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Polyester Microfilament Woven Fabrics

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1. Introduction

Synthetic fiber industry has been enforced to make developments due to the increasing performance demand for textile products. One of the most important developments in synthetic fiber industry, is absolutely producing extremely fine fibers which are named as microfibers and nanofibers (Kaynak & Babaarslan, 2010). Until today, there is no exact definition for microfibers. But common opinion is defining a fiber finer than 1 dtex or 1 denier as microfiber (Leadbetter & Dervan, 1992; Bianchi & Maglione, 1993; Purane & Panigrahi, 2007; Basu, 2001; Mukhopadhyay, 2002; Falkai, 1991; Rupp & Yonenaga, 2000). 1 dtex polyester fiber has a fiber diameter of approximately 10 µm (Falkai, 1991). On the other hand, nanotechnology refers to the science and engineering concerning materials, structures and devices which at least one of the dimensions is 100 nanometers (0.1 µm) or less (Ramakrishna, et al., 2005).

Fabrics produced from microfilaments are superior to conventional fiber fabrics, due to their properties such as light weight, durability, waterproofness, windproofness, breathability and drapeability. Tightly woven fabrics produced from microfilament yarns have a very compact structure due to small pore dimensions between the fibers inside the yarns and between yarns themselves. These fabrics provide very good resistance against wind for different end uses such as parachutes, sails, wind-proof clothes, tents while serving light weight and high durability properties (Babaarslan & Kaynak, 2011). Wind resistance is usually assessed by measuring air permeability. This is the rate of air flow per unit area of fabric at a standard pressure difference across the faces of the fabric (Horrocks & Anand, 2004). Airflow through textiles is mainly affected by the pore characteristics of fabrics. The pore dimension and distribution in a fabric is a function of fabric geometry (Bivainyte & Mikucioniene, 2011). So, for woven fabrics, number of yarns per unit area, yarn linear density, weave type, fabric weight and fabric thickness are the main fabric parameters that affect air permeability (Fatahi & Yazdi, 2010; Çay & Tarakçıoğlu, 2007; Çay & Tarakçıoğlu, 2008; Turan & Okur, 2010). On the other hand, considering the yarn structure; yarn production technology, yarn diameter, yarn twist, hairiness, being staple or filament yarn, fiber fineness, fiber cross-section and yarn packing density are also important parameters (Turan & Okur, 2010). The pores of a fabric can be classified as pores between the fibers inside the yarns and between yarns themselves. The dimensions of the pores between the yarns are directly affected by the yarn density and yarn thickness. By increasing of the yarn density, the dimensions of the pores become smaller, thus the air permeability decreases.

The dimensions of pores between the fibers inside the yarns (micro voids) are generally affected by fiber fineness, yarn count, yarn twist and crimp and also the deformation and flattening of the yarns (Çay & Tarakçıoğlu, 2008).

In an earlier study (Varshney et al., 2010), the effect of filament fineness on air permeability of polyester and polyester/viscose woven fabrics was observed. It was seen that decreasing filament fineness has a decreasing effect on air permeability. An another study, (Laourine & Cherif, 2011) was performed on the effect of filament fineness and weave type on air permeability of polyester woven fabrics for surgical protective textiles. The study showed that air permeability can be reduced by decreasing the filament fineness. Also, for woven fabrics with nearly same degree of cover factor, lower levels of air permeability can be reached with plain weaves than those of twill weaves. Kaynak & Babaarslan (2011), investigated the filament fineness on polyester woven fabrics for plain weave. As a result of this study, lower air permeability values were obtained by decreasing the filament fineness. The present study investigates the effects of filament fineness, weft sett and weave type on air permeability of polyester microfilament woven fabrics in a more detailed manner, aiming to determine the proper construction parameters of fabric. In addition regression analyses were conducted to estimate the air permeability before production.

2. General properties of microfibers

Potentially, any man-made fiber could be made into a microfiber (Smith, n.d.). Microfibers are most commonly found in polyester and nylon (Smith, n.d.; Purane & Panigrahi, 2007; Anonymous, 2000). Trevira Finesse, Fortrel Microspun, DuPont Micromattique and Shingosen are all trade names for various polyester microfibers, whereas Supplex Microfibre, Tactel Micro and Silky Touch are some of the trade names for nylon microfibers (Mukhopadhyay & Ramakrishnan, 2008). Nylon is claimed to have advantages over polyester in having a better cover, plus lower density, higher strength and abrasion resistance. Polyester is easier to spin and is available in finer filaments than nylon. Polyester raised fabrics are easier to produce. This has given polyester an economic advantage in apparel and sportswear markets (Anonymous, 2000). However, micro-denier versions of rayon, acrylic and polypropylene products are available to consumers (Purane & Panigrahi, 2007; Smith, 2011; Anonymous, 2000). Microfibers can be used alone or blended with conventional denier man-made fibers as well as with natural fibers such as cotton, wool, viscose and silk (Smith, n.d.; Anonymous, 2000). This enhances the appearance, hand, drape and performance properties of the fabrics (Basu, 2001).

Ultra-fine fibers were produced in the late 1950s which were not of continuous filament type but were fine staple fibers of random length and found no application except for being processed into nonwoven sheets immediately after spinning. In 1961 a petal-shaped ultra fine filament type fiber described in a patent was probably the first example of a potential ultra-fine filament. Another patent issued simultaneously described splitting two component conjugate fibers of non-circular cross section into the two separate components after weaving. No attention was paid at that time for combining these technologies to produce ultra-fine fibers (Okamoto, 2000). The first microfibers were invented in the mid sixties by Dr. Miyoshi Okamoto, a chemist in the Toray industries textile research laboratory. In the beginning, the single fine man-made fibers found scarcely any appropriate application. The breakthrough came with the success of imitation game leather (Rupp &

Yonenaga, 2000). This was the first attempt to produce an ultra fine fiber intentionally. Matsui et al. of Kanebo also tried multi layer conjugate spinning in 1968 for the production of ultra fine filaments. Since no application of ultra-fine fibers was foreseen in the 1960s, there had been no technical or commercial interest in them until Toray put the new suede-like material on the market in 1970 (Okamoto, 2000).

Microfibers are being increasingly used throughout the world for various end uses due to their fineness, high performance characteristics and their unique ability to be engineered for a specific requirement (Anonymous, 2000). Fundamental characteristics of microfibers are as follows;

- Since bending and torsional stiffness are inversely proportional to fiber diameter, ultrafine fibers are extremely flexible (Okamoto, 1993) and for the same reason microfiber yarns impart excellent drapeability to the fabric (Basu, 2001; Purane & Panigrahi, 2007; Rupp & Yonenaga, 2000)
- Yarn strength is high due to the high number of fiber per cross sectional area (Basu, 2001). Microfiber fabrics are also relatively strong and durable in relation to other fabrics of similar weight (Purane & Panigrahi, 2007).
- The yarns made from micro denier fiber contain many more filaments than regular yarns producing fabrics with water tightness and windproofness but improved breathability (Basu, 2001).
- More filaments in yarn result in more surface area. This can make printed fabrics more clear and sharp as compared to normal fabrics (Basu, 2001). Greater fiber surface area results making deeper, richer and brighter colors possible (Smith, n.d.).
- Microfiber fabrics are very soft and have a luxurious hand with a silken or suede touch (Rupp & Yonenaga, 2000; Purane & Panigrahi, 2007).
- Microfibers have a quick stress relief so microfiber fabrics resist wrinkling and retain shape (Purane & Panigrahi, 2007; Okamoto, 2000).
- Microfiber fabrics are washable and dry-cleanable
- Microfiber fabrics insulate well against wind, rain and cold and also they are more breathable and more comfortable to wear
- Microfibers are super-absorbent, absorbing over 7 times their weight in water
- Microfiber dries in one-third of the time of ordinary fibers (Purane & Panigrahi, 2007).
- A large ratio of length to diameter resulting in easy entanglement
- Good interpenetrating capacity to other materials
- Bio-singularity to living tissues and fluids (Okamoto, 2000).

