.9	17.7
B.S.4	5.8	7.9	9.2	11.5	13.0	14.3	15.2	15.7
B.S.5	6.4	8.4	9.4	12.0	13.5	14.5	15.6	16.0
B.S.6	5.8	8.8	9.7	12.1	13.5	14.5	15.3	16.0
B.S.7	5.0	6.9	8.1	10.1	11.5	10.3	13.1	13.8
B.S.8	5.0	7.4	8.3	10.5	11.6	12.9	13.9	14.7
B.S.9	4.9	7.3	8.8	11.0	12.5	13.6	14.4	15.1
B.S.10	5.7	8.1	9.4	11.9	13.5	14.7	15.3	15.8
B.S.11	5.4	8.0	9.8	12.1	13.8	14.8	15.5	16.1
B.S.12	5.9	8.4	9.9	12.4	13.8	15.1	16.1	17.0
B.S.13	4.7	6.8	8.3	10.5	12.0	13.1	13.9	14.5
B.S.14	5.9	8.4	9.5	11.7	13.1	14.2	14.8	15.5
B.S.15	4.8	7.3	8.6	10.7	12.3	13.2	14.2	14.9
B.S.16	4.1	5.8	7.2	8.8	10.0	10.7	11.6	12.1
B.S.17	4.7	6.7	8.0	10.0	11.3	12.2	12.9	13.7
B.S.18	4.9	7.4	9.0	11.1	12.7	13.9	14.9	15.7
B.S.19	5.0	6.5	8.1	10.7	12.1	13.3	40.3	12.1
B.S.20	4.5	6.7	8.2	10.7	12.2	13.3	14.3	15.0
B.S.21	4.5	6.7	8.3	10.6	12.2	13.1	14.2	14.8
B.S.22	4.3	6.4	7.8	10.0	11.4	12.1	12.9	13.7
B.S.23	5.1	7.1	8.5	10.8	12.2	13.5	14.2	15.0
B.S.24	4.7	6.9	8.4	10.5	12.0	12.9	13.9	14.5
B.S.25	4.4	5.8	6.7	8.6	9.8	10.9	13.2	14.5
B.S.26	3.7	5.4	6.6	8.4	9.6	10.4	11.1	11.7
B.S.27	4.3	6.6	7.9	10.1	11.5	12.6	13.4	14.1

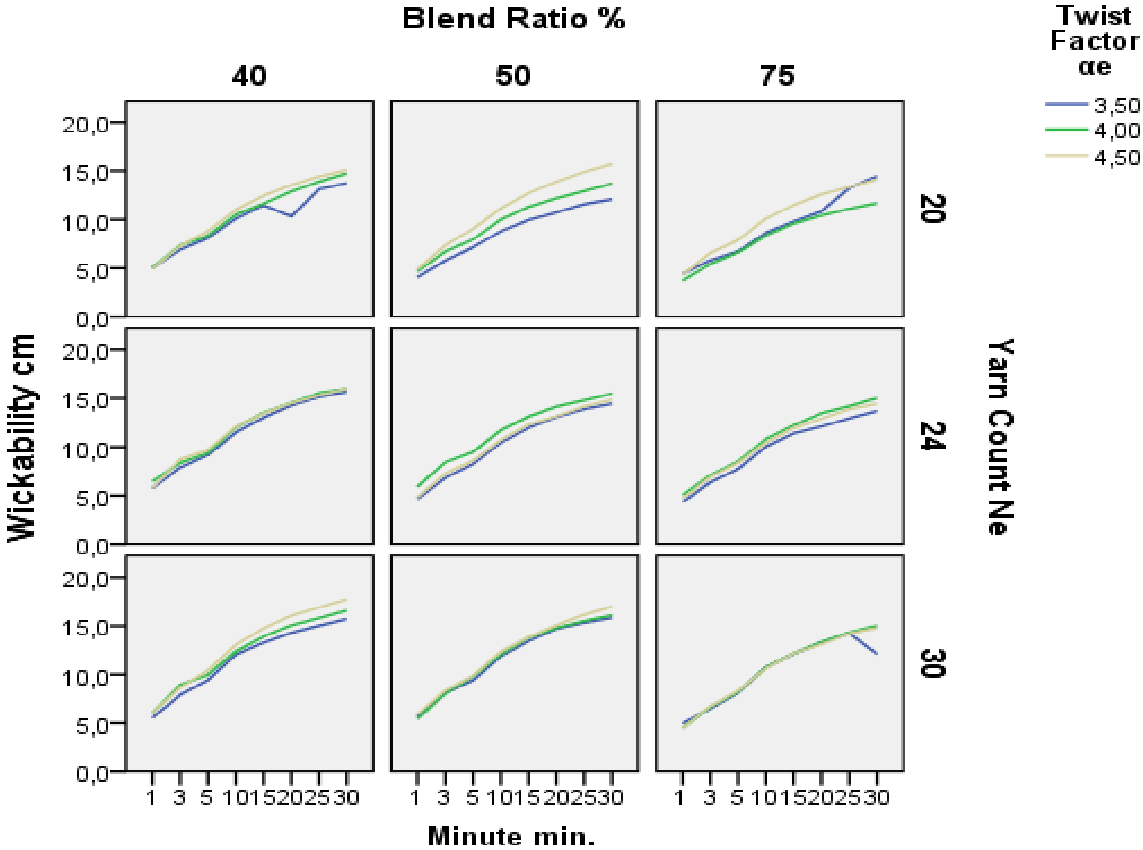


Figure 3.26 Wickability test results of bleached fabric samples

Although the rise speed (that can be analzed from the incline angles of the lines) are different from each other, it can be concluded from Figure 3.26 that all fabric samples have increasing trend from 1 minute to 30 minutes after falling into liquid tank. In order to achieve a statistical analysis, the wickablity values as liquid rising height at 10. minute was taken.

