EFFECT OF SOME YARN TYPES ON COMFORT PROPERTIES OF POLYESTER FABRICS FOR GOVERNMENT OFFICER UNIFORM

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Thesis	Effect of some yarn types on comfort properties of polyester fabrics for government officer uniform
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ABSTRACT

Polyester garments are less comfortable due to hydrophobic in nature. In order to improve the comfort of polyester, six different yarn types were used in this study including polyester yarn 150D/2/96F (standard), Cool quick polyester yarn (specialty yarn with + shape), micro polyester yarn 150D/2/384F, micro polyester yarn 150D/2/576F, ply twisted polyester yarn 300D/288F with 120 TPM, and ply twisted polyester yarn 300D/288F with 200 TPM. Tests of mechanical properties, abrasion resistance, air permeability, and moisture management properties were applied to the fabric produced using the same weaving and dyeing processes. Changing the weft yarn types influenced the warp and weft directional mechanical properties, air permeability, and moisture management properties.

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CHAPTER I

INTRODUCTION

1.1 Statement and significance of the problems

Clothing is one of the basic needs for human being. It protects human body from weather and environment. The role of clothing is not only to protect the body from the elements but also to serve as adornment and symbolize someone’s functions, characteristics and mentality. For a long time ago, people’s state is recognized by their appearance.

Uniform is a type of clothing worn by members of an organization while participating in that organization’s activities. In organization, they share value, attitude, and goals. There are many types of organization using uniform such as education, services and workplace, security, armed force, and government officer. The history of uniform was starting at the beginning of Roman Empire, they are used in warfare [1]. In Thailand, Thai people wear uniform for a long time mostly in military sector but it significantly showed in King Rama IV when the first police department was established. Furthermore, using khaki color in that period has become the standard color for government officer uniform.

Government officers are the heart of every country operation system. They have an important role depending on unit. There are many types and level of government officers. The number of government officer in every country is increasing. In Thailand, the proportion of government officer to other careers is 1:30 excluding military officer that more than 300,000. In reality, each unit may have different uniform causing more easily identity them.

The government officer is the major users of uniform fabrics. They need unity, identity and smart image. Moreover, they also need the comfortable and easy care fabric too. However, polyester fabric is a moisture trapping fabric will hold your sweat against your skin, but will not let the evaporating moisture escape easily. In addition, the weather in Thailand is typically hot and humid causing excessive sweating. The result is the warm clammy garment that holds in your body heat. Concerning above reason, we always get this question from user that is “Is it hot to make a uniform? Most of them use polyester fabric for their uniforms because it looks smart, sharp, easy care and durable. This frequently asked question leads to this research. They need the better fabric while cost concerned.

As comfort aspect of textile fabric is so much important, in this research, comfort characteristics of fabric made of different yarn types are prepared: The normal weft yarn is considerably changed into different yarn types, whereas the warp yarn is still the same polyester yarn. The fabric was subjected to physical properties, and mechanical properties.

1.2 Research objectives

1) To study the effect of yarn types on mechanical and comfort properties of woven fabric
2) To calculate the cost effectiveness of combination of different yarn types by comparing to standard fabric used in government officer in Thailand

1.3 Significance of the research

1) Obtain a suitable comfort performance of woven fabric

2) Know the influence of changes in the cost of produced fabric

CHAPTER II
LITERATURE REVIEW

2.1 Polyester

Since ancient times, natural polyesters have been known to mankind. Shellac, natural polyester, as secreted by the lac insect, was used by the ancient Egyptians for embalming mummies [2]. In 1848, Berzelius synthesized polyester of polybasic acids and polyvalent alcohols by reacting tartaric acid and glycerol [3]. Initially, polyester was developed for coating application and then polyesters were developed into filament in late 1920.

2.1.1 History of polyester [4-5]

In late 1920, Wallance Carothers discovered the process used in the production of filaments. In 1940s, Calico Printers Associations in Great Britain developed Carothers' work and then they were the first to produce polyester. DuPont got the polyester filament production patent rights for the United States and Britain's Imperial Chemical Industries (ICI) got the patent for the rest of the world. Polyester was commercialized and become popular in 1950 as wash and wear fabric. As its properties, it was used in many garments which offer wrinkle-free, durable, high color fastness, and shape-retaining wears.

According to synthetic fiber production record showed that polyester fiber has a strong, long-term growth since 1982. In 2002, statistics show that out of 33.5 million metric tons of synthetic fiber manufactured, 21.0 million metric tons of that amount included manufactured polyester fibers as shown in Figure 2.1 [6].

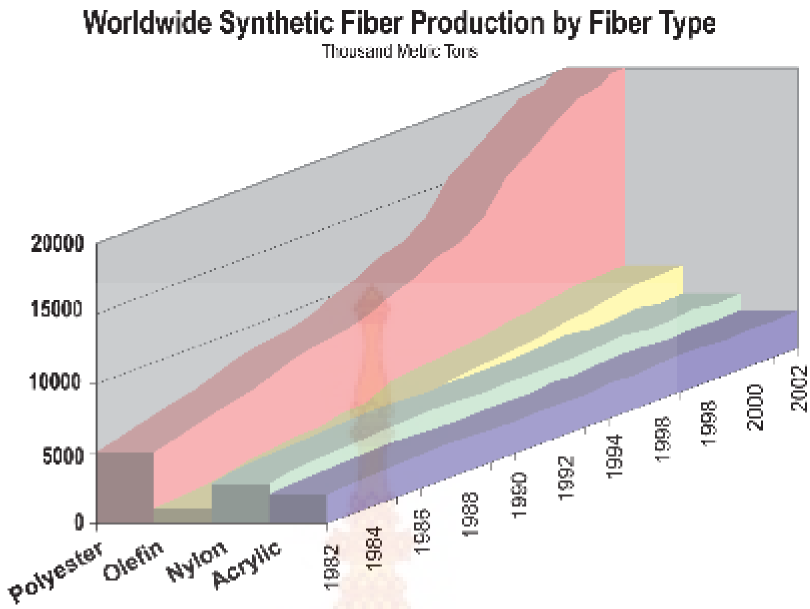

Figure 2.1 Worldwide synthetic fiber production by fiber type [6]

2.1.2 Chemical structure of polyester

The most commercially important polyester is polyethylene terephthalate (PET). It is formed from a dicarboxylic acid and a diol. It is a linear polyester consisting of organic compounds of repeating ester groups (-COO-). PET is a white or light cream material, has high heat resistance and chemical stability and is resistant to acids, bases, some solvents, oils and fats. The chemical structure of PET is given in Figure 2.2

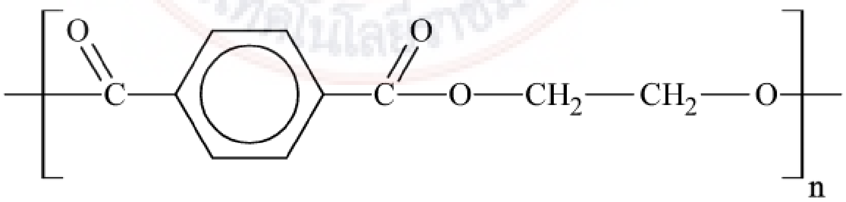

Figure 2.2 Molecular structure of polyethylene terephthalate [7]

2.1.3 Polymerization methods of polyester

The polymerization step in polyesters is similar to polyamides but the formation of high molecular weight in polyesters differs in some extent. The polymerization of polyester can be made in many ways.

Step-growth polycondensation method

Polyester is formed by step-growth polycondensation from dicarboxylic acid or its diester and diol (Figure 2.3). The by-products produced are water or methanol depending on the reactant used. A number of catalysts are used for the polycondensation reactions such as germanium, titanium, aluminium, etc.

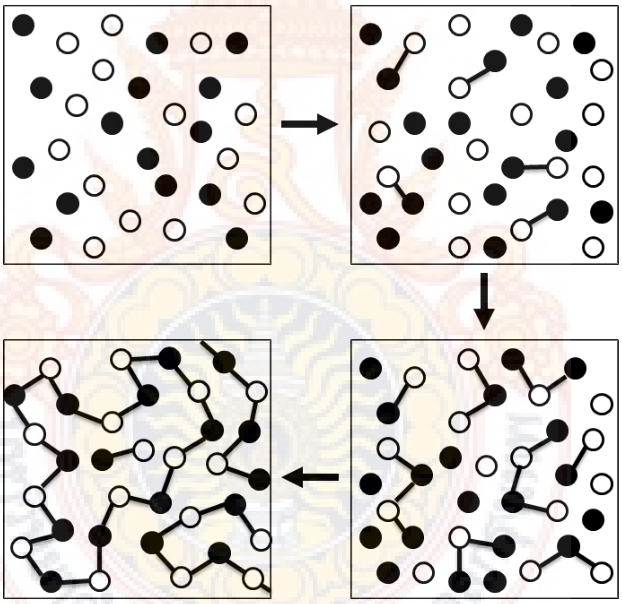

Figure 2.3 A generic representation of a step growth polymerization (white dots represent monomers and black chains represent oligomers and polymers) [8]

Ring-opening polymerization method [9]

Polyester can be prepared by ring-opening polymerization (ROP) (Figure 2.4). The ROP is the method that using cyclic oligomer and polymerization could be achieved at temperatures well below the melting point of the final polymer. It differs from polycondensation reaction that this method does not require removal of any by products. The limitations of this method are that one has to synthesize cyclic oligomer using diol and diacid chloride and that a solvent and catalyst are required.

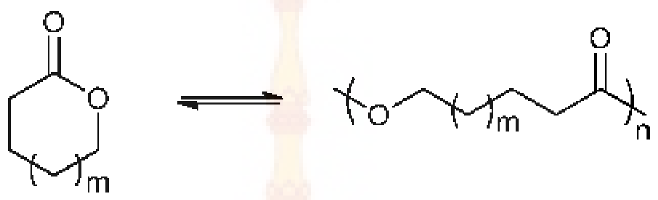

Figure 2.4 Ring opening polymerization of polyester [10]

Polyaddition reaction method

Polyesters can be prepared by polyaddition reaction of diepoxides to diacides [11]. This reaction is catalysed by amines, quaternary ammonium, antimony trioxide, antimony pentachloride. Polyaddition reaction is accompanied by the numerous side reactions that limit its use, where linear polyesters are required. The polyesters polymerized by this method are used as composites, blends, laminates, and biodegradable polymers.

Recycling method

Polyesters can be recycled by physical or chemical methods. In the physical method, post-consumer recycled PET flakes are remelted in an extruder for polyester chips or its can direct melt processing into products (Figure 2.5). Chemical recycling is more complicated. It is versatile to use. Chemical recycling can remove any additive contamination and any type of PET waste can be used. In chemical recycling method, hydrolysis or methanolysis or glycolysis is used (Figure 2.6).

Figure 2.5 Physical recycling of polyester [12]

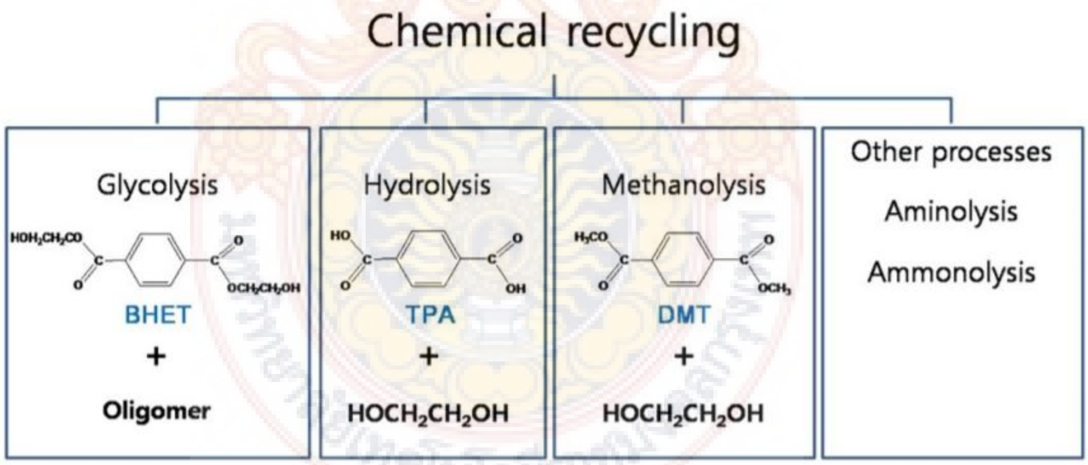

Figure 2.6 Chemical recycling of polyester [13]

2.1.4 Properties of polyester

The physical, mechanical, and chemical properties of polyester fiber can be considered.

Physical and mechanical properties

Typical physical and mechanical properties of PET fibers are given in the Table 2.1.

Table 2.1 Physical and mechanical properties of PET fibers [14]

Property	Mean value
Tenacity (cN/Tex)	7.0 ± 0.2
Elongation at break (%)	20.5 ± 3.0
Shrinkage at boil (%)	6.0 ± 0.2
Oil pick up (%)	0.13 ± 0.01
Specific gravity	1.38
Moisture regain, %	0.4

Chemical properties

Polyester fibers have good resistance to weak mineral acids and to most strong acids at room temperature, but are dissolved with partial decomposition by concentrated sulfuric acid. Hydrolysis is highly dependent on temperature. Polyester are highly sensitive to bases such as sodium hydroxide and methyl amines. Polyester has excellent resistance to oxidizing agents, such as conventional textile bleaches.

2.1.5 Application

Polyesters that are the most important in industry is polyethylene terephthalate (PET). PET grades with relatively higher molecular weights are used for making industrial filament. It can make from thick to thin filament. PET can be made for rubber tyres, conveyor belt, coated fabric, sewing threads, light-weight fabric, etc (Figure 2.7). For staple PET fiber, it is a major use in making blended fabrics such as polyester 65% cotton 35%, polyester 65% rayon 35%. Fabrics made form PET POY microfilaments are breathable and water-repellent with soft and pleasant feel.

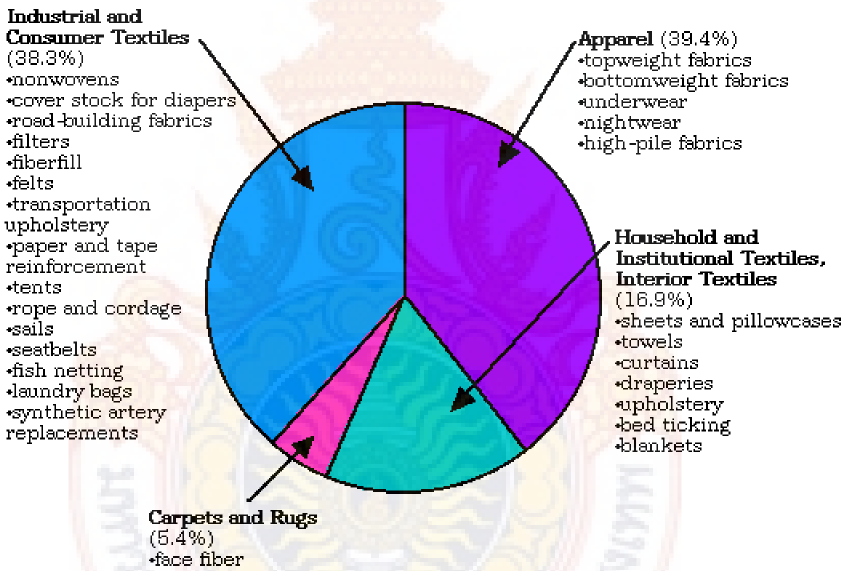

Figure 2.7 Primary market distribution of polyester fiber produced in the U.S. and shipped to domestic customers in 1990 [15]

2.2 Manufacture of polyester fibers

Commercially, PET was produced by using ethylene glycol (EG) and dimethyl terephthalate (DMT). After 1970, Mobil Co. and Amoco Co. were able to develop technology to produce pure terephthalic acid. PET then started to be produced from ethylene glycol (EG) and terephthalic acid (TPA). The sequence for production of PET fibers and yarns depended on the different ways of polymerization and spinning processes [4].

2.2.1 Spinning process

The degree of polymerization of PET is controlled, depending on user. PET for industrial fibers has a higher degree of polymerization, higher molecular weight and higher viscosity. The spinning process of fiber forming polyester converted to fiber passes into three stages. In the first stage (Figure 2.8), a solid fiber-forming polyester is produced from polymerization, which is called polymer chips. These polymer chips can be converted to dope by heat or by dissolving in some solvents.

Polymer chips $\xrightarrow{\text{Conversion by heat or solvent}}$ Dope (viscoelastic fluid or spinning fluid)

Figure 2.8 The conversion of polymer chips to dope [4]

In the second stage (Figure 2.9), dope fluid is extruded through a spinneret and converted to viscoelastic filament, which known as the originally extruded filament.

Dope $\xrightarrow{\text{Spinning}}$ Viscoelastic filament $\xrightarrow{\text{Solidification}}$ Solid filament fiber

Figure 2.9 Dope extrusion to viscoelastic filament [4]

In the third stage (Figure 2.10), the solidification process, there are three methods of solidification that are different in the way of solidate viscoelastic filament into solid fiber.