One caution related to synthetic microfibers is heat sensitivity. Because the fiber strands are so fine, heat penetrates more quickly than thicker conventional fibers. So, microfiber fabrics are vulnerable to damage from careless ironing. They will scorch or glaze if too much heat is applied for a too long period (Smith, n.d.; East, 2005).

They also have a tendency to snag easily and, as with all fine fabrics, they need to be handled with care. Jewelry cause pulls, snags or general abrasion to garments (Smith, n.d.; East, 2005).

Since microfibers have an increased surface area, resulting in a dyeing rate four times higher than that of normal which can cause unlevelness in dyeing. They require more dyestuff than

normal fibers to attain a given shade depth (Jerg & Baumann, 1990; Anonymous, 2000; Falkai, 1991).

3. Production of microfibers

There are various methods of producing microfibers. All three conventional spinning methods, namely melt spinning, wet spinning, and dry spinning can be employed to manufacture microfibers (Purane & Panigrahi, 2007). Although, it is possible to produce microfibers through conventional melt spinning, to create such fine filaments requires very strict process controls and a uniformly high quality of polymer (Tortora & Collier, 1997).

Ultra-fine fibers are classified into two types: filament type, and staple type. Recent developments in the field of ultra-fine fibers have focused on the filament type (Okamoto, 2000).

Ultra fine fiber of the filament type is produced by the methods including:

1. Direct spinning (conventional extrusion)
2. Conjugate spinning
   a. Islands in a sea type
   b. Separation or splitting type
   c. Multi-layer type (Okamoto, 2000).

3.1 Production of filament type microfibers

3.1.1 Direct spinning

In this method microfiber is directly manufactured by melt spinning (Purane & Panigrahi, 2007). With this method, the fineness of the microfibers produced is limited to 0.1 dtex because of the tendency of the individual filaments to stick together. Improvements in processing conditions and finishing, such as more accurate spinnerets and strictly controlled cooling conditions after extrusion, together with lower polymer viscosity, can however make the production of microfiber yarns possible (Rupp & Yonenaga, 2000).

3.1.2 Conjugate spinning

The technical problems in direct spinning can be solved by conjugate spinning, which yields homogenous ultra-fine fibers. Okamoto et al. and Matsui et al. investigated the extrusion of conjugate fibers with a cross section consisting of highly dispersed conjugate components by modifying the spinneret structure. Conjugate spinning is classified into two types from technical viewpoint: the islands in a sea type and separation or splitting type. In either case, the microfiberization is performed in the form of fabrics. No special technical problems arise in later processing, compared with conventional spinning (Okamoto, 2000).

3.1.2.1 Islands in a sea type

In islands in a sea method, a number of continuous very fine filaments are extruded in a matrix of another polymer. In the spinneret a number of bi-component sheath-core polymer flows are combined into a single flow and extruded. The islands in the sea fiber is then quenched and drawn in the usual way (Richards, 2005). Polyester, nylon, polypropylene,

polyethylene and polyphenylene sulfide are the polymers employed as island components (Okamoto, 2000). The various combinations of polymers to form fibers by this method successfully are polystyrene/polyamide and polystyrene/polyester (Purane & Panigrahi, 2007). The sea component is removed by dissolving it in a solvent after conventional processing into woven, knitted or nonwoven fabrics. This technology provided a means of industrial production of suede type artificial leather, silk like fabrics, wiping cloths and fine filters. Since the ultra fine filaments (the island component) are sheathed by the sea component, they are protected from damage during later processing (Okamoto, 2000).

Three component spinning can be carried out with two island components by designing a three component spinneret assembly. The sea component can be reduced to 2-10% of the total components, but the space between the ultra fine filaments is also reduced and this may lead to poorer handle of the products. When the sea component is small in amount and not miscible with the island component, the splitting can be carried our mechanically (Okamoto, 2000).

3.1.2.2 Separation or splitting type

This type of spinning aims to utilize the second component in the final product by splitting the two components instead of removing the second component by dissolving. The ultra fine fiberization is performed by a mechanical or chemical process in the splitting and separation types of spinning (Okamoto, 2000). This method of microfiber production involves extruding a bicomponent fiber which two polymers with poor adhesion to each other are used (Richards, 2005). Applications of these fibers are suede for clothing and upholstery, silk like fabrics, wiping cloths, wall coverings, automobile trims, golf gloves and moisture-permeable and water-repellent fabrics (Okamoto, 2000; Richards, 2005). In this method the overall shape of the fiber determines the ease of splitting. If the components are in a radial configuration then splitting is more difficult than if one polymer is located at the ends of the lobes in a multilobal shape (Richards, 2005). Suitable polymer combinations for splittable bi-component filament spinning are polyamide/polyester and polyester/polyolefin (Purane & Panigrahi, 2007).

3.1.2.3 Multi-layer type

Two components are spun into a conjugate fiber of multilayered structure with an oval-shaped cross section, which is microfiberized into filaments of 0.2-0.3 denier (Okamoto, 2000).

3.2 Production of staple type microfibers

Ultra fine fiber of the staple type is produced by the methods including:

1. Melt blowing or jet spinning
2. Flash spinning
3. Polymer-blend spinning
4. Centrifugal spinning
5. Fibrillation
6. Turbulent flow-moulding
7. Bursting (Okamoto, 2000).

3.2.1 Melt blowing or jet spinning

This method is employed for the production of nonwoven fabrics of polypropylene ultra fine fibers. The polymer melt is blown apart immediately after extrusion by an air jet stream in this method, so it is sometimes termed "jet spinning". Thus, this method is an application of spraying technology rather than true spinning (Okamoto, 2000). It finds applications in an increasing number of fields, such as filtration, absorbency, hygiene and apparel (Mukhopadhyay & Ramakrishnan, 2008).

3.2.2 Flash spinning

The polymer is dissolved in transparent solutions at high temperature under high pressure. The spinning solution is jetted out of a nozzle into the air to form a fibrous network. A fiber network is obtained by spreading a single stream of fiber spun from one spinneret hole. The filament thickness varies from 0.01 denier to 10 denier (Okamoto, 2000).

3.2.3 Polymer blend spinning

In this method the conjugate fiber is produced by extruding and drawing a blended polymer melt of two components. The fiber fineness can not be controlled and the fiber often breaks during spinning, although the spinning stability is strongly dependent on the combination of polymers. Since the dispersed polymer phase is drawn to yield ultra-fine fibers, no filament type of ultra fine fiber is produced at present by polymer blend spinning (Okamoto, 2000).