Table 3.31 Bleached fabric wickability ANNOVA result

Tests of Between-Subjects Effects					
Dependent Variable:	**Wickabiliy10**				
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	180.299[a]	28	6.439	30.968	0.000
Intercept	105.609	1	105.609	507.892	0.000
Packing Density	0.172	1	0.172	0.826	0.366
Acrylic Fiber Migration	0.033	1	0.033	0.161	0.689
Blend Ratio	24.522	2	12.261	58.964	**0.000**
Twist Factor	14.639	2	7.319	35.200	**0.000**
Yarn Count	82.883	2	41.441	**199.300**	**0.000**
Blend Ratio * Twist Factor	1.850	4	0.463	2.224	0.071
Blend Ratio * Yarn Count	3.113	4	0.778	3.743	0.007
Twist Factor * Yarn Count	11.295	4	2.824	13.580	0.000
Blend Ratio * Twist Factor * Yarn Count	5.831	8	0.729	3.505	0.001
Error	22.041	106	0.208		
Total	16237.330	135			
Corrected Total	202.340	134			
a. R Squared = 0.891 (Adjusted R Squared = 0.862)					

According to the results of analysis of variance (Table 3.31); yarn count (p= 0.000), twist factor (p= 0.000), blend ratio (p= 0.000) have statistically significant effect on wickability performance of bleached fabric samples in95% confidence interval. However, the acrylic fiber migration (p= 0.689) and yarn packing density (p= 0.366) parameters have no significant effect on wickability performance in 95% confidence interval. When F values are examined, it is seen that the yarn count parameter has the highest effect (F = 199.300) and the lowest effect is obtained with twist factor.

Table 3.32 Tukey test table showing the effect of blend ratio on wickability of bleached fabric

Blend Ratio %	N	Subset		
		1	2	3
75/25	360	10.021		
50/50	360		10.980	
40/60	360			11.532

Tukey test was applied to compare the wickability values of bleached fabric with regard toblend ratio groups (Table 3.32). According to the results of Tukey analysis, it is seen that there is a significant difference between the wickability values of three blend ratio groups; 40/60%, 50/50% and 75/25%. The highest wickability value was obtained with the blend ratio of 40/60%, while the lowest wickability was obtained in the blend ratio of 75/25%. In addition, as the ratio of cotton in the blend decreases, the wickability value bleached fabric increases. This result can be attributed to the fact that the yarn packing density increase as the cotton ratio increase. On the other hand, the yarn diameter decreases as the acrylic ratio increase. Since the wickability mechanism is based on the replacement of air gap and liquid, the lower yarn packing density and yarn diameter results to higher air gaps and higher wickability performance.

Table 3.33 Tukey test table showing the effect of twist factor on wickability of bleached fabric

Twist Factor α_e	N	Subset		
		1	2	3
3.50	360	10.382		
4.00	360		10.907	
4.50	360			11.244

Tukey comparison test was applied to determine the differences between twist factor groups (Table 3.33). According to the Tukey comparison, there is a significant difference between three of twist factor groups; α_e= 3.5 and α_e = 4 and α_e = 4.5. The lowest wickability value of bleached fabric was obtained in α_e= 3.5 twist factor, while the highest bleached fabric wickability was obtained in α_e=4.5 twist factor.

Also, it is seen that the wickability values increase as the twist factor increases. This result can be attributed to the fact that as the twist coefficient increases, the yarn diameter decreases. This yarn diameter decrease leads to higher fabric porosity and air pockets.

Table 3.34 Tukey test table showing the effect of yarn count on bleached fabric wickability

Yarn Count Ne	N	Subset		
		1	2	3
20	360	9.879		
24	360		11.050	
30	360			11.604

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.34). As seen from Table 3.34, there is a significant difference between each of yarn count groups. The lowest wickability values value was obtained in Ne 20/1 an the highest one is with Ne 30/1. Also, it is seen that the wickability values increase as the yarn count increases (as the yarn gets thinner). Since the working mechanism of wickability bases on the transform between air pockets and liquid, higher air volume in fabric structure provides higher wickability performance. So, it can be revealed that the higher yarn count with thinner yarn diameter provides higher spaces between the yarn loops and so higher air volume in fabric structure.

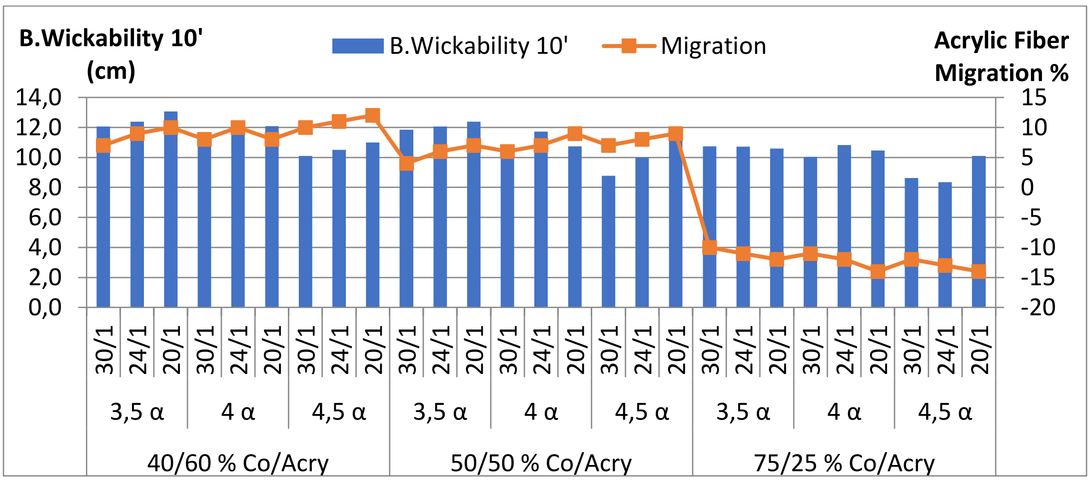


Figure 3.27 Relation between bleached wickability and fiber migration

The relationship between wickability and acrylic fiber migration was examined in Figure 3.27. The migration values and the wickability values have very close trends. In other words, fiber migration increases while wickability values increase. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value, but because of the change the direction of migration value.