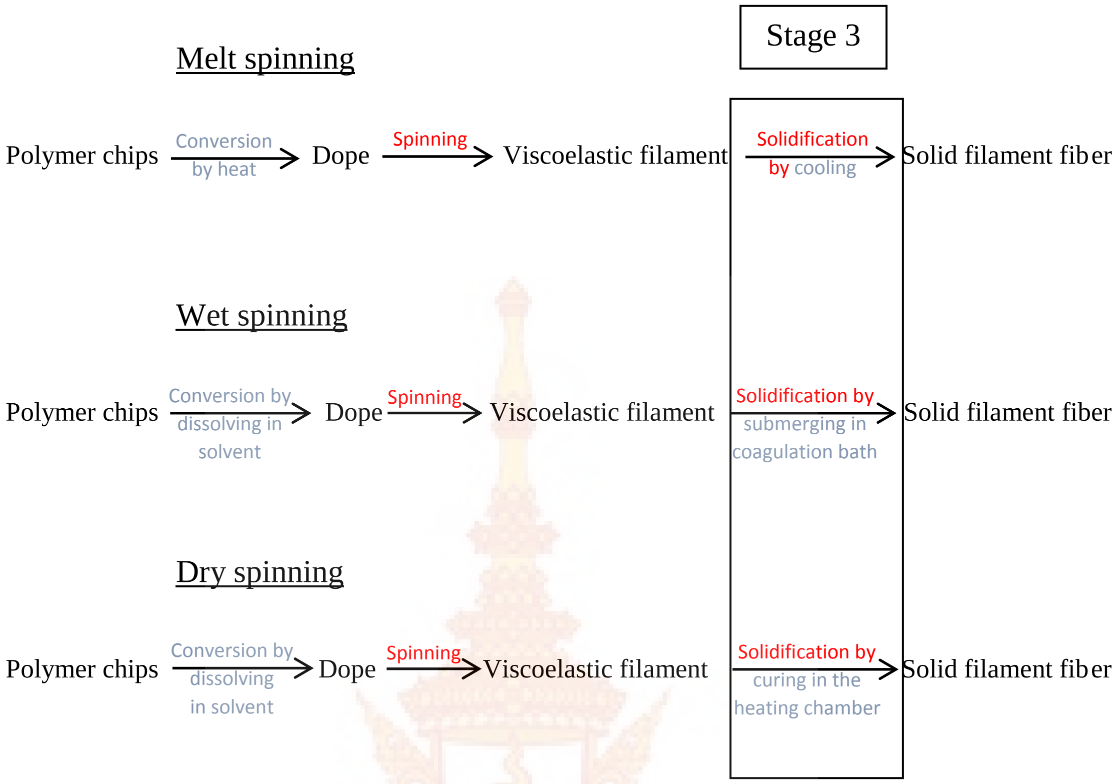

Figure 2.10 The solidification process [4]

These three methods would be selected to use according to the raw material. For example, melt spinning, wet spinning and dry spinning can be used if the polymer chips are thermoplastic polymer such as polyester, polyamide, polyurethane, polypropylene, etc. Usually, melt spinning is used for thermoplastic polymer.

In the third stage, when the viscoelastic filament is solidified into solid filament fiber, it is extended by the drawing process. The drawing process decreases the diameter, and the orientation of solid filament fiber could increase, while it improves the degree of crystallinity.

2.2.2 Melt spinning

PET is one of the thermoplastic polymers that usually uses melt spinning to produce the commercial PET fiber. The diagram shown in the Figure 2.11 explains the melt spinning process of PET fiber. PET fibers are formed by extrusion of the molten polymer. A supply of molten PET (D) is pumped at a constant rate and under very high pressure through small holes in the spinning jet (E). The viscoelastic filaments are extruded to emerge vertically downwards from the face of the spinning jet then cooling, solidify, and after that wind onto the bobbins [4].

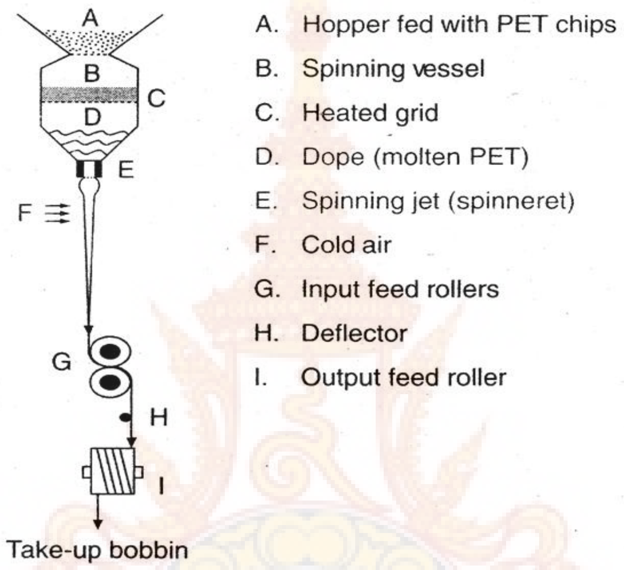

Figure 2.11 Schematic melt spinning process for PET fiber [4]

In Figure 2.11, the profile model of dope fluid flows through the spinning jet (E) described in Figure 2.12.

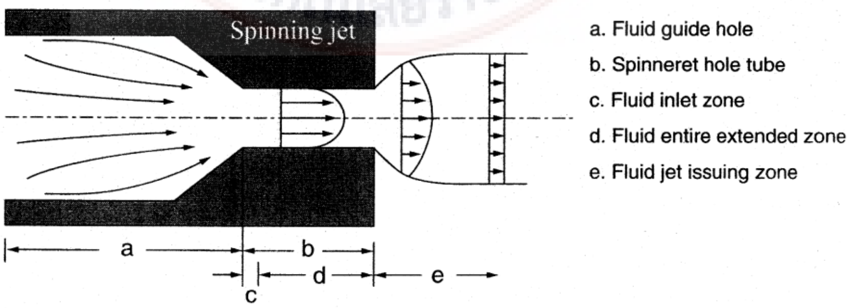

Figure 2.12 The profile model of spinning jet [4]

In the inlet zone (c), the dope fluid is contracted then the polymer chain in the dope fluid produces elastic deformation (Figure 2.12). In the fluid entire extended zone (d), the velocity of viscoelastic fluid is a steady flow. Then, in the fluid jet issuing zone (e), the contraction of viscoelastic fluid is related to the different velocity profiles inside and outside the spinneret hole tube.

Dope fluid (viscoelastic fluid) is extruded through the spinneret and converted to viscoelastic filament. The viscoelastic filament is transformed into solid filament fibers by cooling, where the viscoelastic filament is extended and the diameter of the viscoelastic filament is reduced. The process of viscoelastic filament's deformation by elongation strain can be described in three stages as shown in Figure 2.13.

1) Die swell section with negative parallel (elongation) velocity gradient.
2) Elongation section (or deformation section) with positive parallel (elongation) velocity gradient.
3) Solid motion section (running solid filament fiber section) with zero parallel (elongation) velocity gradient or without deformation.

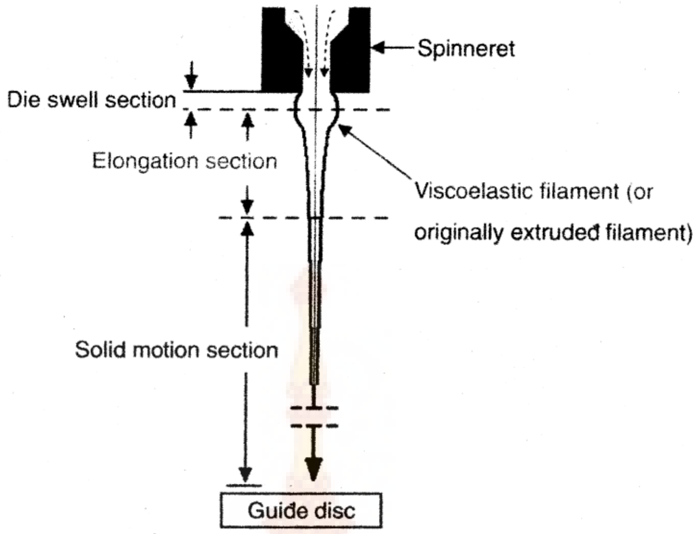

Figure 2.13 The deformation of viscoelastic filament by elongation strain [4]

Die swell can be observed as an extrudate with a cros-section which is greater than the die cross-section. Die swell is associated with the viscoelastic nature of polymer melts as it exceeds the swelling of constant viscosity fluids. The distance of the elongation section is usually 50-150 cm from the spinneret. The viscoelastic filament is then solidified by cooling [16].

2.2.3 Drawing process

To produce uniform PET, the drawing process is carried out of temperature above glass transition temperature (80-90 ^{o}C). The drawing process gives addition orientation to fiber (Figure 2.14). The drawing ratio is varied according to the final end-use [17].

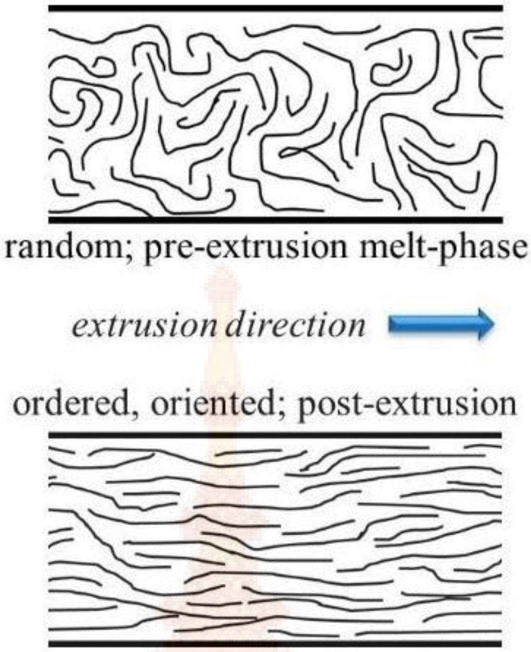

Figure 2.14 The change in polymer chain orientation during the extrusion process[18]

2.3 Specialty fibers from polyester

In commercial market, polyesters and polyamides are widely used textile fibers. Due to the various uses in many industries, the specialty polyester fibers were developed in many ways to serve the application-specific needs. The most common way is to develop non-circular cross-section fibers. Typically, general fibers have a circular cross-section. Other cross-sections such as hollow, trilobal, hexagonal, etc., are considered as specialty fibers. The modification can be produced by installing spinnerets with the desired capillary configuration. Due to the change in cross-section, the fibers with special shape show amazing properties. For example, hollow fibers have better insulation properties [19] and trilobal cross-section have a sparkling luster [20].

In the spinning process, the cross-sectional geometry depends on the spinneret holes. The examples of spinneret holes design are given in Figure 2.15. The fiber shape will be different as the result of spinneret hole as in Figure 2.16.

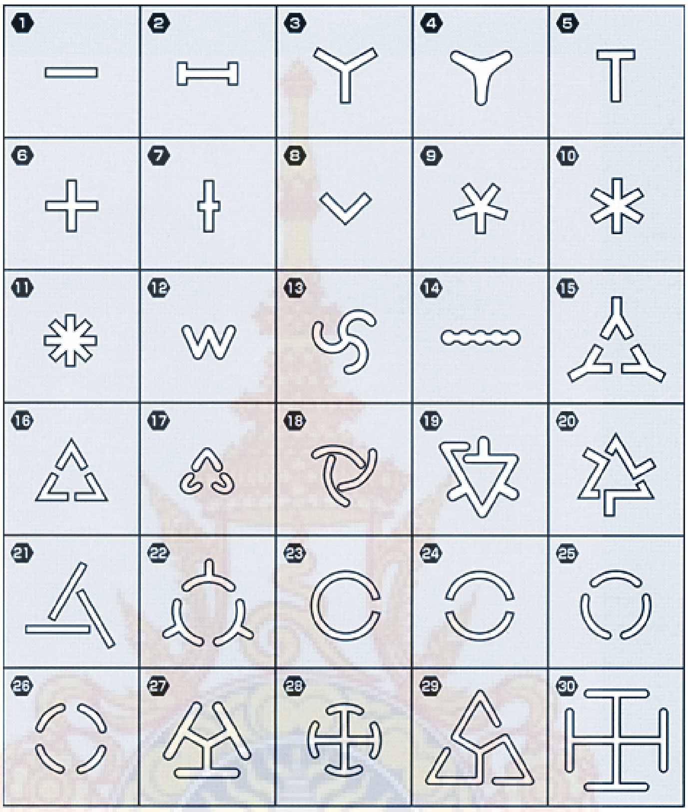

Figure 2.15 Shape of spinneret hole [21]

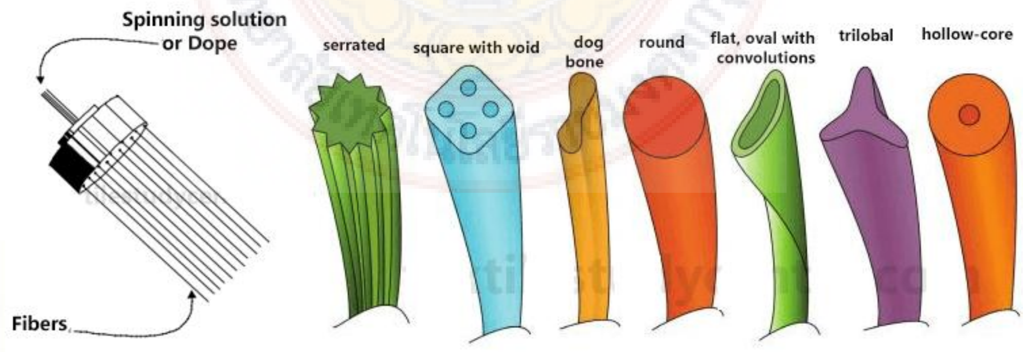

Figure 2.16 Profiled fibers from different spinneret hole [22]

2.3.1 Coolmax yarn

Coolmax yarn is one of specialty yarn made from specially engineered polyester fibers with an increased surface area [23]. Coolmax is a registered trademark of Invista. By expanding the surface area of yarn with four channel shape (Figure 2.17), it can absorb and evaporate moisture better than common yarn.

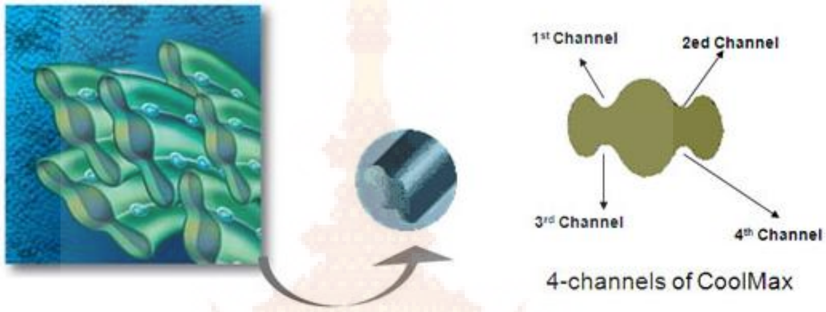

Figure 2.17 Coolmax yarn characteristics [24]

2.3.2 Microfibers

Microfiber is a synthetic fiber that is less than one denier [25]. It is one-third the diameter of cotton, one- quarter the diameter of fine wool and one hundred time finer than human hair [26]. Almost any thermoplastic polymer can be melt blown to produce a microfiber. Fabrics made of microfiber are typically lightweight, wrinkle resistant, soft and smooth, breathable and high absorbent property [27]. Manufacturing of microfibers need sophisticated technology. The production cost is more expensive than common deniers [28]. Further, fine fibers with diameter of less than 100 nm are called nanofibers. It is usually produced by an electrostatic spinning process [29].

2.3.3 Twisted filament yarn

In filament yarn, it is unnecessary to twist yarn to imprt strength [30]. The result of twisting will reduce strength of yarn. But sometime twisted to a fairly high level, it helps to reduce the luster of the yarn or to impact some attribute of the yarn such as hand feel improvement.

2.4 Comfort

2.4.1 Definiton of comfort

Comfort is a fundamental need of human being. When the comfort condition exists, the mind is alert and the body operates more efficiency. The benefits of comfort condition such as increase productivity, improve quality, reduce error, and improve health condition. It is very complex and difficult to define the comfort. According to Slater [31], comfort is a pleasant state of physiological, psychological, neuro-physiological and physical harmony between a human being and the environment. The environment can affect to comfort three ways.

1) Physiological comfort which related to the human body's ability to maintain life.
2) Psychological comfort to the mind' ability to keep it functioning satisfactorily.
3) Physical comfort to the effect of the external environment on the body.

Although it is difficult to identify comfort, discomfort is more easily to identify such as prickle, itch, hot and cold.

2.4.2 **Human physiological aspect of comfort** [32]

Physiological interpretation

Physiological comfort is defined as the achievement of thermal equilibrium at normal body temperature with the minimum amount of bodily regulation. The body feels uncomfortable when it has to work too hard to maintain thermal equilibrium. The comfort condition for body means the production of heat is equal to the loss of heat. In the actual environment, there are many factors affecting to this body interpretation such as local temperature and clothing. So, the body's heat control mechanism will be processed.

Physiology and body temperature

The normal internal human body temperature is 37°C (98.6 °F) with tolerance of ± 0.5°C. If any occur that affect the body temperature away from 37°C, the body's temperature control mechanisms will process. Metabolic activity results in the heat which can be partially controlled by controlling metabolic rate. Metabolism in various activities causes different body's heat production rates. The body temperature change can be effect to physiological response as shown in Table 2.2

The physiological reactions of body temperature will vary depending on the geographical location of the human being. The human, who live in different atmosphere, can tolerate the temperature range exiting in the surrounding area throughout the year.

Table 2.2 Physiological responses at the different body temperature [32]

Body temperature (°C)	Physiological response
43.3	Brain damage, fainting, nausea
37.8	Sweating
37	Normal
<37	Shivering and goose bumps
<32.2	Speechless
26.5	Stiff and deformed body
<26.5	Irreversible body cooling

Role of body components in regulating body temperature

In our body, we have both heat and cold sensors which located in different area. From Figure 2.18, heat sensors, located in the hypothalamus, send signals when skin temperature is higher than 37°C. Cold sensors, located in the skin, send signal when skin temperature is lower than 37°C [32].