4. Applications of microfibers

At the start of the development, the researchers searched intensively for suitable fields of application for their microfibers, since they had not yet existed in previous clothing and technical textile concepts (Rupp & Yonenaga, 2000). Microfibers offer a great variety of applications in fashion clothing owing to their extra softness, full handle, drape, comfort and easy care properties (Anonymous, 2000). One general point that should be mentioned is that the desired properties (i.e. sophisticated handle, pleasant silky appearance, leather look-alike, good filtration properties, etc.) are only obtained when a suitable fabric construction is produced. As well as fineness, the material combination, cross-section of the elementary filaments and their effect when used in combinations are extremely important and can offset negative parameters (i.e. proneness to creasing, somewhat lower absolute tenacity) (Falkai, 1991). Items of polyester microfibers, both 100 percent polyester and blends with other fibers, include coats, suits, blouses, dresses, wall coverings, upholstery, sleeping bags, tents, filters and toweling (Kadolph et al., 1993).

4.1 Protection against the weather

Woven fabrics for protection against the weather were previously coated with polyvinyl chloride in most cases (Rupp & Yonenaga, 2000). But today, closely woven microfilament fabrics offer a new era for protection against weather. As the number of filaments in a yarn of given linear density increases, then the surface area of all the fibers increases and, in a fabric of close construction, the gaps between the fibers become smaller (Richards, 2005).

They are only very tiny gaps for air to blow through. So, closely woven fabrics are constructed from microfilament yarn which results in small size of gaps to give maximum protection against wind and rain. The use of microfibers ensures that gaps in the fabric are very small even when dry (Mukhopadhyay & Midha, 2008; East, 2005). Moreover, the fabric and fiber surface is enlarged; therefore moisture is transported via more channels, since a better capillary effect is achieved (Rupp & Yonenaga, 2000). This type of weaving results in a windproof fabric with an excellent water vapor permeability compared with laminates and coatings (Mukhopadhyay & Midha, 2008).

Tightly woven microfilament fabrics exhibit an exceptional property of obstructing water droplets from penetrating. Liquid water is prevented by surface tension from penetrating the fabric, which will have a degree of water repellency (Richards, 2005; East, 2005; Anonymous, 2000). These fabrics exhibit an exceptional property of obstructing water droplets from penetrating while allowing water vapor to escape resulting in increased comfort (Anonymous, 2000; Falkai, 1991; Rupp & Yonenaga, 2000). Microfilaments make it possible to structure fabrics so that they repel wind and rain without loosing their textile character. In this respect the low water absorption of polyester plays a part (Basu, 2001). Functionality of densely woven microfilament fabrics with respect to waterproofness and windproofness can be reinforced by hot calendering (Rupp & Yonenaga, 2000). Their improved water impermeability and lower air permeability make microfiber fabrics highly suitable for waterproof and windproof application area such as sportswear, rain clothes, and tents.

4.2 Clothing

Microfibers are used in a variety of fabrics, but most commonly in dress and blouse weight garments. Suit jackets and bottom weights are becoming available. (Smith, n.d.). As the color, appearance resembles silk, these fabrics can be used for blouses, dresses, tailored suits, hosiery and evening wear (Basu, 2001). Fabrics produced with microfiber yarns are consequently softer and drape better than those made with normal fiber yarns. Even if tightly woven, microfiber yarns have a low weight per unit area and are not stiff. Polyester microfibers can be used to create fashionable women's outerwear fabrics with a new hand and smooth drape (Jerg & Baumann, 1990).

4.3 Synthetic game leather

Synthetic game leather and leather products are today produced industrially in Japan by impregnating nonwovens produced from PET, PA, PAN microfibers with polyurethane. These products offer outstanding advantages as against natural leather and game leather in terms of uniformity, dimensional stability, ease of care, color fastness and low mass (Rupp & Yonenaga, 2000). Microfiber suede fabrics are used in upholstery due to their elegant look, comfortable feel and easy care and clean properties.

4.4 Filtration

Owing to their fine, compact structure, microfiber textiles offer excellent filtration effects for both air and fluid filtration. Ultra-fine microfiber products such as 0.05 dtex PP microfiber nonwovens, in combination with a high electrical voltage, which will provide permanent

polarization to the nonwoven, attract and absorb charged dust particles. Microfiber textiles can produce excellent filtration effects in the process of filtering solid or liquid materials. Microfiber liquid filters offer; high water passage speed, high extraction performance and ease of cleaning micro-particles from the filter (Rupp & Yonenaga, 2000). The extremely fine diameter of splittable synthetic microfibers makes them suitable for filter applications by increasing the filtration performance. The splittable microfibers are more suited as flex-resistant materials. In pulsing applications where the filter medium is continuously flexed but also requires stiffness, splittable synthetic fibers add a high degree of reinforcement to the filter medium. Because there are at least 16 times the numbers of fibers available for reinforcement when they are split for segmented fibers (Mukhopadhyay & Ramakrishnan, 2008).

4.5 Microfibers for cleaning

The microfiber fabric can be used for producing cleaning cloths. Most of the stick dirt is caused by dust accumulating on thin layers of fat which merely spreads and barely touched by conventional wiping cloths. This is because the fiber of these wiping cloths is normally 10 mm thick and is unable to capture 1 µm thick oil layers (Basu, 2001). Unlike ordinary cleaning fabrics that move or push dirt and dust from one place to another, the microfilaments can penetrate into the thin fatty layer of dirt and trap it within the micropockets among the filaments and then store the dirt particles in the fabric until it is washed. They are perfect for asthma and allergy sufferers, as they remove dust and dust mites without chemicals. They are also excellent at removing fingerprints from any surface. Grease, tar, splattered bugs come off with the cleaning cloth (Purane & Panigrahi, 2007). The cleaning properties of the microfibers are further enhanced because they have a cationic (positive) charge due to the presence of the polyamide in the microfibers. Most dirt and dust particles, bacteria, pollen, oxidation on metals, etc., have an anionic (negative) charge. Thus, the microfibers naturally attract negatively charged particles, bacteria, etc. (Mukhopadhyay & Ramakrishnan, 2008). The dirt trapped in the micropockets can be removed by washing. These wiping cloths are used for cleaning car mirrors, computers, jewels and noble metals, fingerprints from photos and films (Basu, 2001). Microfiber cleaning towels are used for cleaning floors, windows, furnishings and interior and exterior of cars.

4.6 Medical applications

When compared to commonly textiles to microfiber nonwovens, they are lower in cost, easier to use, more versatile, safer, and features of better disposability. With this in mind, it is no wonder that microfiber nonwovens are found in hospital surgical drapes and gowns, protective face masks, gloves, surgical packs, and bedding (Purane & Panigrahi, 2007). Fabrics from microfibers have excellent breathability and have been used for wound care. Polypropylene microfiber spunbonds have application in wound-care, where they are used as hydrophobic backings. At the same time, the air permeability and breathability of these nonwovens promote healing and their softness and flexibility allow excellent adaptation to the skin. In addition, polypropylene microfiber spunbonds have potential application in disposable surgical gowns and masks where spunlaced fabrics are widely used. The barrier properties of these spunbonds are more than 25% better than the spunlaced fabrics at about half their weight. Their softness, high permeability and breathability guarantee a high level

of comfort in wearing when used as surgical gowns and for application as surgical face masks (Mukhopadhyay & Ramakrishnan, 2008).

The biocompatibility of microfibers offers great potential and manifold possibilities of use in the medical field. Microfiber filter produced from melt blown polyester are sold to hospitals for use in blood transfusion and blood donation. Polyester microfibers are very compatible with human organs and have proved themselves in use of vascular prothesis (Rupp & Yonenaga, 2000).