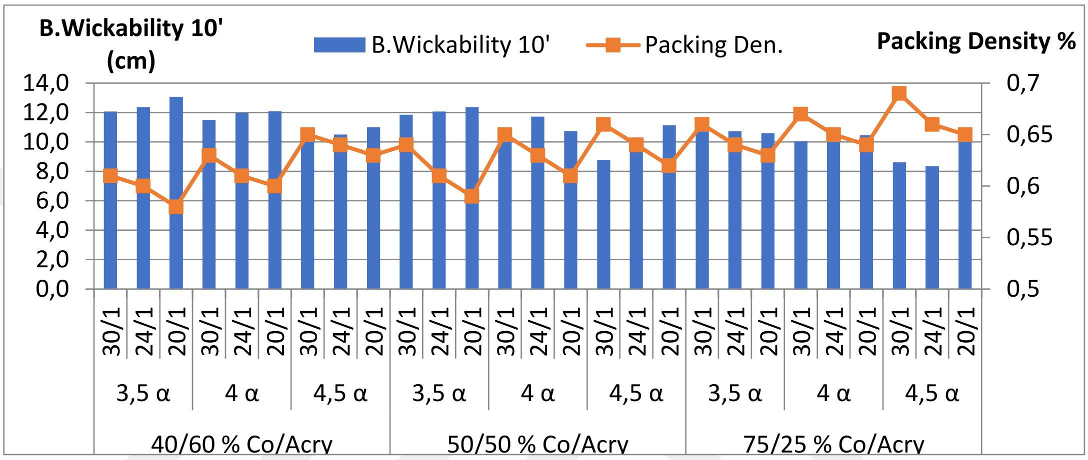


Figure 3.28 Relation between bleached wickability and packing density

The relationship between wickability and yarn packing density was examined in Figure 3.21. While the wickability values decreases, the yarn packing density value increases. There is a reverse relationship between packing density and wickablility. This result can be attributed to the fact that as the packaging density decreases, higher air spaces between fibers is provided and so higher capillarity is obtained due to the loose yarn structure.

3.3.4. Porosity

It was suggested that inter-yarn porosity hinge upon different structural features, such as fabric thickness, setting, weave type, yarn diameter, and yarn twist [15]. The permeability and porosity are exceedingly interrelated to each other. If a fabric has very high porosity, it can be supposed that it is permeable. A fabric with zero porosity can be supposed to have zero permeability in theory [33]. It was stated that the fabric weight and fabric thickness raised, it causes the fabric volume per area to raise which representing porosity [34].

Porosity values of the raw fabric samles are given in Table 3.35. The results are analyzed in accordance with independent parameters; yarn count, twist factor and blend ratio. As seen from Figure 3.29 the porosity of the fabric samples decreases as the yarn number becomes smaller. When the results are examined according to blend ratio, it can be observed that as the cotton ratio of yarn sample increases, the porosity ratio of the raw fabric samples decrease. Likewise, as the twist factor of the yarn samples increases in the sample fabrics, the porosity of the fabric samples decreases. The porosity decreasing effect of blend ratio can be explained with the effect of cotton content on yarn packing density and diameter. As investigated in (Table 3.11) and Table 3.6, when the cotton content of the blend yarn increases, the yarn diameter and packing density also increases. This means that the higher cotton fiber content brings both lower spaces within the yarn structure and between the yarn loops and so lower porosity values are obtained in fabric structure. Similarly, the effect of twist factor on fabric porosity can be attributed to the effect on yarn diameter (Table 3.7). The yarn diameter decreases as the twist factor increases. This effect provides higher spaces between the stitch loops and so higher porosity in fabric structure.

Table 3.35 Porosity values of raw fabric samples (%)

Porosity of Raw Fabric Samples %					
R.S.1	34%	**R.S.10**	29%	**R.S.19**	27%
R.S.2	37%	**R.S.11**	31%	**R.S.20**	30%
R.S.3	41%	**R.S.12**	35%	**R.S.21**	31%
R.S.4	36%	**R.S.13**	30%	**R.S.22**	28%
R.S.5	38%	**R.S.14**	32%	**R.S.23**	32%
R.S.6	43%	**R.S.15**	37%	**R.S.24**	34%
R.S.7	37%	**R.S.16**	32%	**R.S.25**	30%
R.S.8	40%	**R.S.17**	34%	**R.S.26**	33%
R.S.9	46%	**R.S.18**	38%	**R.S.27**	37%