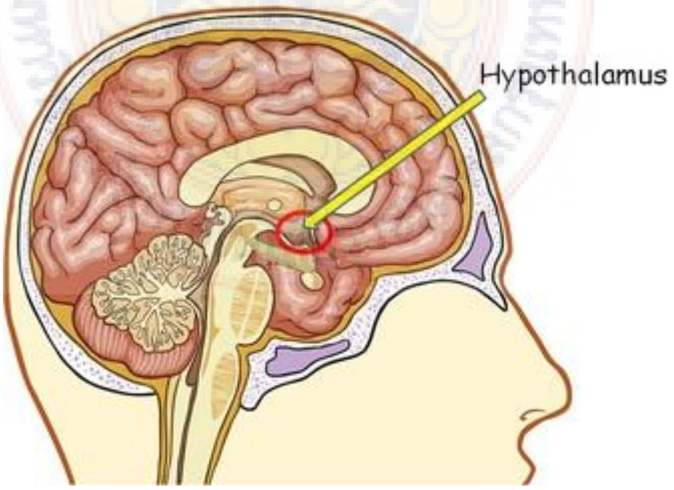

Figure 2.18 Human hypothalamus [33]

The blood which circulates to all body is warmed by the heat release within the body. The body temperature is result of the balance between heat production and heat loss. Hypothalamus regulates body temperature by continuously records blood’s temperature. It is body’s thermostat. By using flow of blood to the skin, hypothalamus can control heat loss mechanisms. Blood has very high thermal conductivity. When blood flows to the skin from the body core, it transmits heat to the skin. The blood vessel that can constrict or expand within the skin is the mechanisms. If the body temperature increases, the blood vessel will expand resulting in more blood transferring to the skin. As a result, skin temperature increases, with consequent increase of heat loss and decrease in body temperature. On the other hand, the blood vessel will be constricted, if the body temperature decreases such as in cold environment. The body tries to avoid higher rate of heat loss.

Acclimatization

The human body can acclimatize itself to thermal environmental change. The acclimatize level is limit. The slower seasonal change is accommodated more easily and changes in clothing support this acclimatization. The rapid change in temperature such as indoor to outdoor can cause body dysfunction. Whenever the body cannot adjust itself to the thermal environment, heat stroke or frost bite to death is possible.

2.5 Clothing as near environment

Clothing is the nearest mobile environment. The primary function of clothing is to protect the body from unsuitable environment. However, clothing serves other functions than that such as social status, decoration and protection. At the interface between human body and its surrounding environment, clothing plays a very important role in determining the subjective perception of comfort status of a wearer. Sometimes it is called a second skin. Clothing is the aspect of our environment with which we are in closest contact and over which we have the most control and is often used as an extension of one's own body.

Human perception of clothing comfort is an interaction between physical, physiological and psychological factors with the surrounding environment when wearing clothing. There are many different aspects of clothing comfort. The comfort issues include the effect of environment, available test methods, fabric handle, moisture and thermal management and psychological comfort.

Comfort is a multidimensional and complex phenomenon. Subjective perception of comfort involves complicated processes in which a large number of stimuli from clothing and external environments communicate to the brain through multi-channels of sensory response to form subjective perceptions. These perceptions involve a psychological process in which all relevant sensory perceptions are formulated, weighed, combined, and evaluated against past experience and present desires to from an overall assessment of comfort status.

Pontrelli [35] developed a Comfort's gestalt in which the variables influencing comfort status of a wearer were listed and classified into three groups; physical variable of the environment and the clothing, psycho-physiological parameters of the wearer and psychological filters of the brain. From Figure 2.19, the flow chart for the subjective perception of comfort explains the process of how the subjective perception of overall comfort is formulated.

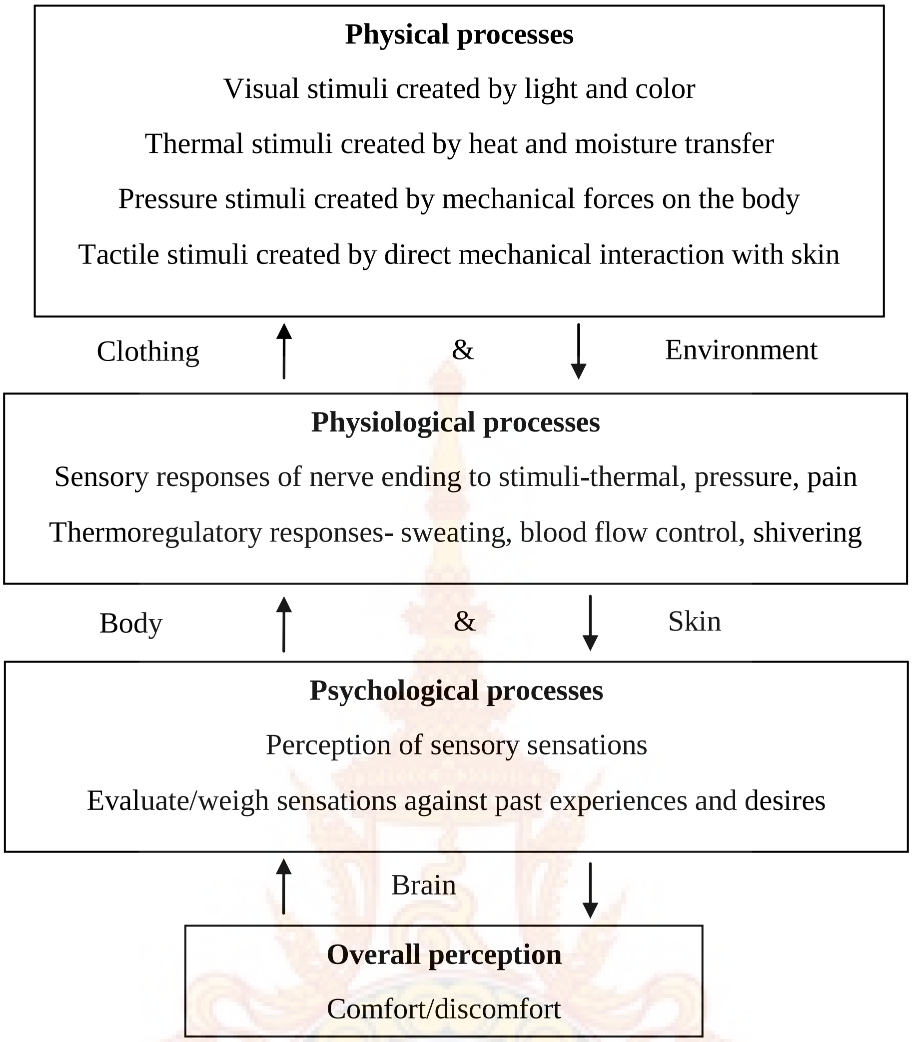

Figure 2.19 Subjective perception of comfort [32]

2.6 Various aspects of clothing comfort [32]

In clothing, comfort is related to subjective perception of various sensations. It may be psychological or physiological. Three aspects of clothing comfort are thermal comfort, sensorial comfort, and body movement comfort.

External environment including physical, social, and cultural have great impact on the comfort status of the wearer [36] and researches have shown that there is a close relationship between moisture and thermal comfort.

2.6.1 Thermal comfort

Thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Human thermal comfort depends on the metabolic rate, the heat loss from the body, and the climate condition. Clothing plays important role to maintain heat balance because it modifies the heat loss and moisture loss from the skin surface. A clothing system which is suitable for one climate may not be suitable for another as clothing insulation is very important for human thermal comfort [37]. In cold climate, the good thermal insulation properties are needed in clothing. The thermal insulation depends on different factors such as thickness, drape, and fiber density.

2.6.2 Sensorial comfort

Human skin is the interface between a human body and its environment and contains specialized sensory receptors to detect various external stimuli. Sensorial properties of a fabric depend on the fiber types, the fabric construction and the fabric finishing treatments. Surface properties like friction and roughness, physical properties like tensile, shear, compression and bending and surface coolness or warmness are the important parameters for clothing comfort.

Comfort of garment is the complex effect of textile properties which depends on the chemical structure and morphology of the constituent fibers. Although the comfort concept has not yet been clearly identified, there are several parameter effects on comfort specifications.

Effect of fibers

The fiber type is the first criterion that affects to comfort characteristic of fabric. Fiber can be natural/ man made, staple/filament. Different fiber types have different fiber properties.

The most important parameter that determines the comfort of a cloth is the material. The main properties and the advantages and disadvantages of fabric of the most used fiber for apparel applications are shown in Table 2.3-2.4.

Table 2.3 Properties of fabrics according to their constituent fiber [32]

Property	Cotton	Wool	Polyester	Acetate	Rayon	Acrylic	Nylon
Durability	Very good	Moderate	Excellent	Poor	Moderate	Moderate	Excellent
Liquid Absorbency	Excellent	Slow/good	Poor	Good	Good	Poor	Poor
Wrinkle Resistance	Poor	Excellent	Excellent	Poor	Moderate	Good	Excellent
Care	Machine wash	Dry clean	Machine wash	Dry clean	Machine wash gently	Machine wash	Machine wash

Table 2.4 Advantages and disadvantages of fabrics made of different fibers [32]

Material	Advantage	Disadvantage
Cotton	Strong, soft, durable, comfortable, absorbent, washable	Shrinks, wrinkle, expensive
Wool	Warm, strong, wrinkle resistant	Shrinks, can be damaged by moths, care difficulties, expensive
Polyester	Strong, blend well with other fibers, washable, wrinkle resistant, dries quickly, cheap	Holds oily stains, does not absorb sweat, weak hand
Acetate	Soft, drapes well, look like silk, cheap	Wrinkle, fades, heat-sensitive, loses strength when it is wet, poor abrasion resistance, care difficulties
Rayon	Soft, comfortable, highly absorbent	Loses strength when wet, wrinkles easily, care difficulties
Acrylic	Soft, light weight, warm, wool like, wrinkle resistance, blend well with other fabrics, non-allergenic, cheap	May pill with abrasion, sensitive to heat
Nylon	Strong, hold shape well, washable, dries quickly, resilient, elastic	Sensitive to heat, does not absorb moisture, can pick up dyes when washed with colored items, static electricity

Considering all the properties from Table 2.3 and 2.4, blending the fibers in a fabric seems to be a best solution to modify the properties and cost of garments.

The finer the fibers are, the smoother and more flexible the yarn is. Longer fibers and smaller variation in the fiber length distribution result in the smoother yarn and fabric surfaces. Micro denier filament fabrics give a better drape and handle properties compared to the normal denier filament fabrics [38]

The cross-sectional shape of the fiber affects the smoothness and bending of the yarn [39]. Another property that is important for fabric handle is the fiber friction. The fiber-fiber friction influences the way that fibers interact with each other. The friction properties affect the flexibility of the yarns. As the fiber-fiber friction increases, the ability of fibers to slide from each other during yarn and fabric deformation decreases [40].

Furthermore, the fibers properties can be improved by chemical treatments. The chemical called “softeners” are usually used to reduce fiber-fiber friction, which makes the fabric move and flow more easily. Another method that normally used in cotton fiber is mercerization. As cellulose is mercerized, the overall shape of the fiber become more circular and more uniform than its irregular form thus becomes stronger and smoother to touch. With its round shape, mercerized cellulose becomes more lustrous [40].

Finally, crystallinity of fiber also affects the handle of the fabrics. If the molecules in a fiber are aligned along the fiber axis, the fiber will be strong in uniaxial tension along the fiber axis. A more crystalline fiber is more resistant to bending [40].

Effect of yarn

The twist of the yarns, which the fabrics are made of, is one of the main parameter affecting the fabric behavior including bending, stiffness, and shearing property [39]. The amount of twist, together with the characteristics of the fibers, determines the appearance and feels of the yarn. The fabric made from yarn with higher levels of twist is known to have higher bending stiffness, less compressibility, less fiber mobility, lower surface friction, less bulkiness than similar fabric made of yarns with less twist. Increase yarn twist leads to increase fiber friction within the yarn structure and reduce softness and bulkiness [40].

In filament yarn, the texturizing process is used to modify the handle of the yarn by adding bulkiness and stretchiness to the filaments and therefore change the smooth surface feel of fabrics [40]. The feel of textured-yarn fabrics against the skin is considerably different than that of flat-yarn fabric. Textured yarns give a fabric more pleasant hand, fabric becomes warmer and softer and it has less synthetic feeling [39].

Comparing multifilament yarns of the same size and fiber composition, yarns containing more filaments are much softer than yarn containing fewer filaments. The cross-section of synthetic fibers depends on the shape of the spinneret and the behavior of fiber dope when it comes out of the spinneret solidifies. The noncircular cross-sectional shape fibers have led to improve fabric properties and comfort. Furthermore, other modifications of fiber including microfibers and hollow fibers play important role in industries.

<u>Effect of fabric</u>

Fabric construction and yarn densities play major role in determining fabric handle [39]. Woven fabric surface is normally smoother than knitted fabric. A smooth fabric surface provides a bigger contact area with the skin and heat flow, while a rougher fabric surface has less contact area. Therefore, a smoother fabric surface has better heat conduction and a cooloer feeling [41]. The fabric finishing in both mechanical and chemical treatment affects to handle and comfort. The finishing state of the fabrics has considerable influence on their thermal touch sensation and water-vapor permeability [42].

2.6.3 Body movement comfort

Body movement comfort is the ability of a textile to allow freedom of movement, reduce burden, and body shaping, as required. In general, body movement increases the transport of air through the textile barrier, which in turn extracts heat from the zone between the body and the textile layers, or between the individual textile layers, and reduces the efficiency of the insulating capability of the clothing. The increase in air transfer between the body and the environment through a textile layer is due to a combination of two factors: the increased air flow velocity and the effect of pumping of the textiles layer while bending during body movement [43].

2.7 Non-sensorial comfort

Non-sensorial comfort deals with physical process which generates the stimuli like heat transfer by conduction, convection and radiation, moisture transfer by diffusion and evaporation. Non-sensory comfort is not only comprised of thermal and moisture transmission but also includes air permeability, water repellency, and water resistance.

2.7.1 Air permeability

The air permeability of the fabric is the measure of how well its allows the passage of air through it. The passage of air is an important for a number of fabric end uses such as industrial filters, tents, parachutes and so on. A material that is permeable to air is usually permeable to water, in either the vapor or the liquid phase. So, the moisture-vapor permeability and the liquid-moisture transmission are normally closely related to air permeability.

2.7.2 Water vapor transmission

The human body cools itself by sweat production and evaporation during periods of high activity. The clothing must be able to remove this moisture in order to maintain comfort and reduce the degradation of thermal insulation caused by moisture build-up in a cold environment. A breathable textile allows extra heat loss by evaporation of moisture through the clothing layers. If clothing layers are impermeable, the moisture is captured between skins. Then, the heat is accumulated in the body resulting in discomfort situation.

2.7.3 Water repellency

Water repellency treatment modifies the surface tension property of fiber or fabric so that it repels water drop. This can be used in outdoor textile such as tent and raincoat. On the other hand, water generated at the body surface as perspiration should be removed quickly if comfort is desired.

2.8 Previous study

Varshney, R.K. et al. [44] studied the effect of linear densities and profiles of polyester fibers on the physiological properties of their fabrics.

Marmarali, A. et. al [45] investigated the thermal comfort parameters of the knitted fabrics made from new yarns generation. A type is tetra-channel polyester which pulls or wicks moisture away from skin to outer layer of fabric. B type is a high functional polyester fiber designed with slots conduct to siphon effect. C type has a patented blend of natural and synthetic fibers. The results found that the looser fabrics possess high insulation and high air permeability values that C type yarn showed the highest air permeability.

Tusief, M.Q. et al [46] studied the effect of various yarn counts and polyester/cotton blend ratios on the comfort of knitted fabric. The increasing share of polyester in the blend and the fine count for yarn put negative impact on the comfort of the knitted fabric.

Özkan, E.T and Kaplangiray, B. M. [47] investigated thermophysiological comfort properties of ring staple polyester, textured polyester, and special type of polyester knitted fabric. The results showed that, textured polyester yarn knitted fabrics were showed the highest air permeability values than moisture management polyester in same yarn count and knit structure. Lower filament number fabrics showed higher thermal resistance values in same yarn count of fabrics.

Dave, J. et al. [48] studied hydrolysis of polyester fabric with sodium hydroxide to impart hydrophilicity and other comfort-related properties to polyester textiles. Alkali degraded polyester by saponification of its ester linkages resulting in a loss in weight of the fabric. Weight loss increased linearly with treatment time and nonlinearly with alkali concentration and reaction temperature. The surface hydrophilicity and feel of the fabric were improved by alkaline hydrolysis, while moisture regains and crease recovery angle remained unchanged.

CHAPTER III

EXPERIMENTAL

3.1 Materials

1) Standard polyester texture yarn semi dull 150D/2/96F intermingle (Kanwal Textile Co., Ltd. Thailand)
2) Cool quick yarn 150D/2/192F cross shape (+) cross-sectional (Kapak Textile Co., Ltd, Taiwan)
3) Micropolyester yarn 150D/2/384F intermingle (Kanwal Textile Co., Ltd. Thailand)
4) Micropolyester yarn 150D/2/576F intermingle (Kanwal Textile Co., Ltd. Thailand)
5) Ply twisted yarn 300D/288F with 120 TPM (S.R. Spinning CO.,Ltd., Thailand)
6) Ply twisted yarn 300D/288F with 200 TPM (S.R. Spinning CO.,Ltd., Thailand)

3.2 Weaving

In this research, twill 2/2 fabric construction was applied for all types of six different weft yarns. In order to keep other factors stable, only weft yarns were changed. The six different yarn counts were the same denier and all types of weft yarn were weaved in the same set of warp yarn using Nissan 210 Model 551 weaving machine (Nissan, Japan). The yarn count in warp direction was 150D/2/96F which D stands for denier and F stands for filament. The density per inch of warp and weft direction was 88 and 76, respectively. Then, the 6 different types of yarn in one piece 2 meters each were produced. After that, the standard dyeing and finishing process were applied to all fabrics.