4.7 Construction applications

Polypropylene and bi-component microfibers can be very important components of fiber-reinforced composites, as they function not only as a reinforcing element, but also as a binder fiber between the individual layers. Polypropylene and bi-component microfibers are used in many different composite products: Microfiber reinforced concrete (to reinforce and prevent cracks), insulation material (to avoid the use of chemical binders), multifunctional liquid transport media (acquisition and distribution layers), woven fabrics (as a dimensional stability network), and laminated products (lamination between textiles and boards) (Purane & Panigrahi, 2007).

5. Weaving of microfibers

Microfilaments demand extraordinarily high quality weaving warps (Rupp & Yonenaga, 2000). In the case of warping microfiber yarns versus warping conventional fiber yarns, it must be considered that the smaller amount of force is needed to break a microfiber filament during warping. In addition, the eyelets used in the tension device in the creel of warping machine must be made of a low friction material. The surfaces must be free of cuts and snags. Also, the reed blades must be absolutely free of any snags or bars (Basu, 2001).

Due to their fineness the total surface area of microfiber yarn is far greater than ordinary fibers (Anonymous, 2000). The surface of microfiber yarns is 10-15% larger than conventional fiber yarns. Due to the higher surface area of microfiber smoothed yarn absorbs approximately 10% more sizing agent and textured yarns approximately 15% more sizing agent than conventional yarn. By reducing the viscosity of the sizing agent distribution of the sizing agent may be improved. The squeezing pressure must be adapted to the speed to achieve regular sizing. As a result of the larger surface and the small mass of the individual filaments the microfiber can be heated faster as drying also occurs faster. So cooling must be effected in a few seconds. The drying temperature can be lowered by 10% in the case of microfilaments (Basu, 2001). Since microfibers have very small interstices, desizing become quite difficult and costly. Desizing must always be clean to prevent problems in dyeing. Knowledge of the type of size used is very important to optimize the desizing process. Pretreatment must be done either on tensionless open width washers or in the overflow or jet dyeing machine. Control of PH is important for optimum size removal (Anonymous, 2000; Rupp & Yonenaga, 2000).

Many machine manufacturers recommend the use of air jet and rapier looms for microfilament woven fabric production. They also recommend the use of prewinding units and yarn brakes, which are suitable for processing filament yarns for weft insertion.

Basically weft yarns must be inserted with the greatest care. In this respect, processing should be effected with at least two yarn storage units in order to keep taking off speed as low as possible. Warp ends should be fed by a finely controlled warp let off system with an absolute tension sensor and a positively controlled rotating back rest roller. Abrasion resistant materials must be employed to prevent filament breakage in the case of the winding unit. For this the use of vulcanized or rubberized materials are suggested. For double width weaving machines, an additional pressure roller should be used for fabric slippage. Textured filament yarns should be more intensively intermingled in order to ensure good running characteristics. This may however have a rather detrimental effect on air consumption in the case of air jet looms (Rupp & Yonenaga, 2000). The harness with drop wires of warp stop motion, the reed and the healds come into particularly intimate contact with microfiber yarns. The surfaces of these items, therefore, need to have particularly low roughness. Fabrics woven with microfiber yarns are often densely constructed; beat up must also be relatively severe. If the reed wires have sharp edges, they can easily cut the individual filaments and thus damage the yarn. Weft accumulators must provide sensitive gentle tensioning of fine yarns. Two or more weft accumulators must be used with weaving machines to reduce the withdrawal of weft insertion. Temples recommended for silk and silk like fabrics must be used for microfiber yarn fabrics in order to prevent the fabric bowing out in the selvedge zone (Basu, 2001).

6. Experimental

This chapter is focused on the effect of filament fineness, weft sett and weave type on air permeability of 100% polyester microfilament woven fabrics. Fabrics were made in three weave types; 1/1 Plain, 2/3 Twill (Z) and 1/4 Satin. The highest and the lowest weft sett values for the weave types were determined by production trials. For each weave type four different weft sett values were applied considering the weaveability limitations. For plain 30, 32, 34, 36 wefts/cm, for twill 41, 43, 45, 47 wefts/cm and for satin 43, 45, 47, 49 wefts/cm were determined as proper values. Polyester microfilament textured yarns of 110 dtex with 0.33, 0.57 and 0.76 dtex filament finenesses and conventional polyester textured yarns of 110 dtex with 1.14, 3.05 dtex filament finenesses were used as weft. For warp yarn 83 dtex polyester yarn with 1.14 dtex filament fineness was used. Warp set was 77 warps/cm for plain weave types and 85 warps/cm for twill and satin weave types. By this way 60 woven fabric samples were produced. Sample fabrics were woven by a loom with an electronic Dobby shedding mechanism and rapier weft insertion at a loom speed of 420 rev/min. Before desizing, to obtain dimensional stability, samples were applied to thermal fixation at 195°C with 25m/min process speed.

Yarn linear density was measured according to ISO 2060, yarn tenacity and elongation were measured according to ISO 2062, shrinkage was determined according to DIN EN 14621, crimp contraction, crimp module and crimp stability were determined according to DIN 53840-1 standards. The properties of weft yarns are given in Table 1.

Figure 1, exhibits the microscopic views of cross sections of weft yarns used in the study. As seen from Figure 1, as the filament fineness decreases, the number of filament in yarn cross section increases. Thus, total void area between the filaments is smaller for finer filaments than that of coarser filaments. Furthermore, number of pores between the filaments and total surface area of the filaments is increased. The cross sections of the filaments are

essentially round. But after the texturizing process the view of the filament cross section was changed to cornered shape.

	Weft yarn filament fineness, dtex				
	3.05	**1.14**	**0.76**	**0.57**	**0.33**
Yarn linear density, dtex	110				
Yarn tenacity, cN/Tex	3.0	3.6	3.6	3.0	3.0
Yarn breaking elongation, %	21	27	25	24	26
Shrinkage , %	3.0	2.6	3.6	4.0	4.5
Crimp contraction, %	15	11	8	8	5
Crimp module, %	10	6	4	4	3
Crimp stability, %	81	82	79	77	72
Oil content, %	3	3	3	3	3
Intermingling frequency, points/meter	90	100	90	70	60
Intermingling retention (Stability at 3% elongation)	45	50	50	45	60

Table 1. Weft yarn properties used in the study

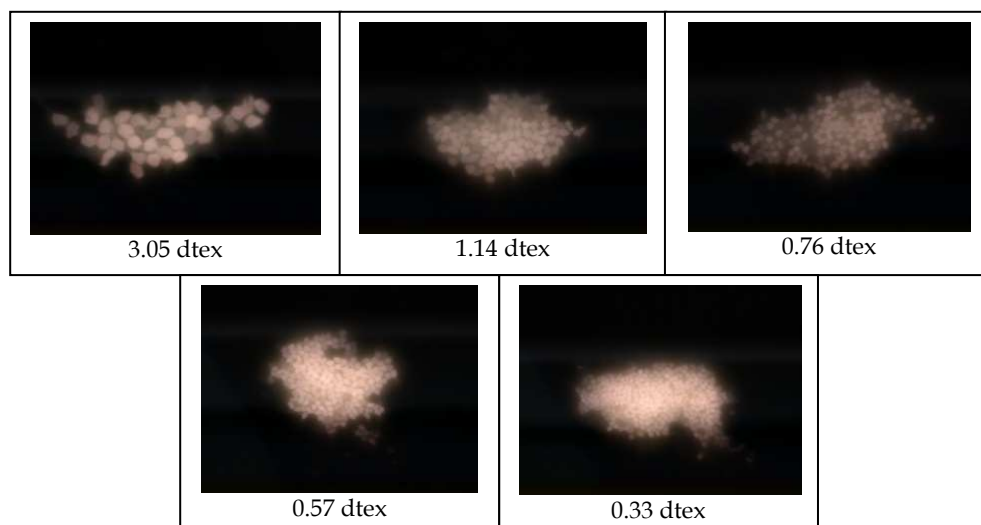3.05 dtex   1.14 dtex   0.76 dtex

0.57 dtex   0.33 dtex

Fig. 1. Microscopic views of weft yarn cross sections by magnification X200

Structural properties of sample fabrics after thermal fixation and desizing processes were determined according to following standards and results were given in Tables 2, 3 and 4.