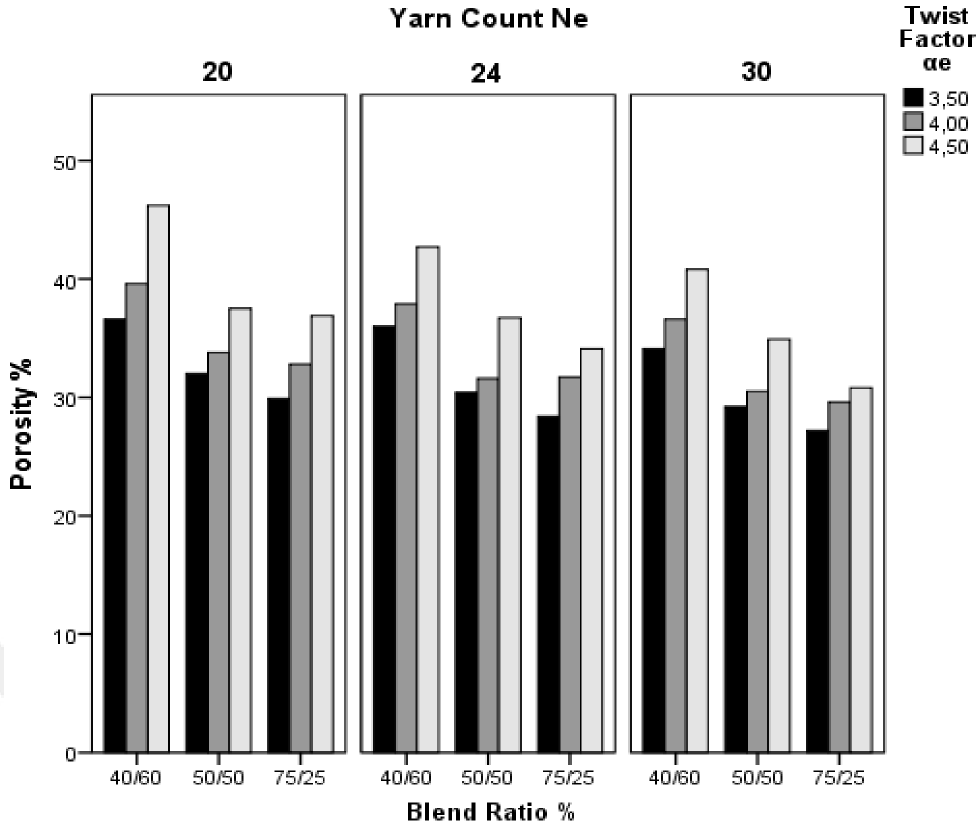


Figure 3.19 Porosity test results of raw fabric samples

According to the results of analysis of variance (Table 3.36); three of independent parameters; yarn count, twist factor, and blend ratio have significant effect ($p<0.05$) on porosity property of the raw fabric in 95% confidence interval. However, it is seen from Table 3.36 that the dependent yarn properties; acrylic migration and packing density have statistically no significant effect ($p>0.05$). When F values are examined, it is seen that the maximum effect is obtained with blend ratio ($F = 156.167$)

Table 3.36 Raw fabric porosity ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Raw_Porosity**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	4173.896[a]	28	149.068	20.407	0.000	0.703
Intercept	2815.789	1	2815.789	385.466	0.000	0.615
Packing_Density	0.024	1	0.024	0.003	0.954	0.000
M_Acrylic	5.414	1	5.414	0.741	0.390	0.003
Blend_Ratio	2281.559	2	1140.779	**156.167**	**0.000**	0.564
Twist_Factor	1025.450	2	512.725	70.189	**0.000**	0.368
Yarn_Count	75.701	2	37.850	5.182	**0.006**	0.041
Blend_Ratio * Twist_Factor	85.280	4	21.320	2.919	0.022	0.046
Blend_Ratio * Yarn_Count	119.218	4	29.805	4.080	0.003	0.063
Twist_Factor * Yarn_Count	1.362	4	0.340	.047	0.996	0.001
Blend_Ratio * Twist_Factor * Yarn_Count	87.702	8	10.963	1.501	0.158	0.047
Error	1760.478	241	7.305			
Total	317171.000	270				
Corrected Total	5934.374	269				
a. R Squared = 0.703 (Adjusted R Squared = 0.669)						

Table 3.37 Tukey test table showing the effect of blend ratio on raw fabric porosity

Blend Ratio %	**N**	**Subset**	
		1	**2**
75/25	90	31.41	
50/50	90	31.99	
40/60	90		38.46

According to Tukey comparison results (Table 3.37), there is a significant difference between the blend ratio of 40/60% and other two blend ratios 75/25%, and 50/50%.

It is seen that there is no difference between the raw fabric porosity values of the yarn samples with the blend ratio of 75/25%, and 50/50%. Although the porosity values of 75/25% and 50/50% blend ratios are close to each other, it can be said that the porosity of the raw fabric samples increase as the cotton content of the yarn samples increase. The lowest raw fabric porosity value was obtained in the blend ratio of 75/25%, while the highest raw fabric porosity value was obtained in the blend ratio of 40/60%.

Table 3.38 Tukey test table showing the effect of twist factor on raw fabric porosity

Twist Factor α_e	N	Subset		
		1	**2**	**3**
3.50	90	31.86		
4.00	90		33.41	
4.50	90			36.59

Tukey comparison test was applied to determine the differences between twist factor groups (Table3.38). According to Tukey table, there is a significant difference between the twist factors; α_e= 3.5, αe = 4 and α_e= 4.5. The lowest raw fabric porosity value was obtained in the α_e=4.5, while the highest raw fabric porosity was obtained in α_e=3.5. Also, it is seen that the raw fabric porosity values increase as the twist factor decreases. This situation is based on the effect of twist factor on yarn packing density and yarn diameter. As explained in Table 3.7 and Table 3.12, there is a reverse relationship between twist factor and yarn structural properties; diameter and yarn packing density. As the twist coefficient increases, the packing density and yarn diameter decrease. Because of the image processing method applied for porosity calculation, the porosity between the loop stitches is more prominent than the porosity within the yarn structure between fibers. So, the decrease in yarn diameter resulted to increase in fabric porosity.

Table 3.39 Tukey test table showing the effect of yarn count on raw fabric porosity

Yarn Count Ne	N	Subset	
		1	2
30	90	33.53	
24	90	33.62	
20	90		34.70

Tukey comparison test was applied to determine the differences between yarn count groups (Table 3.39). According to Tukey table, there is a significant difference between the raw fabric porosity values of the samples with the yarn count groups of Ne 30/1, Ne 24/1 and Ne 20/1. However, it is seen that there is no difference between the Ne 30/1 Ne and Ne 24/1. The lowest raw fabric porosity values value was obtained in Ne 30/1yarn count, while the highest raw fabric porosity values was obtained in the 20 Ne yarn count. Also, it is seen that the raw fabric porosity values increase as the yarn count decreases (as the yarn gets thicker).