3.3 Fiber cross sectional shape

Cross-sectional fibers were carried out under visible light using Olympus BX41 optical microscope (Olympus Corporation, Japan) using 200× magnifications. The fiber cross-section was used to see how the different in geometry and size of all six yarn types.

3.4 Mechanical properties

Every specimen must be condition under standard atmosphere at least 8 hours before testing at relative humidity of 65 ± 4% and a temperature of 20 ± 2 °C.

3.4.1 Tensile strength

Tensile strength is a determination of maximum force and elongation at maximum force. The testing strip method of ISO 13934-1: 1999(E) was used with Instron 5566 universal testing machine (Instron (Thailand) Limited, Thailand) (Figure 3.1). From each test sample, two sets of test specimens were to be prepared, one set in the warp direction and the other in the weft direction. Each test specimen was cut with its length parallel to the warp or the weft of the fabric and was sufficiently wide or allows the necessary fringes. Threads were removed in approximately equal numbers from each of the long edges of the cut strip until the test specimen was as sample size needed. Each set consisted of five test specimens. Sample size for the experiment was

50 mm in width and 300 mm in length. The gauge length was 200 mm and rate of extension was 100 mm/min. The calculation and expression of result showed the arithmetic mean of the maximum force in newtons for each direction tested.

Figure 3.1 Instron 5566 UTM

3.4.2 Tearing strength

Tearing strength is a determination of maximum force and elongation at maximum force. The testing strip method of ISO 13934-1: 1999(E) was used with Instron 5566 universal testing machine (Instron (Thailand) Limited, Thailand) (Figure 3.1). Two sets of test specimens were cut, one set in the warp direction and another in weft direction. Five test specimens were used in each set. The sample sizes ranged from 200 mm in length and 50 mm in width. A longitudinal slit 100 mm in length began from the center of the width. The mark was shown at 25 mm from the uncut end of the strip to indicate the position of the tear at the completion of the test. The test specimen was called trouser-shaped as shown in Figure 3.2.

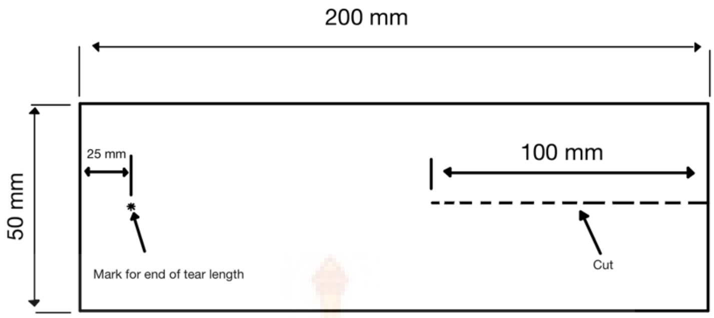

Figure 3.2 Trouser-shaped test specimen

3.4.3 Stiffness

Stiffness is an important mechanical property that influences fabric handle, clothing appearance and fit. According to ASTM D-1388-08, cantilever test was applied in this research; employing the principle of cantilever bending of the fabric under its own mass. The specimen was cut into 2.5 cm × 22 cm. The specimen was placed on the horizontal platform and slided until the fabric overhang like a cantilever. The length of fabric was measured and from these values, the stiffness was calculated.

$$G = 0.10MC^3$$

Where, G = stiffness

M = mass of fabric (gsm)

C = length of fabric drop to 41.5 degree (cm)

3.5 Air permeability

Air permeability means the velocity of air flow passing through a known area under a prescribed air pressure. Air permeability was tested according to ISO 9237:1995(E) by using M021A air permeability tester machine (SDL Atlas Ltd, Hong

Kong) displayed in Figure 3.3. The differential pressure between the two fabric surfaces and testing surface area were 100 Pascal and 20 cm^2, respectively.

Figure 3.3 The M021A air permeability tester

3.6 Abrasion test

Abrasion resistance is the ability of a fabric to resist surface wear caused by flat rubbing contact with another material. The testing method was executed to make specimen abraded by a pair of grinding wheels under the specified load (Figure 3.4). The end point of the test was determined as weight loss method that the fabric was abraded for 50 cycles with speed at 60 rpm. The initial weight and the final weight were determined for calculating the per cent weight loss.

$$\text{Weight loss index (per cycle)} = \frac{(A - B)}{\text{No. of cycle}} \times 100$$

Where, A = sample weight before test

B = sample weight after test

Figure 3.4 Abrasion testing machine

In addition, the morphologies of fabric before and after testing were obtained using a JSM-5410LV scanning electron microscope (JEOL Ltd, Japan) at 100× magnification.

3.7 Liquid moisture management property of textile fabrics

The liquid moisture management property of textile test is method that produces objective measurements of liquid moisture management properties of woven fabrics. The obtained results were based on water resistance, water repellency and water absorption characteristics of the fabric's structure, including the fabric's geometric and internal structure and the wicking characteristics of its fibers and yarns. This testing method was applied from AATCC 195:2009. The specimen was cut into 3 pieces with 8×8 cm^2 in size which was taken diagonally across the width of the sample.

The liquid moisture management properties of textile were evaluated by placing a fabric specimen between two horizontal (upper and lower) electrical sensors each with seven concentric pins. A predetermined amount of the test solution that aided the measurement of electrical conductivity change was dropped onto the center of the upward-facing test specimen surface. The test solution was free to move in three directions: radial spreading on the top surface, movement through the specimen from top surface to the bottom surface, and radial spreading on the bottom surface of the specimen. During the test, changes in electrical resistance of specimen were measured and recorded. The electrical resistance readings were used to calculate fabric liquid moisture change in multiple directions of specimens. Foe each sample tested, compile the average values for each measurement unit as follows:

Absorption rate (AR_T) (top surface) and (AR_B) (bottom surface)

Absorption rate is the average speed of liquid moisture absorption for the top and bottom surfaces of the specimen during the initial change of water content during a test.

Accumulative one-way transport capability (R)

Accumulative one-way transport capability is the difference between the area of the liquid moisture content curves of the top and bottom surfaces of a specimen with respect to time.

Top surface (T)

Top surface is the side of specimen facing the upper sensor. This is the side of the fabric contacting with the skin.

Bottom surface (B)

Bottom surface is the side of the specimen place down against the lower electrical sensor which is the side of the fabric that would be the outer exposed surface of the garment when it is worn.

Maximum wetted radius (MWR_T) and (MWR_B)

Maximum wetted radius is the greatest ring radius measured on the top and bottom surfaces.

Spreading speed (SS)

Spreading speed is the accumulated rate of surface wetting from the center of the specimen.

Overall moisture management capability (OMMC)

Overall moisture management capability is an index of the overall capability of a fabric to transport liquid moisture as calculate by combining three measured attributes of performance which are $AR_{B,}$ R, and $SS_{B.}$ The OMMC formula is:

$$OMMC = C_1 \times AR_B + C_2 \times R_B + C_3 \times SS_B$$

Where, C_1 = 0.25

C_2 = 0.5

C_3 = 0.25

R = one-way transport capability

AR = absorption rate

SS = spreading speed

Wetting time (WT_T) (top surface) and (WT_B) (bottom surface)

Wetting time is the time in seconds when the top and bottom surfaces of the specimen begin to be wetted after the test is started.

The evaluation measurement units, grading and classification was used Table 3.1 and Figure 3.4 to report.

Table 3.1 Grading table of all indices

Index		Grade				
		1	2	3	4	5
Wetting time (s)	Top	≥ 120	20-119	5-19	3-5	< 3
	Bottom	≥ 120	20-119	5-19	3-5	< 3
Absorption rate (%/s)	Top	0-9	10-29	30-49	50-100	> 100
	Bottom	0-9	10-29	30-49	50-100	> 100
Max wetted radius (mm)	Top	0-7	8-12	13-17	18-22	> 22
	Bottom	0-7	8-12	13-17	18-22	> 22
Spearding speed (mm/s)	Top	0.0-0.9	1.0-1.9	2.0-2.9	3.0-4.0	> 4.0
	Bottom	0.0-0.9	1.0-1.9	2.0-2.9	3.0-4.0	> 4.0
One-way transport capability ®		< -50	-50-99	100-199	200-400	> 400
Overall moisture management capability (OMMC)		0.00-0.19	0.20-0.3	0.40-0.59	0.60-0.80	> 0.80

Figure 3.5 Grading summary table

CHAPTER IV

RESULTS AND DISCUSSION

The requirement for fabrics is not only mechanical and dimensional properties but also comfort properties. The thermal comfort of clothing as determined by the movement of heat, moisture, and air, is a large portion of the total clothing comfort [49]. In this chapter, six different yarn types were weaved as the weft yarn by using water jet loom weaving machine.

4.1 Cross-sectional fibers

Optical micrographs of each yarn were taken by using an Olympus BX41 optical microscope with magnification of 200 times. The fiber cross-sectional shapes are presented in Figure 4.1.

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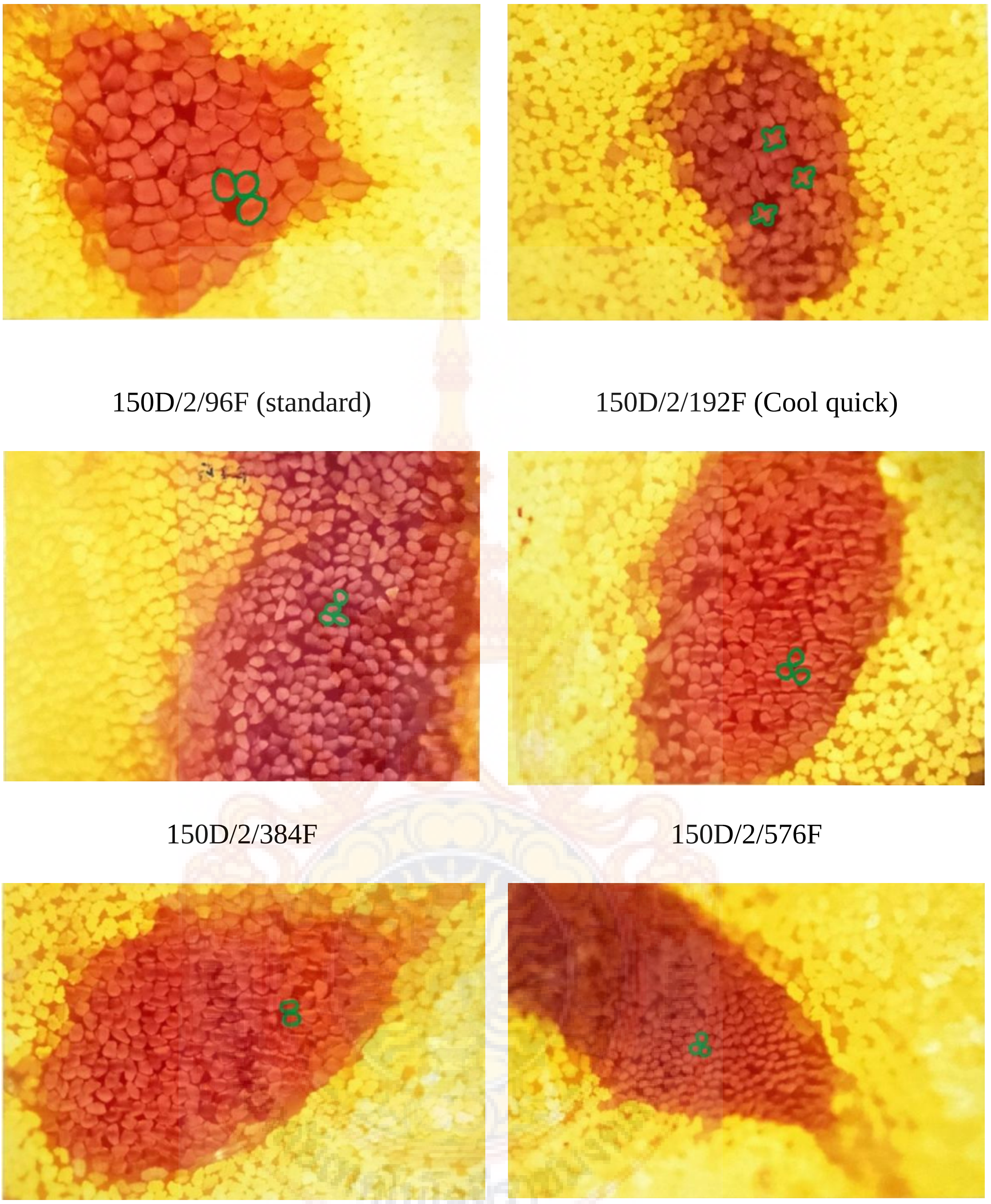


Figure 4.1 Cross-section of 6 yarn types

Even they were the same yarn count; the fibers were different in size and shape (Figure 4.1). The polyester yarn 150D/2/96F (standard) was more circular and bigger fibers in comparison to other yarn types. Cool quick polyester yarn

150D/2/192F was cross shape and smaller fibers compared with standard yarn. Both micro polyester yarn 150D/2/384F and micro polyester yarn 150D/2/576F were circular and fine fibers. Moreover, ply twist polyester yarn 300D/288 with both 120 TPM and 200 TPM were round and tight fibers.

4.2 Breaking load and elongation at break

Breaking load and elongation at break were obtained using Instron 5566 universal testing machine. The results are shown in Table 4.1-4.2, Figure 4.2-4.3, and appendix A.

Table 4.1 Breaking load of fabrics

Yarn types	Breaking load (N)	
	Warp	Weft
Standard yarn 150D/2/96F	1,843.01 ± 43.83	1,747.88 ± 99.41
Cool quick yarn	1,820.85 ± 111.50	1,453.86 ± 97.81
Micro yarn 150D/2/384F	1,908.16 ± 26.62	1,783.66 ± 25.47
Micro yarn 150D/2/576F	1,785.77 ± 83.62	1,808.63 ± 89.72
Ply twist yarn 300D/288F 120TPM	1,911.50 ± 38.87	1,951.33 ± 42.66
Ply twist yarn 300D/288F 200TPM	1,813.98 ± 123.83	1,899.81 ± 18.69

Table 4.2 Percentage elongation at break of fabrics

Yarn types	Elongation at break (%)	
	Warp	Weft
Standard yarn 150D/2/96F	47.22 ± 0.77	53.20 ± 1.10
Cool quick yarn	50.53 ± 1.68	45.35 ± 1.43
Micro yarn 150D/2/384F	52.75 ± 0.10	40.00 ± 0.29
Micro yarn 150D/2/576F	55.68 ± 1.68	42.23 ± 2.04
Ply twist yarn 300D/288F 120TPM	58.15 ± 0.41	54.47 ± 1.45
Ply twist yarn 300D/288F 200TPM	53.80 ± 2.30	43.02 ± 0.61

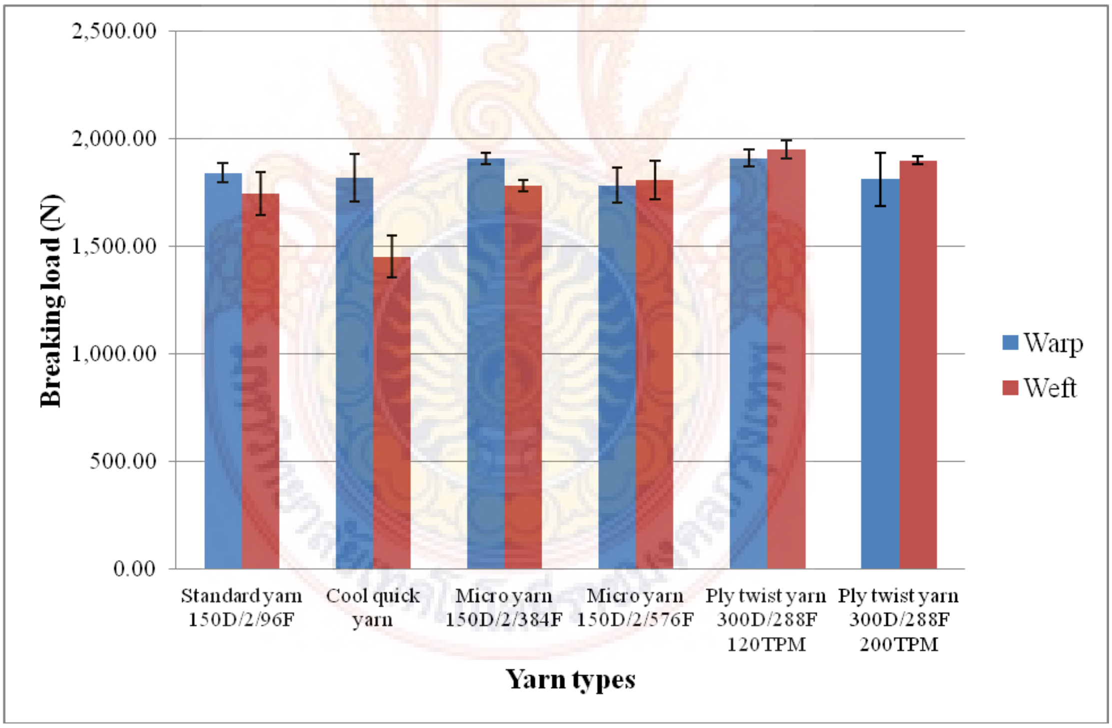


Figure 4.2 Breaking load of fabrics

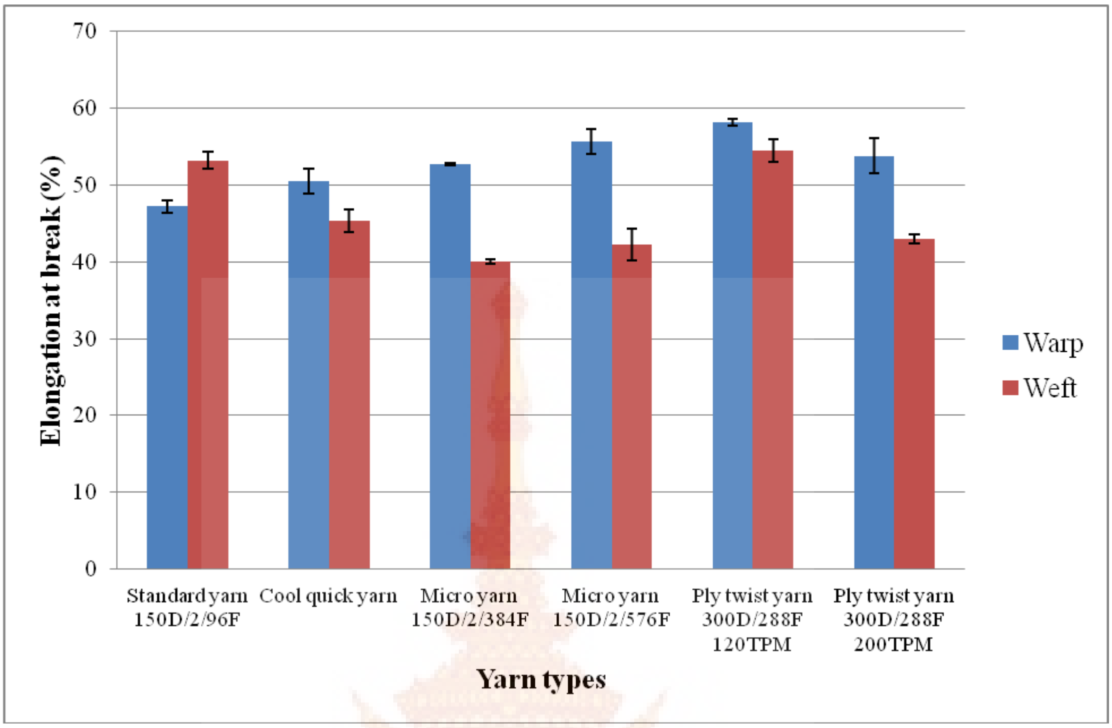


Figure 4.3 Percentage elongation at break of fabrics

From Table 4.1-4.2 and Figure 4.2-4.3, changing the weft yarn types influenced the warp and weft directional breaking load and elongation at break of fabrics.