- ISO 7211-2 Textiles -- Woven fabrics -- Construction -- Methods of analysis -- Part 2: Determination of number of threads per unit length
- ISO 3801 Textiles -- Woven fabrics -- Determination of mass per unit length and mass per unit area
- ISO 5084 Textiles -- Determination of thickness of textiles and textile products

Weave type	Weft yarn filament fineness, dtex	Adjusted weft sett, wefts/cm	Fabric weft sett, wefts/cm	Fabric warp sett, warps/cm	Fabric weight, g/m²	Fabric thickness, mm
Plain	3.05	28	30	77	117	0.25
	1.14	28	30	77	112	0.23
	0.76	28	30	77	111	0.23
	0.57	28	30	77	113	0.24
	0.33	28	30	77	114	0.24
	3.05	30	32	77	118	0.24
	1.14	30	32	77	116	0.23
	0.76	30	32	77	115	0.22
	0.57	30	32	77	116	0.22
	0.33	30	32	77	117	0.22
	3.05	32	34	77	119	0.24
	1.14	32	34	77	120	0.22
	0.76	32	34	77	118	0.21
	0.57	32	34	77	120	0.22
	0.33	32	34	77	121	0.22
	3.05	33	36	77	121	0.23
	1.14	33	36	77	122	0.22
	0.76	33	36	77	120	0.21
	0.57	33	36	77	121	0.22
	0.33	33	36	77	123	0.21

Table 2. Structural properties of plain weave sample fabrics

Weave type	Weft yarn filament fineness, dtex	Adjusted weft sett, wefts/cm	Fabric weft sett, wefts/cm	Fabric warp sett, warps/cm	Fabric weight, g/m²	Fabric thickness, mm
2/3 Twill (Z)	3.05	40	41	85	125	0.22
	1.14	40	41	85	128	0.22
	0.76	40	41	85	126	0.22
	0.57	40	41	85	129	0.22
	0.33	40	41	85	130	0.22
	3.05	42	43	85	128	0.22
	1.14	42	43	85	130	0.22
	0.76	42	43	85	130	0.22
	0.57	42	43	85	132	0.22
	0.33	42	43	85	133	0.22
	3.05	44	45	85	131	0.22
	1.14	44	45	85	133	0.22
	0.76	44	45	85	132	0.22
	0.57	44	45	85	135	0.22
	0.33	44	45	85	137	0.23
	3.05	46	47	85	134	0.23
	1.14	46	47	85	136	0.22
	0.76	46	47	85	136	0.22
	0.57	46	47	85	138	0.23
	0.33	46	47	85	141	0.23

Table 3. Structural properties of twill weave sample fabrics

Weave type	Weft yarn filament fineness, dtex	Adjusted weft sett, wefts/cm	Fabric weft sett, wefts/cm	Fabric warp sett, warps/cm	Fabric weight, g/m²	Fabric thickness, mm
1/4 Satin	3.05	42	**43**	85	129	0.23
	1.14	42	**43**	85	129	0.22
	0.76	42	**43**	85	128	0.22
	0.57	42	**43**	85	130	0.22
	0.33	42	**43**	85	130	0.22
	3.05	44	**45**	85	132	0.23
	1.14	44	**45**	85	131	0.22
	0.76	44	**45**	85	132	0.22
	0.57	44	**45**	85	133	0.22
	0.33	44	**45**	85	133	0.23
	3.05	46	**47**	85	133	0.23
	1.14	46	**47**	85	132	0.23
	0.76	46	**47**	85	134	0.23
	0.57	46	**47**	85	136	0.22
	0.33	46	**47**	85	136	0.23
	3.05	48	**49**	85	136	0.23
	1.14	48	**49**	85	139	0.22
	0.76	48	**49**	85	138	0.23
	0.57	48	**49**	85	140	0.23
	0.33	48	49	85	138	0.23

Table 4. Structural properties of satin weave sample fabrics

Figure 2 shows the SEM views of three of fabric samples which have the highest weft sett and lowest weft yarn filament fineness.
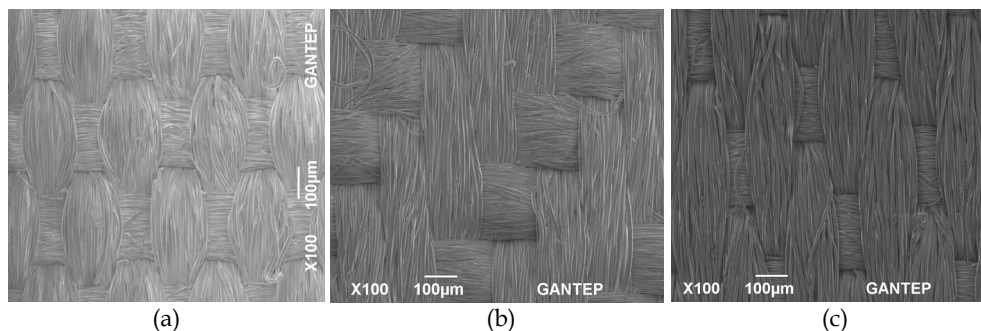

Fig. 2. SEM views of fabric samples X 100 with 0.33 dtex weft yarn filament fineness and 1.14 dtex warp yarn filament fineness (a) Plain, 36 wefts/cm, 77 warps/cm, (b) Twill, 47 wefts/cm, 85 warps/cm, (c) Satin, 49 wefts/cm, 85 warps/cm

All yarn and fabric samples were conditioned according to ISO 139 before tests and tests were performed in the standard atmosphere of 20±2°C and 65±4% humidity. The air permeability of sample fabrics was measured by SDL Atlas Digital air permeability test device according to ISO 9237 with 20 cm² test head and 200 Pa air pressure drop. Each

sample was replicated twice and ten repeated measurements were done for each replication. The mean values of the test results were used in graphical representation.

Design-Expert statistical software package was used to interpret the experimental data and to compose the regression models. Regression models were formed to define the relationship between independent variables (filament fineness and weft sett) and response variable (air permeability) for plain, twill and satin weave types. General Factorial Design was selected to compose regression models. The air permeability test results of samples were used to analyze the general factorial design. The analysis of variance, lack of fit tests and residual analysis were performed to select the proper model for the air permeability.