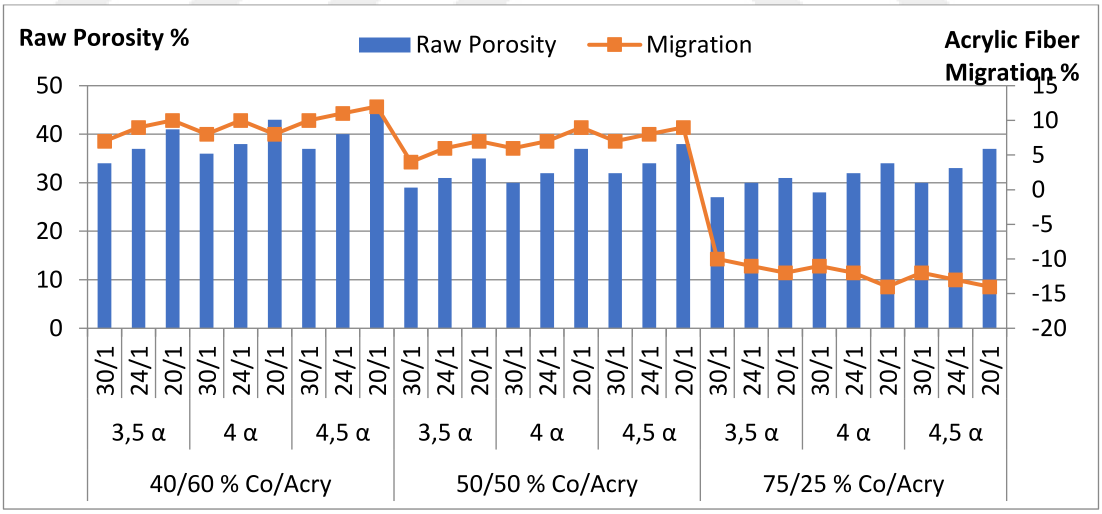


Figure 3.30 Relation between raw porosity and fiber migration

The relationship between raw fabric porosity and acrylic fiber migration was examined according to the Figure 3.30. The migration value and the raw fabric porosity generally progressed to the parallel of each other. In other words, fiber migration was increased while raw fabric porosity was increased. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value, but because of the change the direction of migration value.

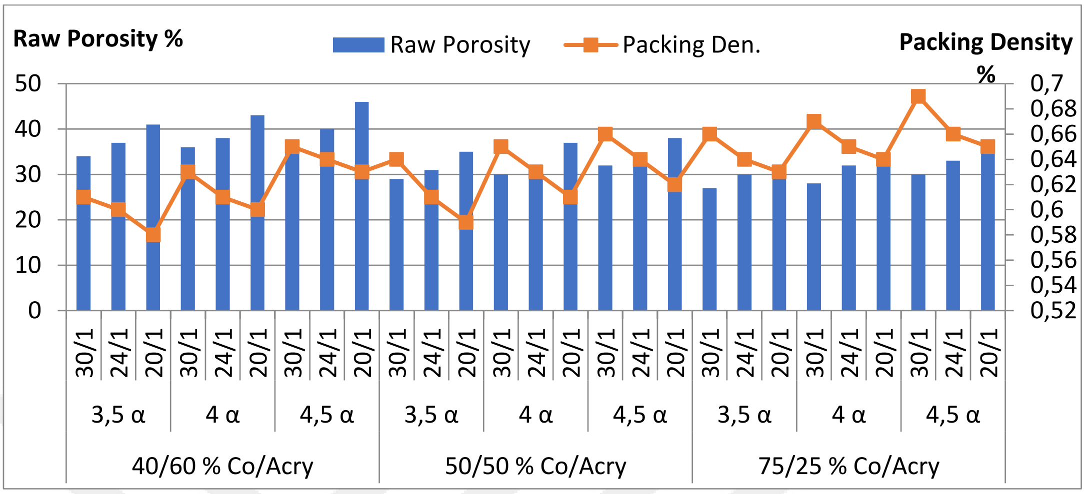


Figure 3.31 Relation between raw porosity and packing density

The relationship between raw fabric porosity and yarn packing density was examined according to the Figure 3.31. While the raw fabric porosity values were decreasing, the yarn packing density value increases at the same time. There is an opposite increase and decrease in general terms.

Table 3.40 Porosity values of bleached fabric samples (%)

Porosity of Bleached Fabric Samples %					
R.S.1	30%	**R.S.10**	29%	**R.S.19**	27%
R.S.2	31%	**R.S.11**	30%	**R.S.20**	28%
R.S.3	33%	**R.S.12**	32%	**R.S.21**	31%
R.S.4	28%	**R.S.13**	27%	**R.S.22**	25%
R.S.5	30%	**R.S.14**	29%	**R.S.23**	27%
R.S.6	31%	**R.S.15**	30%	**R.S.24**	29%
R.S.7	27%	**R.S.16**	25%	**R.S.25**	23%
R.S.8	28%	**R.S.17**	28%	**R.S.26**	25%
R.S.9	30%	**R.S.18**	29%	**R.S.27**	26%