The warp directional breaking load of fabric containing microyarn 150D/2/384F and ply twisted yarn 300D/288F 120 TPM were higher than the fabric using standard yarn. In the other hand, the warp directional breaking load of Cool quick yarn, micro yarn 150D/2/576F and ply twisted yarn 300D/288F 200TPM were lower than the standard one. In the case of weft direction, fabrics made from other yarns in weft direction gave the higher breaking load than standard fabric except Cool quick yarn (Table 4.1 and Figure 4.2).

By changing weft yarn, it affected the breaking load in warp and weft direction. The physical construction of fabrics was changed causing the strength transfer efficiency of warp and weft yarn in woven fabric. According to Taylor [50], strength of woven fabrics of common constructions usually ranges between 85% and 125% of the integral strength of all yarns in the direction tested. It is very important for fabric developer to be able to know that how much of the strength of the individual yarns will translate into the fabric strength in a particular direction after weaving in a specific woven structure.

The physical characteristic of each yarn was different. The ply twisted yarn 300D/288F 120 TPM was the strongest yarn. Ply twist helped to increase durability and flexibility of yarn. The proper amount of twist showed a positive correlation with yarn strength [51]. For micro polyester yarn, the breaking load showed slightly higher than that of standard yarn and finer filament was stronger than another lower filament (Table 4.1 and Figure 4.2) because of an increase in breaking load as the diameter for the monofilament decreased [52]. The filament fineness has considerable effect on breaking strength and breaking elongation. Higher fabric breaking strength results were observed for finer filament in fabric structure [53]. The decrease in yarn diameter led to the reduction of breaking elongation of the constituent yarns, which reflected in lower fabric breaking elongation. It was seen that breaking load and breaking elongation values of yarns with cross cross-sectional shapes were low. Therefore, it was argured that round cross-sectional shape was ideal for yarn with high breaking load and breaking elongation values [54]. The yarn twist affected the fabric extension. Elongation increased with increasing twist. However, the presence of higher twist level in the yarn resulted in loss of extensibility [55].

The fiber cross-section in Figure 4.1 showed the different fineness of yarn that affected to breaking load of fabric. Yarn count and its filament were identified by number. In this study, two types of micro polyester yarn with different amount of filament were used. For example, the number 150 refers to yarn count in denier; 192 means number of filaments; and 2 is the result of twisting two yarns together. Therefore, the output of 150D/2/384F is 300 denier yarn with 384 filaments (192F+192F). The lowest weft directional tensile strength was Cool quick yarn.

According to the fiber cross-sectional shape of fiber in Figure 4.1, Cool quick yarn exhibited low inter-fiber contact potential around 27% while circular cross-sectional shape presented 100% inter-fiber contact potential. Fiber friction was affected by the surface structure of fibers and lower friction leaded to lower yarn strength [56].

4.3 Tearing strength

Tearing strength is used to evaluate the ability of fabric resistant to tear along the breach or damaged position in the process of use. The numerical test results are shown in Table 4.3 and appendix B and graphically presented in Figure 4.4.

Table 4.3 Tearing load of fabrics

Yarn types	Tearing load (N)	
	Warp	Weft
Standard yarn 150D/2/96F	76.05 ± 1.25	82.83 ± 1.40
Cool quick yarn	71.10 ± 1.66	52.10 ± 2.36
Micro yarn 150D/2/384F	71.93 ± 3.25	62.28 ± 1.80
Micro yarn 150D/2/576F	67.44 ± 3.24	59.03 ± 2.29
Ply twist yarn 300D/288F 120TPM	74.12 ± 2.66	69.11 ± 2.69
Ply twist yarn 300D/288F 200TPM	68.53 ± 1.82	58.43 ± 2.19

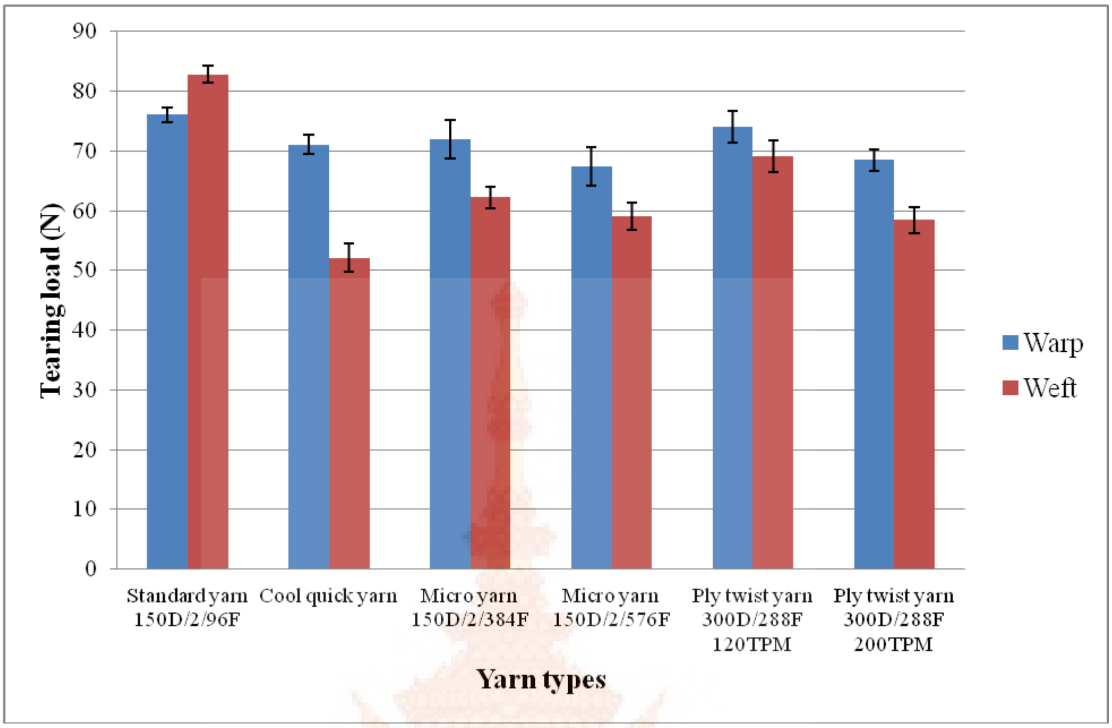


Figure 4.4 Tearing load of fabrics

The tearing load was affected by changes in weft yarn types (Table 4.3 and Figure 4.4). The standard yarn revealed higher tearing load properties than other weft yarn types. Tearing strength of fabrics depended on the mobility of the yarns within the fabric structure. Even though a weft yarn was changed at the same fabric construction, it affected to total strength transfer efficiency of warp and weft yarn. The movement of the yarns was restricted in tight constructions and resulted in a low tearing strength. Loose and open constructions allowed yarns to move and group together, thus resulted in a high tearing strength [57].

It was observed from Figure 4.4 that an increase in weft TPM decreased the tearing load of fabric when the warp particulars were kept constant. Teixeira [58] also reported that the most important factor which influenced the tearing strength of the fabric was its surface or yarn-to-fabric friction. Increase in TPM caused a corresponding decrease in the elongation of the yarn and these resulted in decrease in the thread breaking strength. Secondly, increase in TPM decreased the area of cross-section of the yarn and thus increased the yarn-to-fabric friction. Due to this, the force needed for the withdrawal of yarn from the fabric was increased and this resulted in decrease in the tearing strength of the fabric. It may be concluded that decrease in tearing load with increase in TPM was due to decrease in elongation and yarn breaking strength and increase in the yarn-to-fabric friction.

The fiber cross-sectional shape had statistically meaningful effect on tearing load values. Tearing load of fabric constituting full fibers was expected to be higher than tearing load of fabrics constituting cross fibers [59]. It was noticed that the number of filaments presented an effect on fabric tearing strength that was the number of filament increased; the fabric tearing strength decreased. This meant that the tearing strength of micropolyester fabric had lower tearing strength compared to other woven fabrics. This was because the higher number of filaments in the yarn cross-section. Under tearing force, the higher number of filaments in yarn cross-section behaved as single filament. For the fabrics having lower number of filaments, these filaments withstanded the tearing load individually [60].

4.4 Stiffness

The effect of structure of weft yarn on fabric stiffness have been investigated displayed in Table 4.4, Figure 4.5 and appendix C, keeping the warp yarn, fabric setting and weaving the same.

Table 4.4 Stiffness of fabrics

Yarn types	Weight (g/m^2)	Stiffness (g.cm)	
		Warp	Weft
Standard yarn 150D/2/96F	394	2,919.07 ± 0.00	2,054.05 ± 186.89
Cool quick yarn	395	2,003.72 ± 162.29	1,341.20 ± 192.21
Micro yarn 150D/2/384F	401	2,147.02 ± 200.63	2,090.55 ± 190.21
Micro yarn 150D/2/576F	421	1,515.73 ± 137.60	1,911.16 ± 91.90
Ply twist yarn 300D/288F 120TPM	428	1,739.06 ± 234.61	1,787.10 ± 181.67
Ply twist yarn 300D/288F 200TPM	400	2,194.88 ± 0.00	1,191.64 ± 0.00

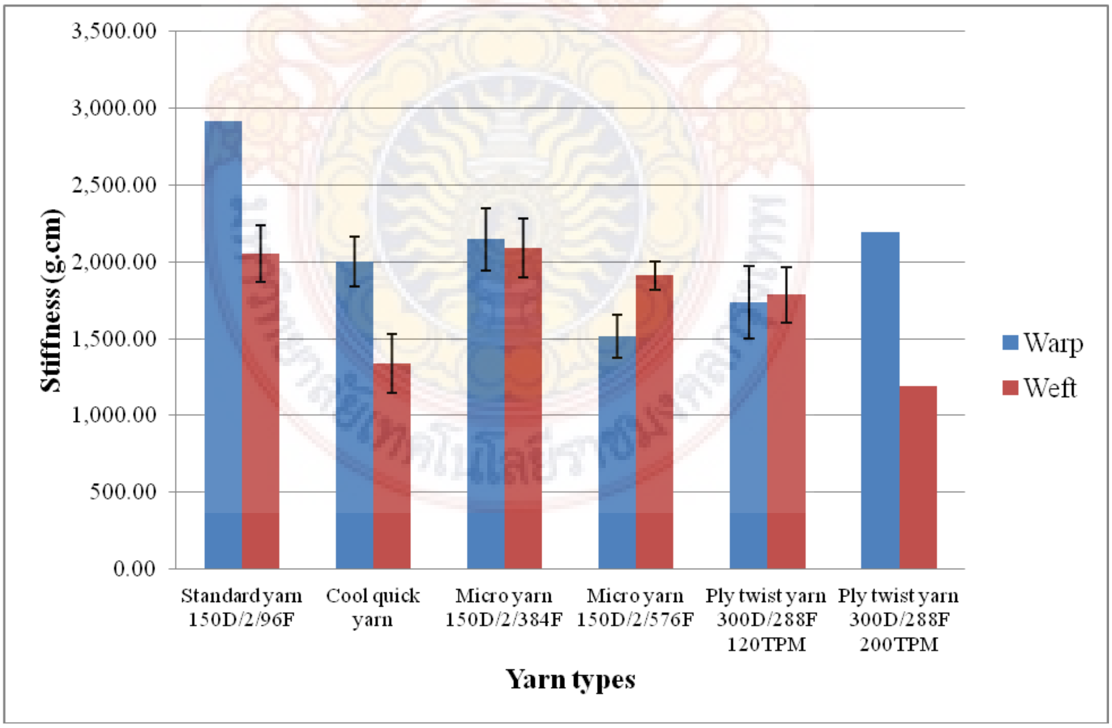


Figure 4.5 Stiffness of fabrics

As a result of the stiffness values of yarns shown in Table 4.4 and Figure 4.5, it was observed that the maximum stiffness values were obtained as 2,919.07 for the standard yarn in warp direction and 2,090.55 for micro yarn 150D/2/384F in weft direction, while the minimum values were obtained as 1,515.73 for micro yarn 150D/2/576F in warp direction and 1,191.64 for ply twist yarn 300D/288F 200TPM in weft direction. Change in the structure of weft yarn had a marked influence on warp-way stiffness and mariginal influence on weft-way stiffness.

It is well established that the characteristics of a fabric are dependent mainly on the type of fiber, yarn, weaving, and fabric setting used. When the type of fiber, weaving, and fabric setting are fixed, the structure of yarn is decided [61]. Yarn stiffness is usually controlled by fibre stiffness. Fiber stiffness depends upon fiber material, shape of cross-section and denier [62].

As the fiber fineness increased, resistance to bending decreased. It meant the fabric made from yarn of finer fiber was less stiff in feel [63]. In addition, it was found that an increase in TPM affected the stiffness of fabrics. This was because the increase in the twist level made a stronger interaction between the filaments. Also, the different fiber cross-sectional shapes affected the stiffness of fabrics.

4.5 Air permeability

The air permeability of woven fabric depends on many parameters of fabric. Thus, the determination of air permeability of woven fabric is highly complex. The results are shown in Table 4.5, Figure 4.6, and appendix D.

Table 4.5 Air permeability of fabrics

Yarn types	Air permeability ($cm^3/cm^2/s$)
Standard yarn 150D/2/96F	7.27 ± 0.31
Cool quick yarn	4.41 ± 0.35
Micro yarn 150D/2/384F	7.00 ± 0.27
Micro yarn 150D/2/576F	5.61 ± 0.33
Ply twist yarn 300D/288F 120TPM	5.01 ± 0.51
Ply twist yarn 300D/288F 200TPM	6.13 ± 0.39

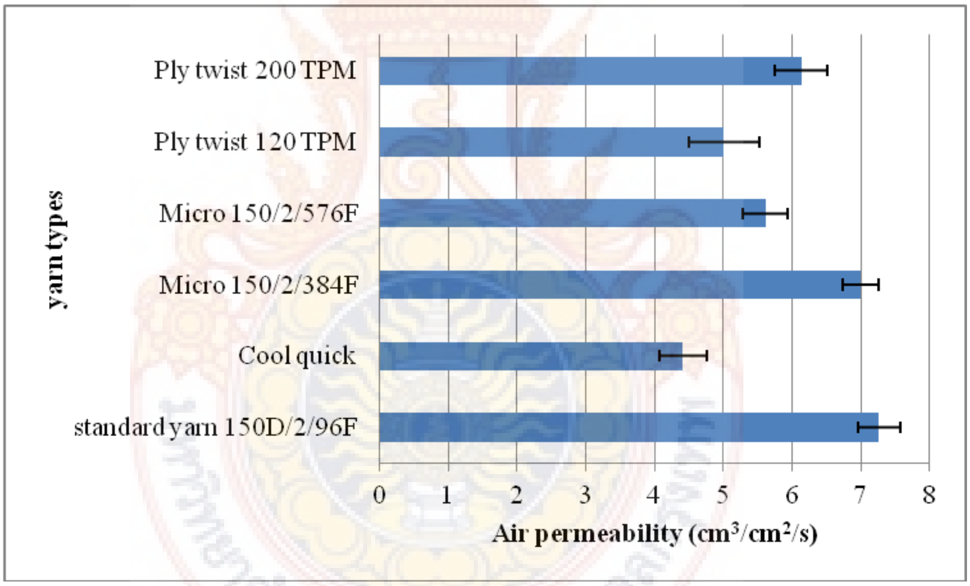


Figure 4.6 Air permeability of fabrics

It has been found that there were many factors that could affect the air permeability of a fabric. Several early studied of air permeability of different materials showed the following factors to affect air permeability: porosity, fabric thickness, fiber count, yarn twist, yarn crimp, and size of pores [64].