7. Results and discussion

Tightly woven fabrics produced from microfilament yarns have a very compact structure due to small pore dimensions between the fibers inside the yarns and between yarns themselves. These fabrics provide very good resistance against wind for different end uses such as parachutes, sails, wind-proof clothes, tents while serving light weight and high durability properties (Kaynak & Babaarslan, 2011). Wind resistance is usually assessed by measuring air permeability. Air permeability is the rate of air flow per unit area of fabric at a standard pressure difference across the faces of the fabric (Horrocks & Anand, 2000). The passage of air is of importance for a number of fabric end uses such as industrial filters, tents, sail cloths, parachutes, raincoat materials, shirting, down proof fabrics and airbags (Saville, 2002). Airflow through textiles is mainly affected by the pore characteristics of fabrics (Bivainyte & Mikucioniene, 2011). As fabric interstices increase in number and size, air permeability increases. In other words as fabric porosity increases, air permeability increases (Collier & Epps, 1999).
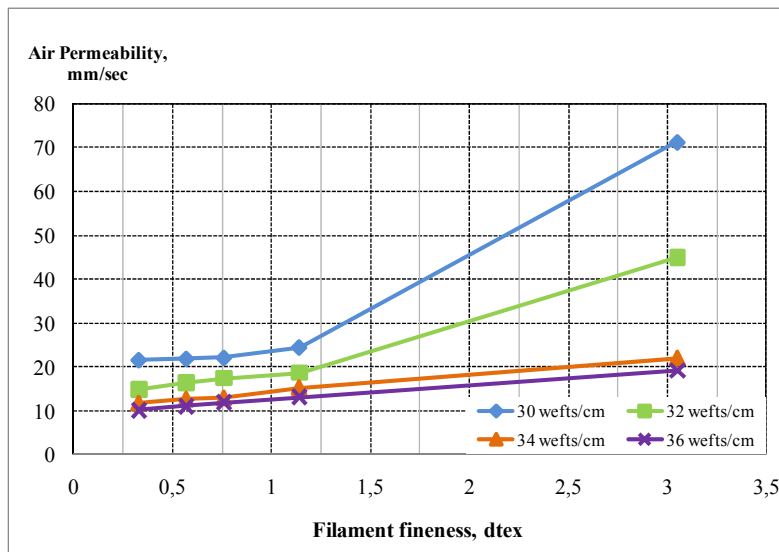

Fig. 3. Air permeability of plain weave type samples

Figure 3 exhibits the air permeability of plain weave samples for different filament fineness and weft sett. The highest air permeability value is 71.2 mm/sec and the lowest value is 10.2 mm/sec. As seen from Figure 3, increasing weft sett values cause a decrease of air permeability values for plain weave samples. Higher weft sett values provide the gaps between the yarns which the air pass through to become smaller thus lead to lower air permeability. The literature survey shows that some former studies on this topic (Fatahi & Yazdi, 2010; Çay &Tarakçıoğlu, 2008; Çay &Tarakçıoğlu, 2007) are agree with our work. Nevertheless, it must be considered that the effect of weft sett on air permeability is more obvious for coarser filaments. In other words the influence of weft sett on air permeability decreases as the filament fineness decreases. On the other hand lower filament finenesses cause lower air permeability. Because, lower filament fineness results in higher number of filament in yarn cross section. Thus, dimensions of gaps between the filaments within the yarns decreases. This is an expected result, since micro voids between the fibers become smaller as the fiber diameter decreases, thus the air permeability decreases as pointed out in an earlier study (Varshney, 2010).

The statistical analyses show that the best fitting model is the cubic model for plain weave type. ANOVA results for air permeability of plain weave type samples is given in Table 5.

Source	Sum of squares	Degree of freedom	Mean Square	F value	P value	Significance
Model	7541.65	7	1077.38	637.04	< 0.0001	Significant
A	635.42	1	635.42	375.72	< 0.0001	Significant
B	261.96	1	261.96	154.89	< 0.0001	Significant
A^2	90.57	1	90.57	53.55	< 0.0001	Significant
B^2	280.35	1	280.35	165.77	< 0.0001	Significant
AB	1174.29	1	1174.29	694.34	< 0.0001	Significant
A^2B	118.57	1	188.57	70.11	< 0.0001	Significant
AB^2	138.09	1	138.09	81.65		
Residual	54.12	32	1.69			
Lack of Fit	47.25	12	3.94	11.46	< 0.0001	Significant
Pure Error	6.87	20	0.34			
Cor. Total	7595.77	39				

Table 5. ANOVA results for air permeability of plain weave type samples

ANOVA results in Table 5 show that the effect of filament fineness (A) and weft sett (B) on air permeability is significant for plain weave samples from a statistical approach.

The regression equation of the cubic model for plain weave type is as follows:

$$\text{Air Permeability (mm/sec)} = 36.02279 + 450.27578\,A + 1.132469\,B + 47.20693\,A^2$$
$$+ 0.053972\,B^2 - 29.40924\,AB - 1.35053\,A^2B + 0.47562\,AB^2 \qquad (1)$$

In this equation (1); A and B are the filament fineness (dtex) and weft sett (wefts/cm) independent variables respectively. The air permeability of plain weave polyester

microfilament woven fabrics can be predicted by this equation. Mean Square Error (MSE), Mean Absolute Error (MAE), Mean Absolute Percent Error (MAPE%), R-square predicted (R^2predicted) and R-squared (R^2) values which contribute the performance of the statistical model for plain weave type samples are seen in Table 6.

According to model performance values, the correlation coefficient between predicted and observed air permeability values is 0.9854 indicating a strong predictive capability of the regression model for plain weave types. Also, this regression model can predict the air permeability with 95.47% accuracy. So it can be said that the regression equation gave satisfactory results.

Performance parameter	Value
R^2	0.9936
R^2predicted	0.9854
MSE	1.35
MAE	0.89
MAPE, %	4.53

Table 6. Performance of the model for plain weave type
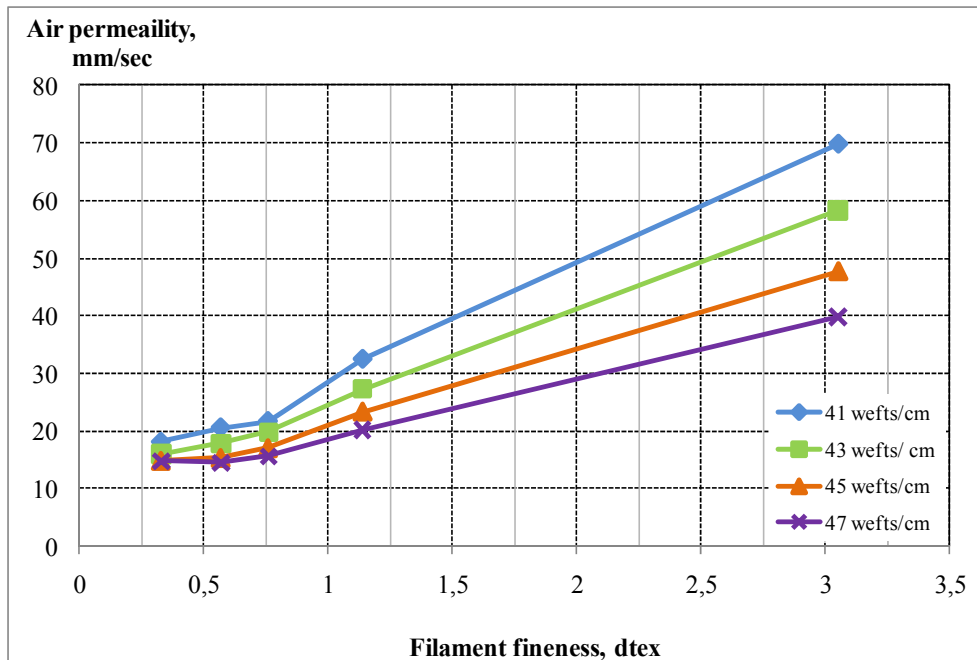
Fig. 4. Air permeability of twill weave type samples

Figure 4 illustrates the air permeability versus filament fineness of twill weave samples for different weft sett values. The highest air permeability value is 69.9 mm/sec while the lowest value is 14.5 mm/sec. It must be emphasized that reducing the air permeability from 69.9 mm/sec to 14.5 mm/sec is an important result showing the effect of filament fineness and weft sett on the air permeability. It is clear from Figure 4 that decreasing the filament fineness has a decreasing effect on the air permeability. A direct linear relationship between filament fineness and air permeability is also obvious. This relationship is similar for all weft sett values.