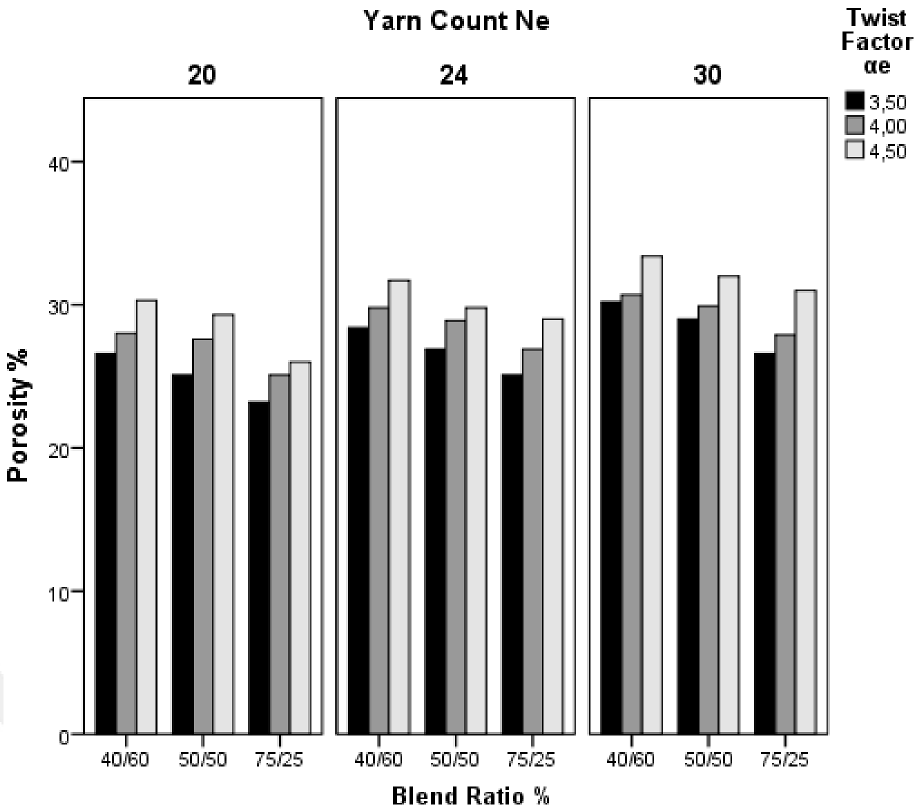


Figure 3.32 Porosity test results of bleached fabric samples

In Table 3.40 and Figure 3.32, porosity values of the bleached fabric samples are given. As shown in Figure 3.32 the porosity of the sample fabrics decreases as the yarn count gets smaller i.e. the yarn get courser. When it is investigated according to blend ratio, it is analyzed that as the cotton ratio of the fabric sample increases, it leads to decrease in porosity value. This result can be attributed to the effect of cotton content on packing density and yarn diameter. As the cotton ratio of the yarn samples increases, the packing density and the yarn diameter values increase. This effect results to lower spaces in fabric structure and so lower porosity values. According to the twist factor view, it is seen that as the twist factor increases, the fabric porosity also increases.

Table 3.41 Bleached fabric porosity ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Bleached Porosity**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	1013.832[a]	28	36.208	3.397	0.000	0.283
Intercept	2761.291	1	2761.291	259.067	0.000	0.518
Packing_Density	41.041	1	41.041	3.851	0.051	0.016
M_Acrylic	6.000	1	6.000	0.563	0.454	0.002
Blend_Ratio	167.154	2	83.577	7.841	**0.001**	0.061
Twist Factor	309.927	2	154.963	**14.539**	**0.000**	0.108
Yarn Count	62.590	2	31.295	2.936	0.055	0.024
Blend_Ratio * Twist_Factor	39.641	4	9.910	0.930	0.447	0.015
Blend_Ratio * Yarn_Count	212.293	4	53.073	4.979	0.001	0.076
Twist_Factor * Yarn_Count	4.630	4	1.157	0.109	0.979	0.002
Blend_Ratio * Twist_Factor * Yarn_Count	51.173	8	6.397	0.600	0.777	0.020
Error	2568.720	241	10.659			
Total	237607.000	270				
Corrected Total	3582.552	269				
a. R Squared = 0.283 (Adjusted R Squared = 0.200)						

In ANOVA, the effect of independent parameters; yarn count, twist factor and blend ratio and dependent parameters; fiber migration and yarn density are investigated statistically. According to the results of analysis of variance (Table 3.41); twist factor (p= 0.000) and blend ratio (p= 0.001) have statistically significant effect on fabric porosity values in 95% confidence interval. On the other hand, acrylic migration (p= 0.454), packing density (p= 0.051) and yarn count (p=0.055) have no significant effect on fabric porosity. When F values are examined, it is seen that the effect of twist factor (F = 14.539) is higher than blend ratio (F=7.841).

Table 3.42 Tukey test table showing the effect of blend ratio on bleached fabric porosity

Blend Ratio	N	Subset	
		1	2
75/25	90	28.43	
50/50	90	29.20	
40/60	90		30.69

Tukey test was applied to compare the bleached fabric porosity values of the blend ratio groups (Table 3.42). According to the results of Tukey analysis, it is seen that there is a significant difference between the values of 75/25%, 50/50% blend ratio samples and 40/60% blend ratio samples. However, it is seen that there is no difference between the the blend ratio of 75/25% and 50/50%. The lowest bleached fabric porosity value was obtained in the blend ratio of 75/25%, while the highest bleached fabric porosity value was obtained in the blend ratio of 40/60%. In addition, as the ratio of cotton in the blend increases, the porosity value of bleached fabric decreases.

Table 3.43 Tukey test table showing the effect of twist factor on bleached fabric porosity

Twist Factor αe	N	Subset		
		1	2	3
3.50	90	26.79		
4.00	90		28.31	
4.50	90			30.28

Tukey comparison test was applied to determine the differences between twist factor groups (Table 3.43). According to Tukey table, there is a significant difference between the three of twist factor groups; $\alpha e = 3.5$, $\alpha e = 4$ and $\alpha e = 4.5$. The lowest porosity value was obtained in $\alpha e=3.5$ and the highest porosity was obtained in $\alpha e=4.5$ twist factor. Also, it is seen that the bleached fabric porosity values increase as the twist factor decreases.