As shown in Table 4.5 and Figure 4.6, the standard fabric displayed the highest value of air permeability followed by micro polyester 150D/2/384F, polyester 300D/288F 200 TPM, micro polyester 150D/2/576F, polyester 300D/288F 120 TPM, and Cool quick yarn, respectively.

Studies on the structural factors influencing the air permeability of fabric assumed that air flow took place in the spaces between yarns. Therefore, the inter-yarn pore was an important parameter influencing the openness of the fabric structure [65].

It was shown that air permeability of micro polyester woven fabric was lower than those woven from normal polyester fibers. The statistical analysis proved that fabric air permeability has significantly affected with the number of filaments. The increased number of filament decreased the air permeability of the polyester woven fabrics [60].

As shown in Figure 4.6, fabric showed increased air permeability as the yarn twist factor increased. As twist multiplier increased, the yarn bilkiness reduced since the constituent fibers bound to the body of the yarn compactly. The openness size in the fabric would not be changed but the opened spaces became clearer with high twist multiplier since the yarn hairiness became reduced to a high extent. The clearner surface on fabric due to high twist level brought high permeable woven fabric. When a large twist was given to a yarm, it became compact and spaces in it was increased making the fabric more air permeable [66].

The woven fabric constituting cross fibers had a lower interyarn pore when compared with fabric constituting standard yarn for the same warp and weft density.

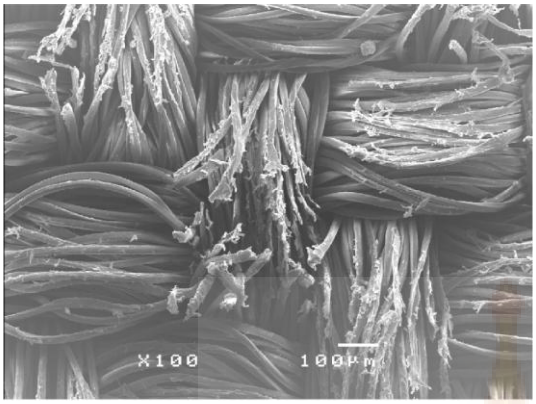
As a result, the air permeability values of this fabric were lower than fabric constituting standard yarn.

4.6 Abrasion resistance

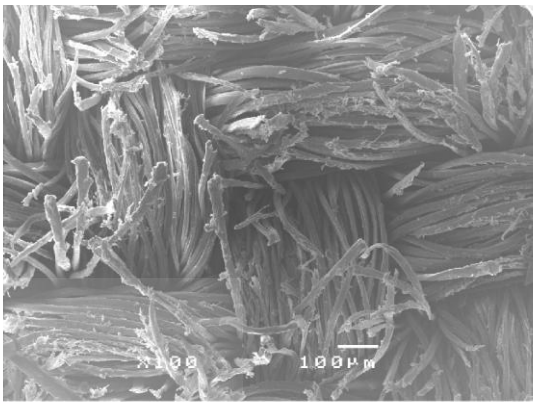
Abrasion resistance of the textile materials is very complex phenomenon and affected by many factors e.g. fiber, yarn, and fabric properties. The abrasion resistance of fabrics is displayed in Table 4.6 and appendix E. The fabric surface after test is shown in Figure 4.7

Table 4.6 Abrasion resistance of fabrics

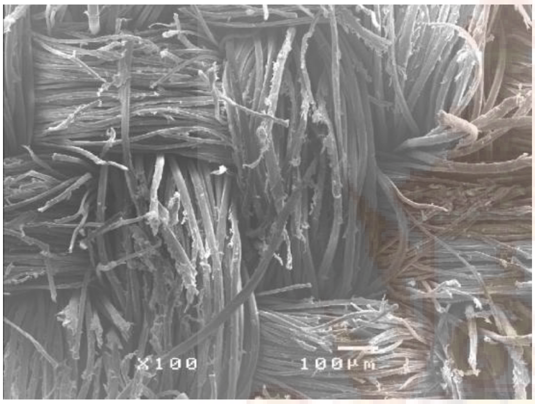
Yarn types	Weight loss index
Standard yarn 150D/2/96F	0.087 ± 0.001
Cool quick yarn	0.055 ± 0.003
Micro yarn 150D/2/384F	0.107 ± 0.001
Micro yarn 150D/2/576F	0.024 ± 0.002
Ply twist yarn 300D/288F 120TPM	0.033 ± 0.004
Ply twist yarn 300D/288F 200TPM	0.056 ± 0.002



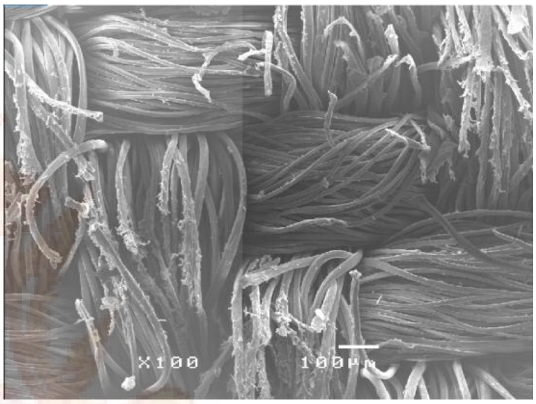
Standard yarn 150D/2/96F



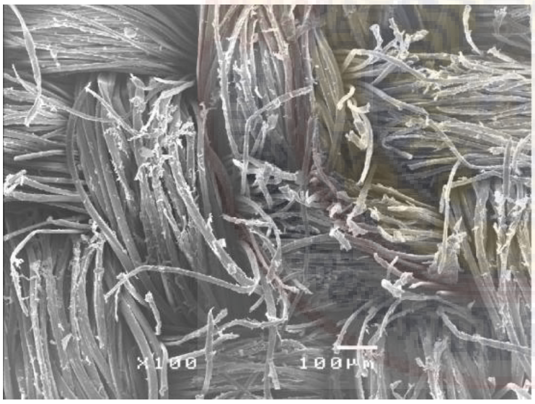
Cool quick yarn



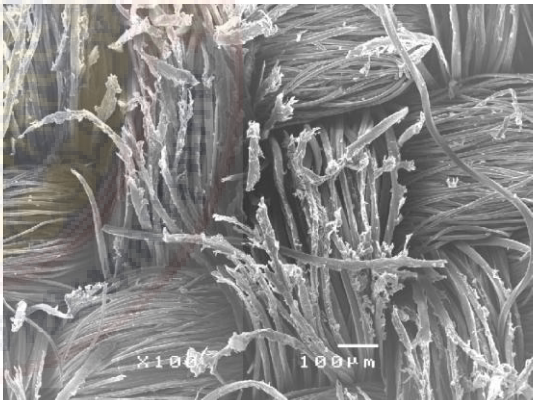
Micro yarn 150D/2/384F



Micro yarn 150D/2/576F



Ply twist yarn 300D/288F 120TPM



Ply twist yarn 300D/288F 200TPM

Figure 4.7 SEM micrographs of fabrics after abrasion test

From Table 4.6, the lowest weight loss index was micro yarn 150D/2/384F, followed by ply twisted yarn 300D/288F 120TPM, cool quick yarn, ply twisted yarn 300D/288F 200TPM, and standard yarn 150D/2/96F, respectively. Weight loss index was lower, the abrasion resistance quality of fabric was better (Figure 4.7).

Shape of filament cross section affected the abrasion. The cool quick dry showing a cross cross section had higher surface area than the standard yarn (round cross section). Therefore, the cross cross section would give unsatisfactory abrasion test results for a single filament. However, in this case, there was another factor affecting abrasion test result that was the number of yarn piles. As the number of ply threads per yarn increased, the mass per unit area increased amd it caused an improvement in abrasion characteristics of the fabric [67].

The comparison of micro yarn, using finer fibers in yarn production caused increment in the number of the fiber in cross section with higher cohesion which results better abrasion resistance [67]. Normally, at low twist, fibers could easily be removed from the yarn so that it was gradually reduced in diameter. At high twist levels, the fibers were held more tightly but the yarn was stiffer so it was unable to distort under pressure when being abraded (Figure 4.8) [67]. However, the increase of yarn twist above the optimum level increased the cohesion between the fibers and also the stiffness of yarn. Increase of stiffness may reduce abrasion resistance because the stiffer yarn is unable to flatten or distort under pressure when being abraded [68].

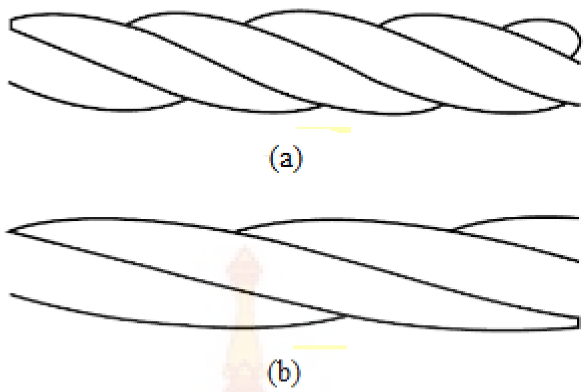


Figure 4.8 Twisting of the threads (a) high twist (b) low twist [69]

4.7 Liquid moisture management properties of textile fabrics

The aim of moisture management fabric is to make the skin feel dry. In order to achieve this, humidity should be evaporated and transfered to the atmosphere as soon as possible (Figure 4.9). From the testing done by moisture management tester, the moisture management properties value of 6 yarn types is shown in Table 4.7 – 4.12 and appendix F.

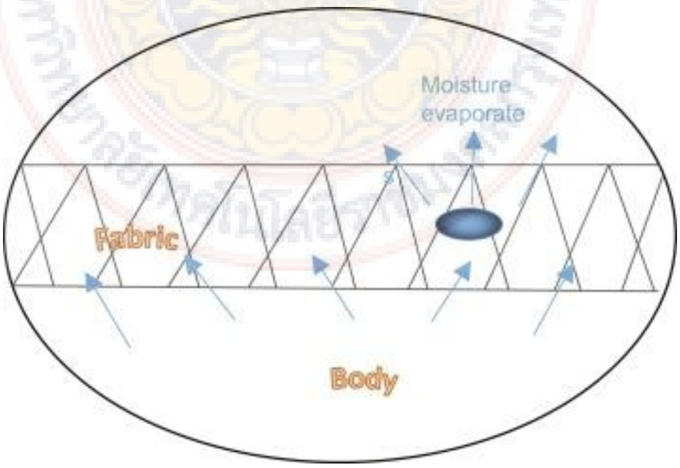


Figure 4.9 Moisture management in clothing [70]

Table 4.7 Moisture management properties value of fabric containing 150D/2/96F standard fiber

Measurement units	Top surface	Bottom surface
Wetting time (s)	4.23 ± 0.52	4.57 ± 0.67
Absorption rate (% / s)	24.17 ± 0.79	32.29 ± 2.83
Maximum wetting radius (mm)	15.0 ± 0.0	16.67 ± 2.89
Spreading speed (mm/s)	2.84 ± 0.30	3.42 ± 0.38
Accumulative one-way transport capability (%)	477.68 ± 48.79	
Overall (liquid) moisture management capability	0.76 ± 0.04	

Table 4.8 Moisture management properties value of fabric containing Cool quick

Measurement units	Top surface	Bottom surface
Wetting time (s)	7.10 ± 0.09	19.34 ± 6.91
Absorption rate (% / s)	49.14 ± 12.40	31.43 ± 6.18
Maximum wetting radius (mm)	15.0 ± 0.0	15.0 ± 0.0
Spreading speed (mm/s)	1.29 ± 0.13	1.66 ± 0.21
Accumulative one-way transport capability (%)	239.68 ± 59.77	
Overall (liquid) moisture management capability	0.44 ± 0.07	

Table 4.9 Moisture management properties value of fabric containing micro 150/2/384F

Measurement units	Top surface	Bottom surface
Wetting time (s)	7.03 ± 0.12	13.19 ± 1.55
Absorption rate (% / s)	65.29 ± 16.06	42.79 ± 2.90
Maximum wetting radius (mm)	15.0 ± 0.0	15.0 ± 0.0
Spreading speed (mm/s)	1.64 ± 0.05	2.27 ± 0.20
Accumulative one-way transport capability (%)	297.46 ± 32.04	
Overall (liquid) moisture management capability	0.58 ± 0.06	

Table 4.10 Moisture management properties value of fabric containing micro 150/2/576F

Measurement units	Top surface	Bottom surface
Wetting time (s)	6.97 ± 0.05	11.78 ± 3.60
Absorption rate (% / s)	68.67 ± 17.90	33.39 ± 1.49
Maximum wetting radius (mm)	15.0 ± 0.0	15.0 ± 0.0
Spreading speed (mm/s)	1.67 ± 0.25	1.80 ± 0.20
Accumulative one-way transport capability (%)	313.19 ± 62.87	
Overall (liquid) moisture management capability	0.54 ± 0.09	

Table 4.11 Moisture management properties value of fabric containing ply twist 300D/288 with 120 TPM

Measurement units	Top surface	Bottom surface
Wetting time (s)	6.15 ± 0.57	16.70 ± 3.17
Absorption rate (% / s)	49.38 ± 2.05	45.24 ± 26.92
Maximum wetting radius (mm)	15.0 ± 0.0	15.0 ± 0.0
Spreading speed (mm/s)	1.42 ± 0.11	1.62 ± 0.23
Accumulative one-way transport capability (%)	263.33 ± 21.47	
Overall (liquid) moisture management capability	0.50 ± 0.04	

Table 4.12 Moisture management properties value of fabric containing ply twist 300D/288 with 200 TPM

Measurement units	Top surface	Bottom surface
Wetting time (s)	7.40 ± 1.25	11.45 ± 1.24
Absorption rate (% / s)	57.64 ± 27.65	34.90 ± 2.93
Maximum wetting radius (mm)	15.0 ± 0.0	13.33 ± 2.89
Spreading speed (mm/s)	2.26 ± 0.24	2.40 ± 0.32
Accumulative one-way transport capability (%)	250.55 ± 16.56	
Overall (liquid) moisture management capability	0.52 ± 0.03	

From the Table 4.7 – 4.12 showed the liquid moisture management predetermined indices value. The moisture management tester measures moisture in different direction of the fabric to obtain indices of moisture transfer. Wetting time, absorption rate, maximum wetted area, spreading speed, accumulative one-way transport index and overall moisture-management capacity are measured to determine the appropriateness of fabrics for the different apparel end uses.

Wetting time

The wetting time of fabrics was measured in this study and the result is shown in Figure 4.10.

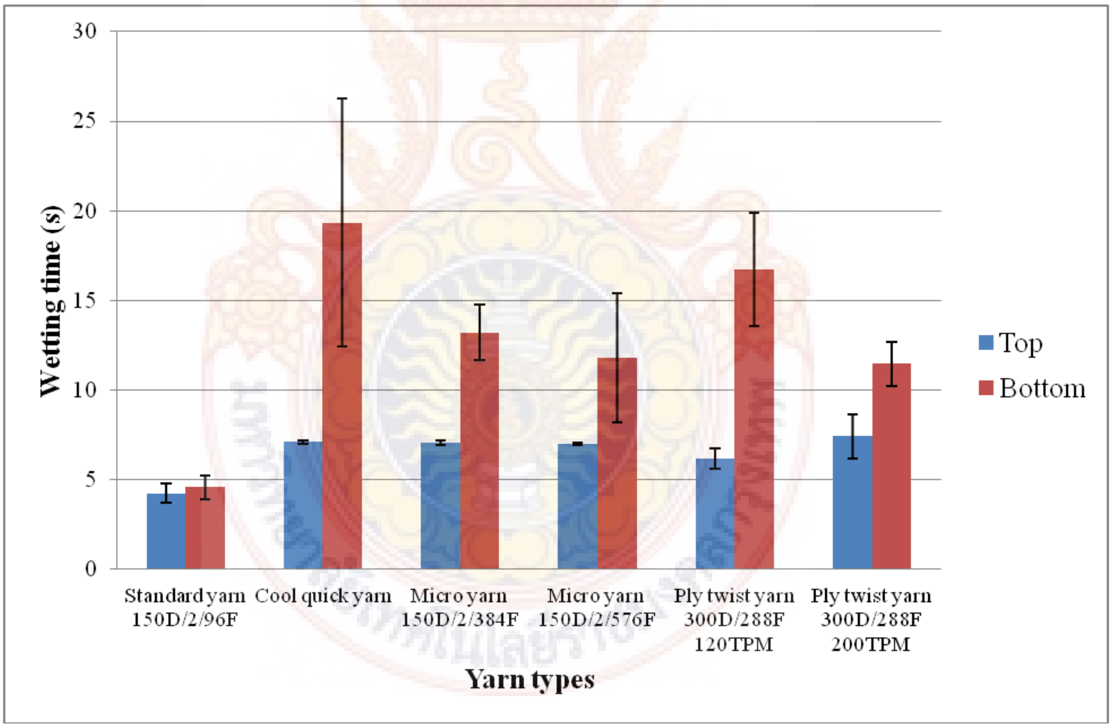


Figure 4.10 Wetting time

For the wetting time of top surface and bottom, standard polyester yarn 150D/2/96F displayed the fastest when comparing with other yarn types (Figure 4.10). The cross fibers could have been packed densely in the yarn structure.

Absorption rate

Absorption rate is defined as the average speed of liquid moisture absorption for the top and bottom surfaces of the specimen during the initial change of water content during a test. The absorption rate of samples is shown in Figure 4.11.