Furthermore, increasing weft sett causes a decrease of air permeability for twill woven fabrics. But the magnitude of this effect is decreased as the filament fineness decreased. The difference of air permeability value between the highest and the lowest weft sett are; 30.1 mm/sec, 12.3 mm/sec, 6.1 mm/sec, 6.1 mm/sec and 3.3 mm/sec for 3.05, 1.14, 0.76, 0.57 and 0.33 dtex filament finenesses respectively. These findings suggest that, total void volume has the vital importance with respect to air permeability and total void volume which the air flow pass through is affected by filament fineness much more than weft sett.

The statistical analyses show that the best fitting model is the cubic model for twill weave type. ANOVA results for air permeability of twill weave type samples are given in Table 7.

Source	Sum of squares	Degree of freedom	Mean Square	F value	P value	Significance
Model	9399.30	6	1566.55	3897.76	< 0.0001	Significant
A	190.33	1	190.33	473.56	< 0.0001	Significant
B	1232.42	1	1232.42	3066.40	< 0.0001	Significant
A²	11.58	1	11.58	28.80	< 0.0001	Significant
B²	10.10	1	10.10	25.13	< 0.0001	Significant
AB	526.39	1	526.39	1309.71	< 0.0001	Significant
A³	34.22	1	34.22	85.15	< 0.0001	Significant
Residual	13.26	33	0.40			
Lack of Fit	8.28	13	0.64	2.55	0.0289	Significant
Pure Error	4.98	20	0.25			
Cor. Total	9412.56	39				

Table 7. ANOVA results for air permeability of twill weave type samples

ANOVA results in Table 7 show that the effect of filament fineness (A) and weft sett (B) on air permeability is significant for twill weave samples from a statistical approach.

The regression equation of the cubic model for twill weave type is as follows:

$$\text{Air Permeability (mm/sec)} =$$
$$261.98458 + 55.06852\, A - 11.05995\, B + 27.54636\, A^2 + 0.12562\, B^2 - 1.66115\, AB - 5.87156 A^3 \quad (2)$$

In this equation (2); A and B are the filament fineness (dtex) and weft set (wefts/cm) independent variables respectively. The air permeability of polyester microfilament woven fabrics can be predicted by this equation. Mean Square Error (MSE), Mean Absolute Error (MAE), Mean Absolute Percent Error (MAPE%), R-square predicted (R^2predicted) and R-

squared (R^2) values which contribute the performance of the statistical model are seen in Table 8.

According to model performance values, the correlation coefficient between predicted and observed air permeability values is 0.9979 indicating a strong predictive capability of the regression model for twill weave types. Also, this regression model can predict the air permeability with 98.4% accuracy. So it can be said that the regression equation gave satisfactory results.

Performance parameter	Value
R^2	0.9986
R^2 predicted	0.9979
MSE	0.33
MAE	0.41
MAPE %	1.60

Table 8. Performance of the model for twill weave type
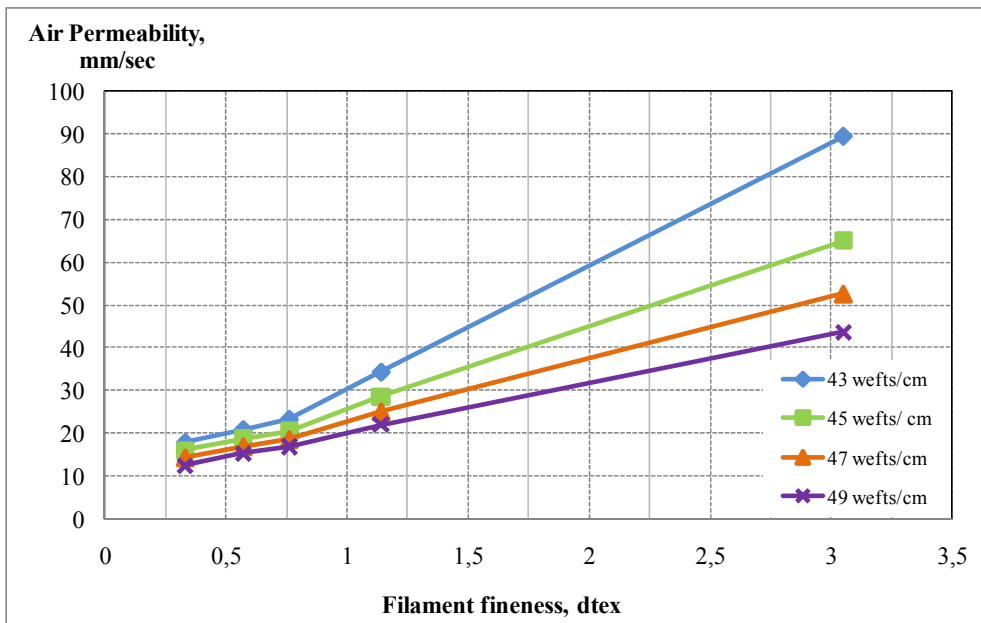
Fig. 5. Air permeability of satin weave type samples

The air permeability of satin weave type samples are shown in Figure 5. The highest and the lowest air permeability values are 89.3 mm/sec and 12.4 mm/sec respectively. The value of

76.9 mm/sec as the difference between these values is considerable. This value (76.9 mm/sec) is higher than the value (61 mm/sec) obtained for plain weave samples and the value (55.4 mm/sec) obtained for twill weave samples. Based on this result, it is clear that the effects of filament fineness and weft sett on satin weave type samples are higher than those of plain and twill weave type samples. Decreasing filament fineness causes a decrease on air permeability for satin weave samples. This is the result of reducing the void volume of the fabric due to decreasing filament fineness as seen before in plain and twill weave samples. A direct linear relationship between filament fineness and air permeability is also available for satin weave samples.

Besides, higher weft sett values resulted in lower air permeability for satin weave type samples. Similar with plain and twill weave samples, the influence of decreasing weft sett on air permeability decreases as the filaments become finer. The difference of the air permeability value between the highest and the lowest weft sett are; 45.7 mm/sec, 12.3 mm/sec, 6.4 mm/sec, 5.6 mm/sec and 5.5 mm/sec for 3.05, 1.14, 0.76, 0.57 and 0.33 dtex filament fineness respectively. This common tendency for both all weave types explains the effect of filament fineness on total void volume of fabrics. It should be noted that, for satin weave type there is a direct proportion between filament fineness and air permeability and a reverse proportion between weft sett and air permeability as seen in earlier studies (Fatahi & Yazdi, 2010; Çay &Tarakçıoğlu, 2008; Çay &Tarakçıoğlu, 2007; Varshney, 2010).

ANOVA results for air permeability of satin weave type samples are given in Table 9.