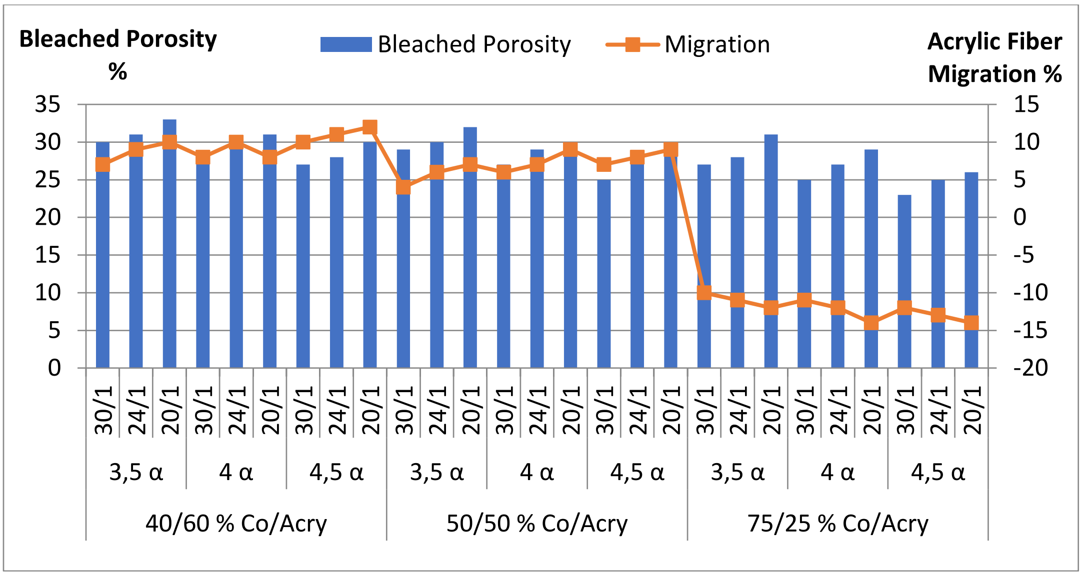


Figure 3.33 Relation between bleached porosity and fiber migration

The relationship between bleached fabric porosity and acrylic fiber migration was examined according to the Figure 3.33. The migration value and the bleached fabric porosity generally progressed to the parallel of each other. In other words, fiber migration was increased while bleached fabric porosity was increased. In addition, there is a decrease in the negative direction of migration between samples 18-27. The change here was not because of the decrease in the migration value, but because of the change the direction of migration value.

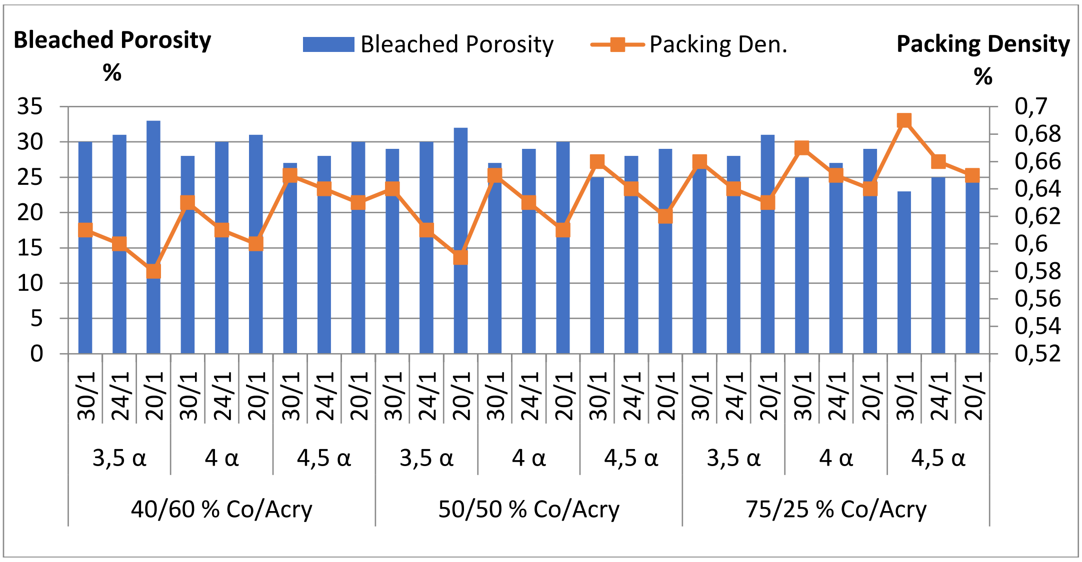


Figure 3.34 Relation between bleached porosity and packing density

The relationship between bleached fabric porosity and yarn packing density was examined according to the Figure 3.34. While the bleached fabric porosity values were increasing, the yarn packing density value decreases at the same time. There is an opposite increase and decrease in general terms.

CHAPTER 4

CONCLUSION

4. CONCLUSION

In this thesis, the effect of yarn physical parameters; cotton/acrylic fiber blend ratio, twist factor and yarn count on yarn fiber distribution property; fiber migration, packing density and yarn diameter were investigated. The effect of above-mentioned yarn parameters and fiber distribution properties on fabric permeability and transmission performances; air permeability, water vapor permeability and wickability were also analyzed. The discussions on all findings of the study were presented in two parts such as yarn properties and fabric properties.

<u>Discussions on Yarn Properties</u>

Fiber Migration;

- Acrylic fibers are distributed to outward of the yarn cross-section except 75/25% cotton/acrylic yarn samples. It is seen that when the cotton fiber occupies the very great proportion of yarn cross-section, the acrylic fibers are oriented toward the yarn core and so they have the minus migration index values for 75-25% cotton / acrylic blend ratio.
- According to ANOVA results, it is determined that only the blend ratio has significant effect on fiber migration property. The migration index values are near to each other for all three blend ratios. It was revealed that the highest and lowest migration index values are obtained with 75/25% and 50/50% cotton/acrylic blend ratios respectively.
- There is no general trend for twist factor and yarn count. As the amount of cotton in the blend ratio was increased, acrylic fibers were showed a tendency towards the core.

Yarn Diameter;

- In accordance with the statistical analysis, it was revealed that three of yarn independent parameters; blend ratio, twist factor and yarn count have significant effect on yarn diameter. The highest effect comes from the yarn count parameter.
- It was observed that as the ratio of cotton content in the yarn constituent fibers increases the yarn diameter value also increases.
- It was revealed that that the yarn diameter values decrease as the twist factor increases. This result was attributed to the fact that higher twist coefficient causes higher radial force effect on the yarn structure and so the diameter of the yarn gets thinner.
- As expected from the spinning process and yarn physical structure, the yarn diameter decreases with the increase in yarn count. The most effective parameter on the yarn diameter value was the yarn number.