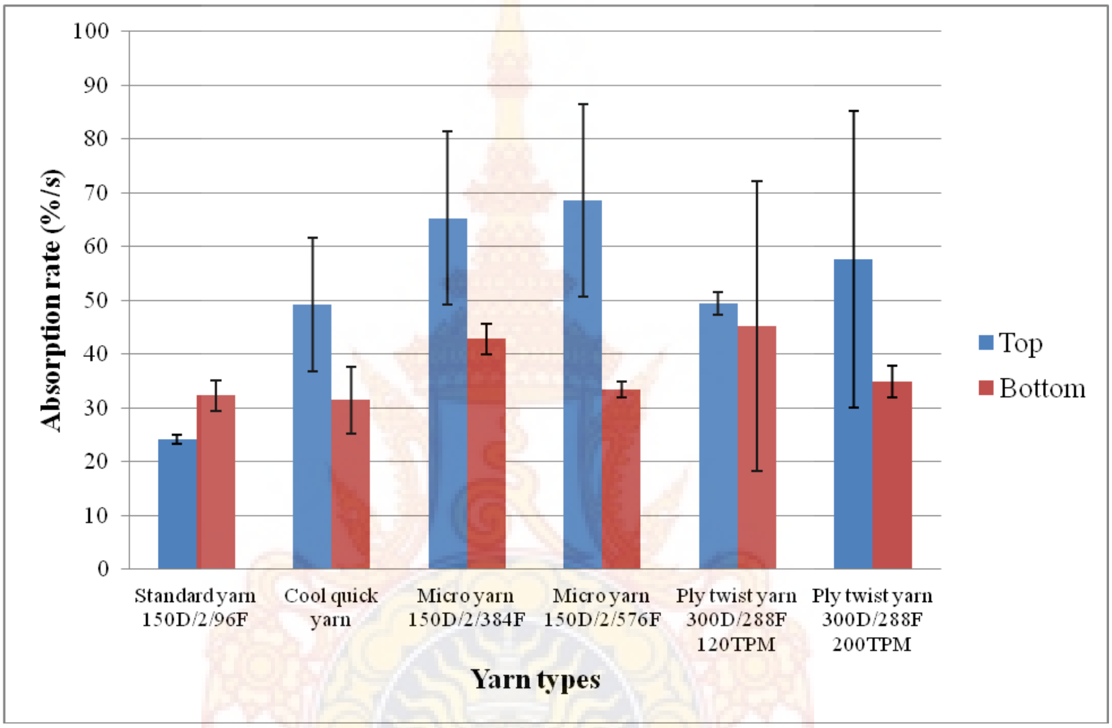


Figure 4.11 Absorption rate

For absorption rate, the maximum absorption of top surface was micro polyester yarn 150D/2/576F while maximum absorption of bottom was ply twist polyester yarn 300D/288F 120 TPM as shown in Figure 4.11.

Max wetted radius

Maximum wetted radius is defined as the greatest ring radius measured on the top and bottom surfaces. The max wetted radius is displayed in Figure 4.12.

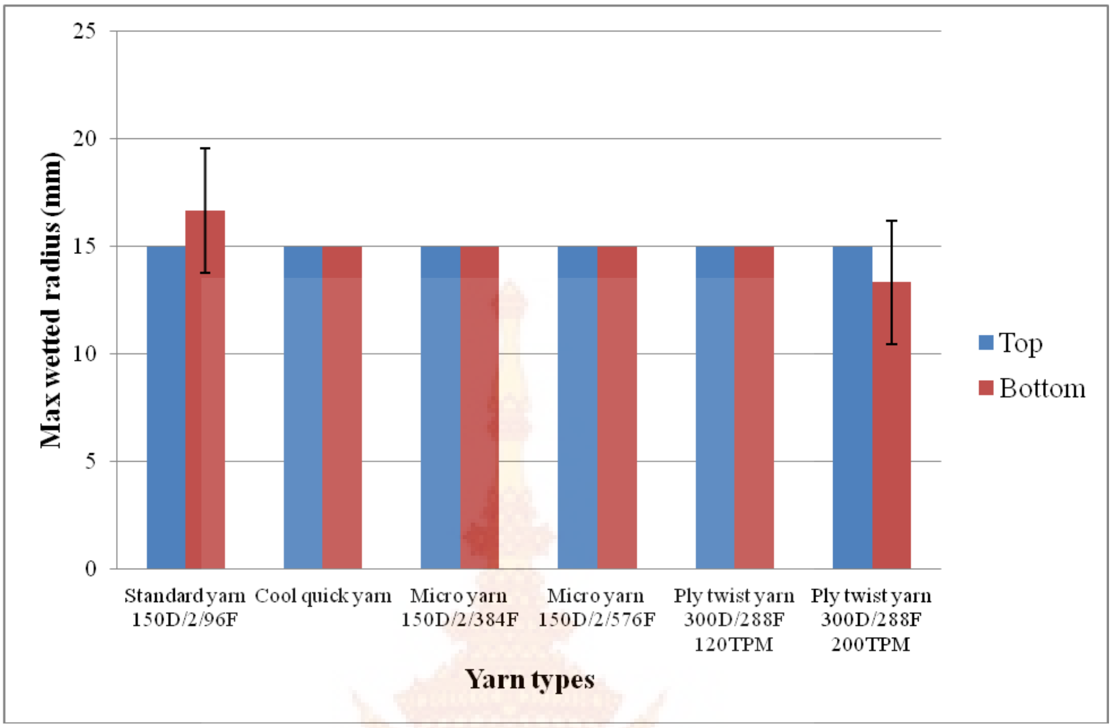


Figure 4.12 Max wetted radius

In max wetted radius, the higher radius was better grading value. The max wetted radius values of all of 6 yarn types showed no difference among them for top surface, while standard polyester 150D/2/96F presented the highest value for bottom surface (Figure 4.12).

Spreading speed

Spreading speed is defined as the accumulated rate of surface wetting from the center of the specimen where the test solution is dropped to the manimum wetted radius. The spreading speed values of the samples are determined in Figure 4.13.

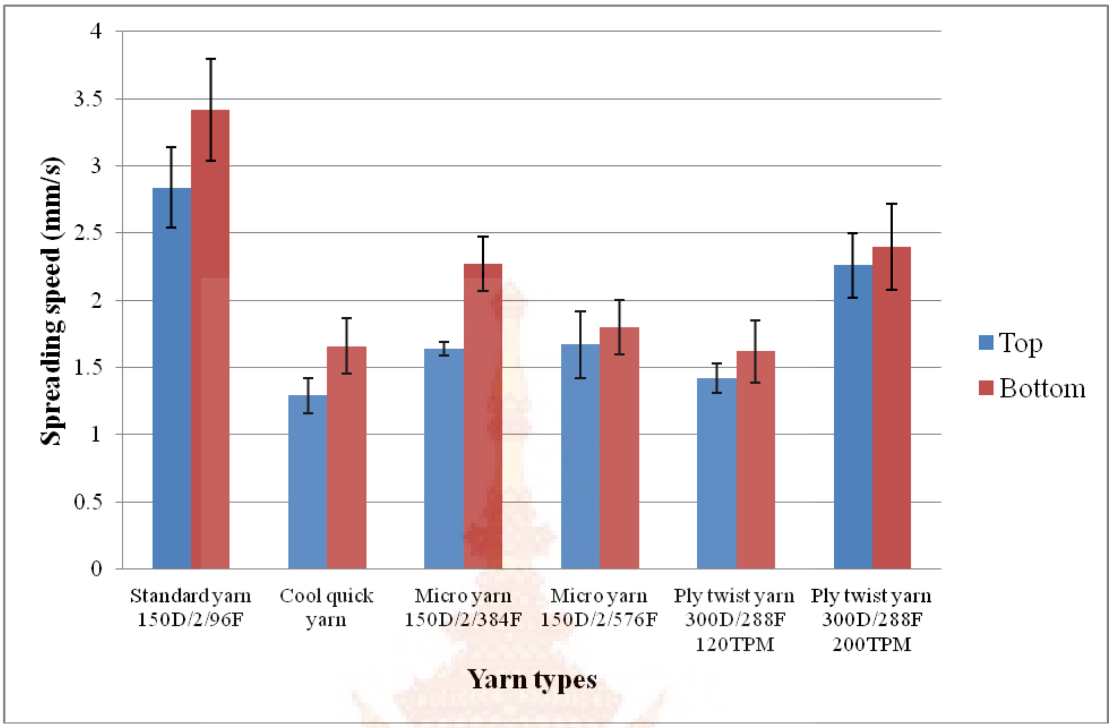


Figure 4.13 Spreading speed

The woven polyester fabric made of 150D/2/96F standard yarn showed the highest spreading speed in top and bottom surface at 2.84 mm/s and 3.41 mm/s, respectively as shown in Figure 4.13.

<u>Accumulative one-way transport capacity</u>

For one-way transport capability, polyester 150D/2/96F still has the highest value at 477.68 as shown in Figure 4.14.

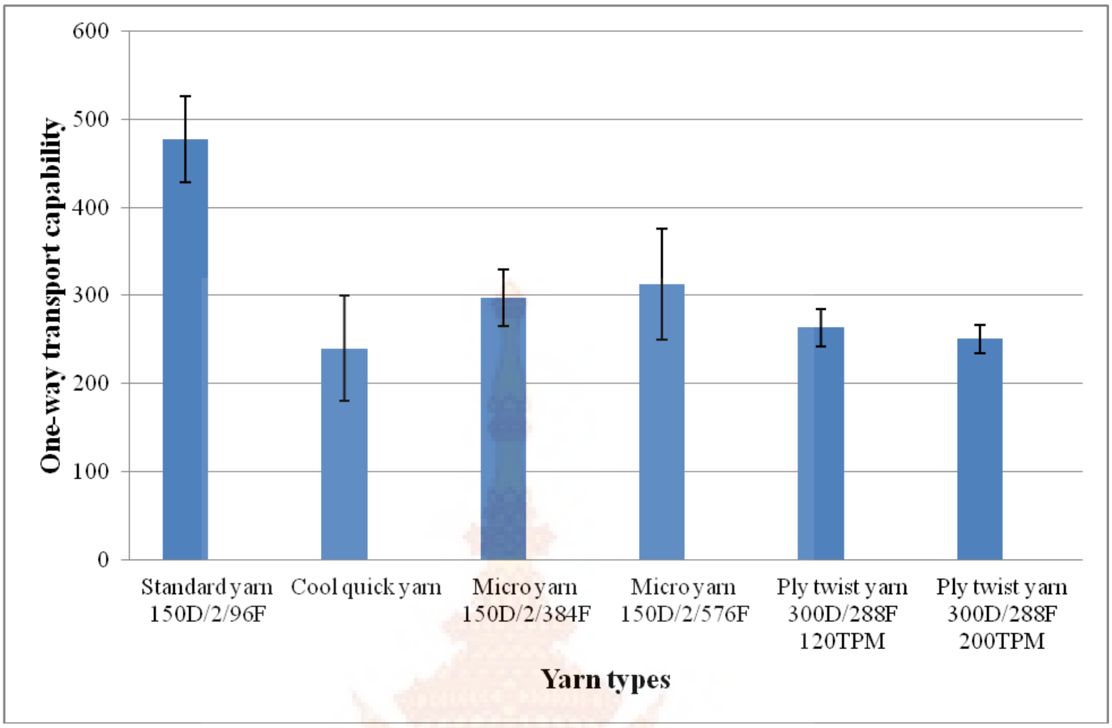


Figure 4.14 Accumulative one-way transport capacity

Overall moisture management capability

Overall moisture management capacity is defined as an index of the overall capability of a fabric to transport liquid moisture. The overall moisture management capacity result is presented in Figure 4.15.

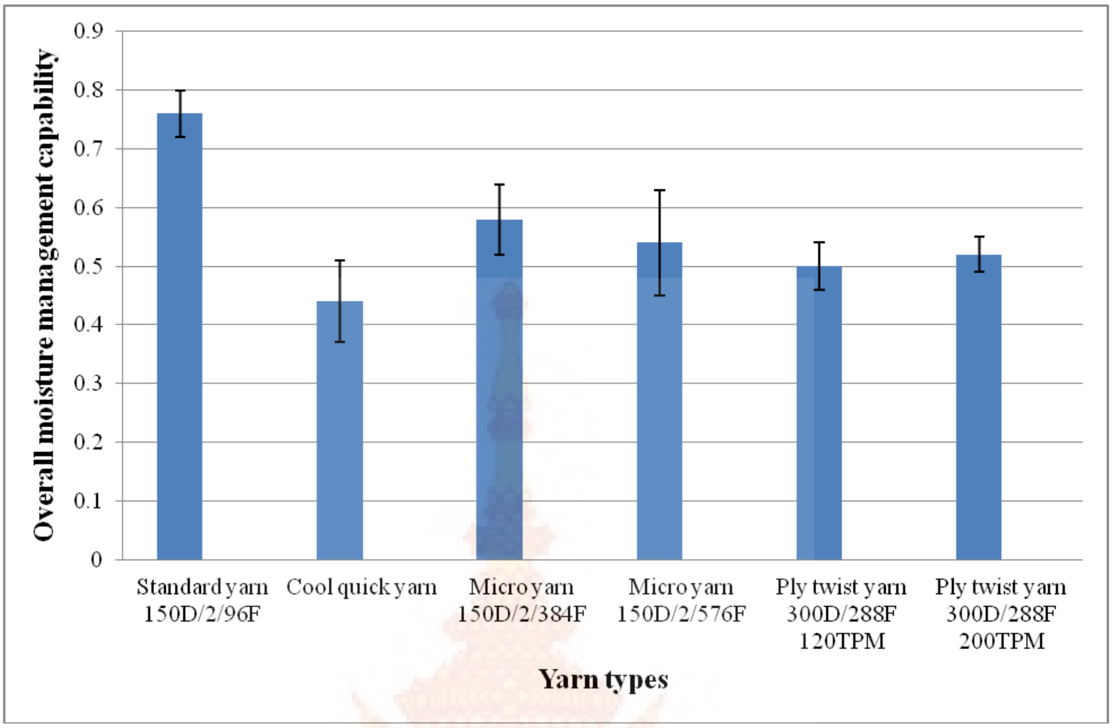


Figure 4.15 Overall moisture management capability

For overall moisture management capability, polyester 150D/2/96F showed the highest value at 0.76 (Figure 4.15). It was grade 4 in evaluating table while other 5 types of yarn get lower value and rank at grade 3. This may be because of fabric cover factor. All of the weft yarns used in this study had the same yarn count but they had different amount of filament. Tightly woven fabrics produced from microfilament yarns showed a very compact structure due to small pore dimensions between the fibers inside the yarns and between yarns themselves. These fabrics provided 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 [71].

Polyester has a moisture regain of only 0.4%, while cotton has a regain of 8% [72]. So, polyester does not absorb water. The mechanism of polyester fabric absorption is liquid pass through inter yarn pores and space of fabric construction.

Even though the production of micro fibers and its fabrics is the solution to improve wickability; increasing specific surface area, increasing water vapour transmission through increase in inter fiber and inter yarn spaces in the fabric structure, but moisture management is poor due to the tightness of fabric construction.

Water vapour and the liquid water are transmitted through the textiles by 3 mechanism; simple diffusion through inter yarn spaces, capillary transfer through fiber bundles, and diffusion through individual fibers.

1) Simple diffusion through inter yarn spaces: This process is controlled by the water vapour pressure gradient across the inner and outer faces of the fabric. The resistance to diffusion is governed by the fabric construction, i.e., the size and concentration of inter yarn pores and the fabric thickness.

2) Capillary transfer through fiber bundles: Here the liquid water is "Wicked" through the yarns and desorbed or evaporated at the outer surface. The efficiency of yarn wicking depends on the surface tension, i.e., wettability of the fiber surfaces, and the size, volume and number of capillary spaces is determined by the choice of yarn and fabric construction.

3) Diffusion through individual fibers: This mechanism involves absorption of water vapour into the fibers at the inner surface of the fabric, diffusion through the fiber structure, and desorption at the outer surface. The ability of fibers to undergo water vapour diffusion depends on the hydrophilic or hydrophobic nature of the fiber.

From OMMC formula, OMMC value is depended on 3 factors that are absorption rate (AR), accumulative one-way transport capacity (R), and spreading speed (SS). The weight average of each factor is different. The weight average of absorption rate (AR), accumulative one-way transport capacity (R), and spreading speed (SS) are 0.25, 0.5, and 0.25, respectively according to standard. Other types of yarn; Cool quick polyester, micro polyester 150D/2/384F, micro polyester 150D/2/576F, ply twist polyester 300D/288 with 120 TPM, ply twist polyester yarn 300D/288F with 200 TPM, was significantly higher in absorption rate (AR) but the weight average value is only 0.25. To improve OMMC value, accumulative one-way transport capacity (R) is more effective. Accumulative one-way transport capacity (R) is 0.50 weight average value. Polyester 150D/48F/2 yarn was outstanding accumulative one-way transport capacity R value.

4.8 Costing of fabrics

Fabric costing is the principle concern of a garment merchandiser. In this study, fabric costing is calculated based on only the price of yarns. The costing of woven fabric is shown in Table 4.13 and appendix G which was calculated only material cost.

Table 4.13 Costing of fabrics

Yarn types	Cost (THB/yarn)
Standard yarn 150D/2/96F	17.72
Cool quick yarn	20.87
Micro yarn 150D/2/384F	18.67
Micro yarn 150D/2/576F	18.67
Ply twist yarn 300D/288F 120TPM	48.67
Ply twist yarn 300D/288F 200TPM	48.67

Using standard polyester yarn contained the lowest cost compared with other polyester yarn types (Table 4.13). To compare with standard fabric, the cost of fabric containing Cool quick yarn increased at a rate of 17.4%. Both micro yarns showed 5.4% higher cost than that of standard fabric. For fabric constituting both ply twist yarn, the cost of fabrics showed the highest value which were 174.7% higher than standard fabric.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This study showed that yarn types with the same yarn count affected to fabric tensile strength, tearing strength, stiffness, abrasion resistance, and air permeability. The maximum tensile strength in warp and weft direction was ply twisted yarn 300D/288F 120TPM yarn. The highest tearing strength in warp and weft direction was the standard polyester yarn 150D/2/96F, while other yarn types showed lower tearing strength value than that of standard yarn. For air permeability test, the standard yarn still had the maximum air permeability at 7.27 $cm^3/cm^2/s$. The application of developed fabrics depended on the purpose or utility of fabric. For example, ply twisted yarn 300D/288F 120TPM exhibited the highest tensile strength properties with low air permeability rates. By reducing fabric density construction, the air permeability was improved.