Source	Sum of squares	Degree of freedom	Mean Square	F value	P value	Significance
Model	14798.49	5	2959.70	778.77	< 0.0001	Significant
A	3831.95	1	3831.95	1008.28	< 0.0001	Significant
B	2267.35	1	2267.35	596.60	< 0.0001	Significant
B²	95.39	1	95.39	25.10	< 0.0001	Significant
AB	1259.27	1	1259.27	331.35	< 0.0001	Significant
AB²	81.93	1	81.93	21.56	< 0.0001	Significant
Residual	129.22	34	3.80			
Lack of Fit	76.20	14	5.44	2.05	0.0691	Not Significant
Pure Error	53.01	20	2.65			
Cor Total	14927.70	39				

Table 9. ANOVA results for air permeability of satin weave type samples

ANOVA results in Table 6 show that the effect of filament fineness (A) and weft sett (B) on air permeability is statistically significant for satin weave samples.

The regression equation of the cubic model for satin weave type is as follows:

$$\text{Air Permeability (mm/sec)} =$$
$$-400.27938 + 909.42821\, A + 17.24904\, B - 0.18175\, B^2 - 36.27354\, AB + 0.36635\, AB^2 \qquad (3)$$

In this equation (3); A and B are the filament fineness (dtex) and weft sett (wefts/cm) independent variables respectively. The air permeability of polyester microfilament woven fabrics can be predicted by this equation. Mean Square Error (MSE), Mean Absolute Error (MAE), Mean Absolute Percent Error (MAPE%), R-square predicted (R^2predicted) and R-squared (R^2) values which contribute the performance of the statistical model are seen in Table 10.

According to model performance values, the correlation coefficient between predicted and observed air permeability values is 0.9815 indicating a strong predictive capability of the regression model for twill weave types. Also, this regression model can predict the air permeability with 95.37% accuracy. So it can be said that the regression equation gave satisfactory results.

Performance parameter	Value
R^2	0.9913
R^2predicted	0.9815
MSE	3.23
MAE	1.22
MAPE %	4.63

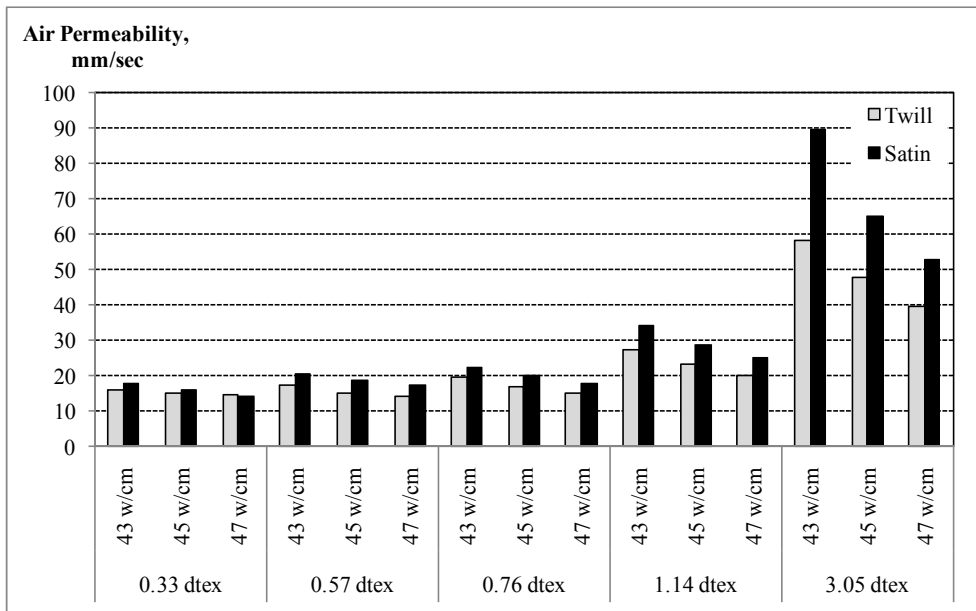Table 10. Performance of the model for satin weave type

Fig. 6. The effect of weave type on air permeability

It is seen from Figure 6 that for all filament fineness and weft sett values, satin woven fabric samples show higher air permeability than twill fabric samples. The number of interlacing is lower in satin weave type than twill weave type. So the yarn mobility is higher for satin weave types. Yarn mobility is higher, thus the pore dimensions become larger because of the deformation during air flow (Çay & Tarakçıoğlu, 2008). So enlarging the pore dimensions cause the air flow to pass through the fabric more easily and air permeability of the fabrics increase. On the other hand, the effect of weave type on air permeability is considerable for 3.05 dtex filament fineness.

8. Conclusion

Wind resistance was achieved by coating fabrics formerly. But, it is already known that obtaining the wind proof fabrics with a better breathability is possible by weaving microfilament yarns with high densities. These types of fabrics provide a good thermal insulation in windy conditions in addition to submitting a comfortable wear by transporting the sweat vapor more easily than other counterparts. So, it is widely important to know how the woven fabric parameters affect wind resistance and to determine the proper values of these parameters for particular end uses. Consequently, air permeability of polyester microfilament and conventional filament fabrics is presented here. It is already known that a good wind resistance can be achieved by ensuring lower gaps in fabric structure with finer filaments and higher densities. A considerable effect of filament fineness on air permeability is seen, for all weave types used in this study. The experimental results showed that decreasing the filament fineness have a decreasing effect on fabric air permeability. This is not surprising, since the air gaps between the filaments within the yarns become smaller as the filament fineness decreases. Thus, air flow through the filaments is prevented. Furthermore, higher weft sett values provided lower air permeability values because of obtaining smaller air gaps between the yarns in fabric structure. This situation causes the air flowing through the fabric more difficultly and fabric air permeability decreases. It should be noted that our study was investigated the effect of filament fineness and fabric density by differentiating the parameters of weft direction solely. It may be concluded that by changing the parameters in the warp direction, lower air permeability can be achieved. From the point of weave type, it is observed that weave types with higher number of float or lower number of interlacing have higher air permeability values. Because this type of weaves provides better mobility for yarns in their structure and gaps between these yarns become larger with air flow more easily than others.

As mentioned earlier, very good resistance against wind can be achieved by tightly woven microfilament fabrics for different end uses. The most convenient fabric construction can be determined for a particular end use such as wind proof cloth, tent, e.t.c. with the aid of the results and regression analysis obtained from this experimental study. This study also lends assistance to decide the structural parameters for barrier fabrics in specialized applications such as surgical gowns which will be on horizon in near future. For further studies, fabric properties can be developed by using different fiber blends, applying fabrics mechanical surface treatments and special finishes. In the near future, it is expected to see nanofiber yarns for producing woven and knitted fabrics as well as

microfiber yarns. Thus, several vast developments might be seen in fabric performance properties and fabric functionality.

9. Acknowledgement

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Woven Fabrics

Edited by Prof. Han-Yong Jeon

"Woven Fabrics" is a unique book which covers topics from traditional to advanced fabrics widely used in IT, NT, BT, ET, ST industry fields. In general, woven fabrics are known as the traditional textile fabrics for apparel manufacturing and are used widely in various fabric compositions as intermediate goods that affect human activities. The relative importance of woven fabrics as traditional textile materials is extremely large and currently application fields of woven fabrics as technical textiles are rapidly expanded by utilizing its geometric features and advantages. For example, the book covers analytical approaches to fabric design, micro and nano technology needed to make woven fabrics, as well as the concept for industrial application.

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