Packing Density;

- From the statistical analysis, it was determined that yarn count, twist factor and blend ratio have significant effect on packing density.
- It was seen that as the cotton ratio increases, the yarn packing density value also increases.
- The yarn packing density value increased as the twist factor increased. The higher twist factor leads to higher packing density. This result was attributed to the increasing twist radial force.
- As the yarn count increased (as the yarn count becomes thinner) packing density decreases. In other words, when the yarn gets courser, the number of fibers in unit area increase and so the packing density increase.
- The most effective parameter on the yarn packing density value was the blend ratio.

Discussions on Fabric Properties

Air Permeability;

- According to variance analysis, it was revealed that all of yarn independent parameters; yarn count, twist factor and blend ratio have significant effect on air permeability performance of both raw and bleached fabrics.
- The air permeability of the raw and bleached fabric samples increases with the decrease in yarn cotton content. This result was explained with the diminishing effects of cotton content to yarn diameter and packing density.
- It was determined that the air permeability values of both raw and bleached fabrics increase as the twist factor increases. This result was explained with the effect of twist factor on yarn diameter. As the yarn twist factor increases, the yarn diameter decreases and so the air gapes between the yarns increases.
- Since all fabric samples were produced with constant stitch density, it was seen that both the raw and bleached fabric air permeability values increase as the yarn count increases (as the yarn gets thinner).
- The most effective parameter on air permeability performance of raw and bleached fabrics was as yarn count.
- According to ANOVA results, the fiber migration and packing density parameters have no significant effect on fabric air permeability performance. However, the air permeability and fiber migration trends are compared, it was seen that there is a reverse proportion between the migration value and the air permeability. It means that as the fiber migration increases, the air permeability of both raw and bleached fabrics decrease.

Water Vapor Permeability;

- The fiber blend ratio, yarn count and twist factor parameters have no significant effect on raw fabric water vapor permeability performance.
- When the statistical analysis of the bleached fabric water vapor permeability was investigated, it was obtained that the blend ratio and yarn count have significant effect on water vapor permeability performance. On the other hand, twist factor, fiber migration and packing density properties have no significant effect.

- It was revealed that the effects of blend ratio (F = 6,841) and yarn count (F=6.127) are close to each other.
- When the fiber migration and water vapor permeability results are compared, it was observed that general trend of acrylic fiber migration index was similar to that of water vapor permeability values of the bleached fabric
- Similarly, it was seen that general trends of both two parameters; WVP and acrylic fiber migration were very close to each other.

Wickability;

- The raw fabric wickability could not be performed. Since the cotton fibers in the blend were not bleached in raw fabrics, the fabric was not having any hydrophilic effect and no capillary effect was created on this occasion.
- The bleached fabric wickability value increased as the acrylic fiber content increased in the blend. This result was attributed to the fact that the yarn packing density and so air pockets increase as the cotton ratio decrease.
- As the twist factor increased, the wickability performance also increased.
- It was revealed that the higher yarn count with thinner yarn diameter provides higher spaces between the yarn loops and so higher air volume in fabric structure. Thus, the wickability performance increased, as the yarn count increased (the yarn became thinner).
- The most effective parameter on the bleached fabric wickability value was the yarn count.
- The migration values and the wickability values have very close trends.
- There was a reverse relationship between packing density and wickablility.

Porosity;

- It was determined that three of independent parameters; yarn count, twist factor, blend ratio have significant effect on porosity of raw fabrics. However, only the twist factor and blend ratio have significant effect on porosity of bleached fabrics.
- Both raw and bleached fabric porosity values increased as the acrylic fiber content increased in the blend.

- As the twist factor decreased and the porosity value of the raw and bleached fabric increased.
- It was seen that the raw fabric porosity values increased as the yarn count decreased (as the yarn got thicker).
- The most effective parameter on the raw fabric porosity value was the blend ratio.
- The most effective parameter on the bleached fabric porosity value was the twist factor.

The effects of independent variables; yarn count, twist factor and blend ratio on the yarn structural properties; packing density, fiber migration and diameter are summarized in Table 4.1. The effects of fiber migration and packing density beside independent variables on fabric thermal comfort performances are summarized in the Table 4.2.

Table 4.1 Summary of yarn analysis results

Material	Test Method	Blend Ratio	Yarn Count	Twist Factor
Yarn	Fiber Migration	✓	✓	✓
	Yarn Diameter (mm)	✓	✓	✓
	Packing Density (%)	✓	✓	✓

Table 4.2 Summary of fabric analysis results

Material	Test Method	Blend Ratio	Yarn Count	Twist Factor	Fiber Migration	Packing Density
Fabric	Raw Air Perm.	✓	✓	✓	✘	✘
	Bleached Air Perm.	✓	✓	✓	✘	✘
	Raw WVP	✘	✘	✘	✘	✘
	Bleached WVP	✓	✓	✘	✘	✘
	Raw Wickability	✘	✘	✘	✘	✘
	Bleached Wickability	✓	✓	✓	✘	✘
	Raw Porosity	✓	✓	✓	✘	✘
	Bleached Porosity	✓	✘	✓	✘	✘

5. FURTHER WORK

At further work, there are recommendations for the study with obtained parts and works to be done in future. A number of difficulties were experienced during the tests that are all given in the following.

- In the study, fiber migration index values were measured manually. An image processing-based algorithm can be developed to measure the fiber migration index more easily and automatically.
- In different blends such as cotton-polyester, peeling and abrasion can be observed and the migration and packaging properties of different blends can be compared.
- In order to obtain a reliable correlation between porosity and air permeability, a novel porosity measurement method under the low mechanical stress and that simulates the air pressure effect can be developed.
- By applying artificial intelligence method, a robust model can be built to predict the yarn packing density and fiber migration index.
- The effect of yarn spinning method, fabric formation process and finishing process on fiber migration index and yarn packing density can be investigated by analyzing the yarn cross-section view after each process.

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