For liquid moisture management properties of textile fabrics, the result showed that the overall moisture management capability (OMMC) of standard 150D/2/96F yarn had highest value at 0.76 (0.00-1.00) or grade 4 (1-5), whereas the OMMC values of other 5 yarn types were around 0.52 or grade 3.

For the further research, liquid moisture management properties of textile fabrics should test with fabric that do not pass any processes e.g. dyeing and finishing. Both mechanical and chemical processes of dyeing and finishing may affect to yarn’s properties. The types of yarn and fabric construction should be concerned in order to develop comfort property of the fabric.

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APPENDICES

APPENDIX A

BREAKING LOAD AND ELONGATION

Table A-1 Breaking load of fabric containing standard yarn 150D/2/96F

Sample No.	Direction	
	Warp	Weft
1	1873.43	1659.85
2	1879.38	1720.35
3	1776.32	1656.44
4	1820.72	1876.21
5	1865.21	1826.56
Avg	1843.01	1747.88
SD	43.83	99.41

Table A-2 Breaking load of fabric containing Cool quick yarn

Sample No.	Direction	
	Warp	Weft
1	1914.77	1305.91
2	1666.22	1491.91
3	1821.50	1545.55
4	1763.73	1406.61
5	1938.02	1519.34
Avg	1820.85	1453.86
SD	111.50	97.81

Table A-3 Breaking load of fabric containing micro yarn 150D/2/384F

Sample No.	Direction	
	Warp	Weft
1	1902.22	1753.78
2	1947.23	1792.57
3	1900.14	1799.13
4	1916.75	1760.27
5	1874.48	1812.56
Avg	1908.16	1783.66
SD	26.62	25.47

Table A-4 Breaking load of fabric containing micro yarn 150D/2/576F

Sample No.	Direction	
	Warp	Weft
1	1729.34	1791.82
2	1710.83	1730.62
3	1743.98	1718.26
4	1837.51	1885.17
5	1907.21	1917.28
Avg	1785.77	1808.63
SD	83.62	89.72

Table A-5 Breaking load of fabric containing ply twist yarn 300D/288 with 120 TPM

Sample No.	Direction	
	Warp	Weft
1	1854.72	1927.46
2	1947.52	1952.73
3	1888.39	1892.79
4	1929.97	1992.23
5	1936.90	1991.43
Avg	1911.50	1951.33
SD	38.87	42.66

Table A-6 Breaking load of fabric containing ply twist yarn 300D/288 with 200 TPM

Sample No.	Direction	
	Warp	Weft
1	1740.50	1883.42
2	1919.80	1919.82
3	1784.83	1876.85
4	1960.52	1912.17
5	1664.26	1906.78
Avg	1813.98	1899.81
SD	123.83	18.69

Table A-7 Percentage elongation of fabric containing standard yarn 150D/2/96F

Sample No.	Direction	
	Warp	Weft
1	46.17	52.17
2	48.00	52.92
3	46.92	53.75
4	47.00	54.83
5	47.92	52.33
Avg	47.20	53.20
SD	0.77	1.10

Table A-8 Percentage elongation of fabric containing Cool quick yarn

Sample No.	Direction	
	Warp	Weft
1	52.42	43.08
2	51.25	46.67
3	50.58	46.00
4	50.58	44.83
5	47.83	46.17
Avg	50.53	45.35
SD	1.68	1.43

Table A-9 Percentage elongation of fabric containing micro yarn 150D/2/384F

Sample No.	Direction	
	Warp	Weft
1	52.83	39.83
2	52.58	40.17
3	52.83	39.92
4	52.75	39.67
5	52.75	40.42
Avg	52.75	40.00
SD	0.10	0.29

Table A-10 Percentage elongation of fabric containing micro yarn 150D/2/576F

Sample No.	Direction	
	Warp	Weft
1	55.58	43.08
2	56.92	41.67
3	54.50	39.83
4	53.67	41.33
5	57.75	45.25
Avg	55.68	42.23
SD	1.68	2.04

Table A-11 Percentage elongation of fabric containing ply twist yarn 300D/288 with 120 TPM

Sample No.	Direction	
	Warp	Weft
1	58.50	55.50
2	58.67	54.42
3	57.75	52.08
4	58.00	54.58
5	57.83	55.75
Avg	58.15	54.47
SD	0.41	1.45

Table A-12 Percentage elongation of fabric containing ply twist yarn 300D/288 with 200 TPM

Sample No.	Direction	
	Warp	Weft
1	55.92	43.67
2	54.58	43.17
3	52.83	42.42
4	55.42	43.50
5	50.25	42.33
Avg	53.80	43.02
SD	2.30	0.61

APPENDIX B

TEARING LOAD

Table B-1 Tearing load of fabric containing standard yarn 150D/2/96F

Sample No.	Direction	
	Warp	Weft
1	77.70	82.44
2	74.52	80.95
3	76.51	84.52
4	75.0	82.36
5	76.50	83.87
Avg	76.05	82.83
SD	1.28	1.40

Table B-2 Tearing load of fabric containing Cool quick yarn

Sample No.	Direction	
	Warp	Weft
1	71.11	56.14
2	69.58	51.81
3	73.57	50.88
4	71.33	50.05
5	69.47	51.64
Avg	71.01	52.10
SD	1.66	2.36

Table B-3 Tearing load of fabric containing micro yarn 150D/2/384F

Sample No.	Direction	
	Warp	Weft
1	73.97	60.00
2	74.83	61.82
3	73.98	62.08
4	67.66	62.47
5	69.21	65.02
Avg	71.93	62.28
SD	3.25	1.80

Table B-4 Tearing load of fabric containing micro 150D/2/576F

Sample No.	Direction	
	Warp	Weft
1	65.05	59.57
2	69.91	57.79
3	65.56	57.98
4	71.87	57.03
5	64.79	62.78
Avg	67.44	59.03
SD	3.24	2.29

Table B-5 Tearing load of fabric containing ply twist yarn 300D/288 with 120 TPM

Sample No.	Direction	
	Warp	Weft
1	77.92	66.55
2	72.06	73.50
3	72.47	69.66
4	72.23	68.13
5	75.95	67.73
Avg	74.12	69.11
SD	2.66	2.69

Table B-6 Tearing load of fabric containing ply twist yarn 300D/288 with 200 TPM

Sample No.	Direction	
	Warp	Weft
1	68.40	60.79
2	70.46	57.87
3	65.73	60.54
4	67.62	57.21
5	69.51	55.73
Avg	68.35	58.43
SD	1.82	2.19

APPENDIX C

STIFFNESS

Table C-1 Stiffness of fabric containing standard yarn 150D/2/96F

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	4.20	2919.07	3.80	2161.96
2	4.20	2919.07	3.60	1838.25
3	4.20	2919.07	3.80	2161.96
Avg	4.20	2919.07	3.73	2054.05
SD	0.00	0.00	0.12	186.89

Table C-2 Stiffness of fabric containing Coolquick yarn

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	3.60	1842.91	3.10	1176.74
2	3.70	2000.79	3.20	1294.34
3	3.80	2167.44	3.40	1552.51
Avg	3.70	2003.72	3.23	1341.20
SD	0.10	162.29	0.15	192.21

Table C-3 Stiffness of fabric containing micro yarn 150D/2/384F

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	3.90	2378.69	3.80	2200.37
2	3.70	2031.19	3.80	2200.37
3	3.70	2031.19	3.60	1870.91
Avg	3.77	2147.02	3.73	2090.55
SD	0.12	200.63	0.12	190.21

Table C-4 Stiffness of fabric containing micro yarn 150D/2/576F

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	3.30	1512.95	3.50	1805.04
2	3.20	1379.53	3.60	1964.22
3	3.40	1654.70	3.60	1964.22
Avg	3.30	1515.73	3.57	1911.16
SD	0.10	137.60	0.06	91.90

Table C-5 Stiffness of fabric containing ply twist yarn 300D/288 with 120 TPM

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	3.40	1682.21	3.60	1996.88
2	3.30	1538.10	3.40	1682.21
3	3.40	1996.88	3.40	1682.21
Avg	3.43	1739.06	3.47	1787.10
SD	0.15	234.61	0.12	181.67

Table C-6 Stiffness of fabric containing ply twist yarn 300D/288 with 200 TPM

Sample No.	Warp direction		Weft direction	
	Length (cm)	Stiffness (g.cm)	Length (cm)	Stiffness (g.cm)
1	3.80	2194.88	3.10	1191.64
2	3.80	2194.88	3.10	1191.64
3	3.80	2194.88	3.10	1191.64
Avg	3.80	2194.88	3.10	1191.64
SD	0.00	0.00	0.00	0.00

APPENDIX D

AIR PERMEABILITY

Table D-1 Air permeability of fabric

Sample No.	standard yarn 150D/2/96F	Cool quick	Micro yarn 150D/2/384F	Micro yarn 150D/2/576F	Ply twist yarn 120TPM	Ply twist yarn 200TPM
1	7.36	4.99	7.47	5.58	5.37	6.20
2	7.53	4.13	7.01	6.03	5.54	5.74
3	7.24	4.45	7.09	5.33	5.84	5.96
4	6.71	4.04	6.76	5.98	4.90	5.92
5	7.27	4.23	6.67	5.98	4.64	5.42
6	6.96	4.18	7.06	5.25	4.68	6.35
7	7.69	4.64	7.16	5.49	5.13	6.24
8	7.63	4.81	6.97	5.08	5.06	6.45
9	6.97	4.00	7.20	5.76	4.92	6.79
10	7.30	4.65	6.59	5.62	4.01	6.25
Avg	7.27	4.41	7.00	5.61	5.01	6.13
SD	0.31	0.35	0.27	0.33	0.51	0.39

APPENDIX E

ABRASION RESISTANCE

Table E-1 Abrasion resistance of fabric containing standard yarn 150D/2/96F

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.3889	3.3845	0.088
2	3.3787	3.3744	0.086
3	3.3877	3.3834	0.086
Avg	3.3851	3.3808	0.087
SD	0.0056	0.0055	0.0012

Table E-2 Abrasion resistance of fabric containing Cool quick yarn

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.3768	3.3741	0.054
2	3.3646	3.362	0.052
3	3.3774	3.3745	0.058
Avg	3.3729	3.3702	0.055
SD	0.0072	0.0071	0.003

Table E-3 Abrasion resistance of fabric containing micro yarn 150D/2/384F

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.4255	3.4201	0.108
2	3.4464	3.4411	0.106
3	3.3464	3.3410	0.108
Avg	3.4061	3.4007	0.107
SD	0.0527	0.0528	0.001

Table E-4 Abrasion resistance of fabric containing micro yarn 150D/2/576F

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.5718	3.5707	0.022
2	3.5678	3.5665	0.026
3	3.5851	3.5839	0.024
Avg	3.5749	3.5737	0.024
SD	0.0091	0.0091	0.002

Table E-5 Abrasion resistance of fabric containing ply twist yarn 300D/288F 120TPM

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.8234	3.8218	0.032
2	3.8121	3.8102	0.038
3	3.7878	3.7863	0.030
Avg	3.8078	3.8061	0.033
SD	0.0182	0.0181	0.004

Table E-6 Abrasion resistance of fabric containing ply twist yarn 300D/288F 200TPM

Sample No.	Before weight (g)	After weight (g)	Weight loss index
1	3.4133	3.4105	0.056
2	3.4254	3.4227	0.054
3	3.4574	3.4545	0.058
Avg	3.4320	3.4292	0.056
SD	0.0228	0.0227	0.002

APPENDIX F

MOISTURE MANAGEMENT PROPERTIES

Table F-1 Moisture management properties value of fabric containing standard yarn 150D/2/96F

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	4.766	3.719	4.203	4.229	0.524
Wetting time Bottom (s)	4.031	5.312	4.359	4.567	0.665
Absorption rate Top (%/s)	23.276	24.785	24.455	24.172	0.793
Absorption rate Bottom (%/s)	29.025	33.788	34.058	32.290	2.831
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	20.0	15.0	16.67	2.89
Spreading speed Top (mm/s)	2.721	3.180	2.619	2.840	0.299
Spreading speed Bottom (mm/s)	3.071	3.826	3.347	3.415	0.382
Accumulative one-way transport capability (%)	464.82	436.62	531.61	477.68	48.786
Overall (liquid) moisture management capability	0.725	0.802	0.762	0.763	0.038

Table F-2 Moisture management properties value of fabric containing Cool quick yarn

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	7.000	7.156	7.157	7.104	0.090
Wetting time Bottom (s)	27.235	16.437	14.360	19.344	6.912
Absorption rate Top (%/s)	41.327	42.653	63.436	49.139	12.400
Absorption rate Bottom (%/s)	25.070	31.806	37.405	31.427	6.177
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	15.0	15.0	15.0	0.0
Spreading speed Top (mm/s)	1.143	1.363	1.374	1.294	0.130
Spreading speed Bottom (mm/s)	1.876	1.6405	1.4550	1.6572	0.2110
Accumulative one-way transport capability (%)	207.40	202.99	308.64	239.68	59.77
Overall (liquid) moisture management capability	0.401	0.395	0.513	0.436	0.067

Table F-3 Moisture management properties value of fabric containing micro yarn 150D/2/384F

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	7.000	7.156	6.922	7.026	0.119
Wetting time Bottom (s)	11.485	13.563	14.515	13.188	1.550
Absorption rate Top (%/s)	55.132	83.806	56.932	65.290	16.060
Absorption rate Bottom (%/s)	43.316	45.392	39.662	42.790	2.901
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	15.0	15.0	15.0	0.0
Spreading speed Top (mm/s)	1.697	1.624	1.605	1.642	0.049
Spreading speed Bottom (mm/s)	2.503	2.200	2.113	2.272	0.205
Accumulative one-way transport capability (%)	331.54	292.91	267.95	297.47	32.04
Overall (liquid) moisture management capability	0.642	0.579	0.528	0.583	0.057

Table F-4 Moisture management properties value of fabric containing micro yarn 150D/2/576F

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	6.921	7.000	7.000	6.974	0.046
Wetting time Bottom (s)	7.640	13.484	14.203	11.776	3.600
Absorption rate Top (%/s)	48.475	74.980	82.561	68.672	17.897
Absorption rate Bottom (%/s)	34.862	33.438	31.875	33.392	1.494
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	15.0	15.0	15.0	0.0
Spreading speed Top (mm/s)	1.963	1.527	1.516	1.669	0.255
Spreading speed Bottom (mm/s)	2.026	1.669	1.706	1.800	0.196
Accumulative one-way transport capability (%)	385.48	282.70	271.38	313.19	62.87
Overall (liquid) moisture management capability	0.638	0.491	0.477	0.535	0.090

Table F-5 Moisture management properties value of fabric containing ply twist yarn 300D/288 with 120 TPM

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	5.484	6.516	6.438	6.146	0.575
Wetting time Bottom (s)	14.672	15.078	20.360	16.703	3.173
Absorption rate Top (%/s)	51.518	49.184	47.426	49.376	2.053
Absorption rate Bottom (%/s)	76.327	29.758	29.644	45.243	26.920
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	15.0	15.0	15.0	0.0
Spreading speed Top (mm/s)	1.521	1.433	1.311	1.422	0.105
Spreading speed Bottom (mm/s)	1.409	1.599	1.861	1.623	0.227
Accumulative one-way transport capability (%)	240.71	265.84	283.43	263.33	21.47
Overall (liquid) moisture management capability	0.541	0.456	0.497	0.498	0.043

Table F-6 Moisture management properties value of fabric containing ply twist yarn 300D/288 with 120 TPM

Measurement units	Sample No.			Avg	SD
	1	2	3		
Wetting time Top (s)	5.953	8.125	8.125	7.401	1.254
Wetting time Bottom (s)	10.125	11.640	12.593	11.453	1.245
Absorption rate Top (%/s)	43.724	39.717	89.492	57.645	27.654
Absorption rate Bottom (%/s)	32.531	33.993	38.183	34.903	2.934
Maximum wetting radius Top (mm)	15.0	15.0	15.0	15.0	0.0
Maximum wetting radius Bottom (mm)	15.0	10.0	15.0	13.33	2.89
Spreading speed Top (mm/s)	2.532	2.061	2.196	2.263	0.243
Spreading speed Bottom (mm/s)	2.606	2.037	2.561	2.401	0.317
Accumulative one-way transport capability (%)	231.88	263.43	256.34	250.55	16.56
Overall (liquid) moisture management capability	0.510	0.501	0.549	0.520	0.025

APPENDIX G

COSTING OF FABRICS

Table G-1 Costing of fabric containing standard yarn

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	150D/2/96F	195.6	1.50	48.00	9.39
		Total cost yarn			17.72

Table G-2 Costing of fabric containing Cool quick yarn

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	Cool quick	195.6	2.00	64.12	12.54
		Total cost yarn			20.87

Table G-3 Costing of fabric containing micro yarn 150D/2/384F

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	150D/2/384F	195.6	1.65	52.89	10.35
		Total cost yarn			18.67

Table G-4 Costing of fabric containing micro yarn 150D/2/576F

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	150D/2/576F	195.6	1.65	52.89	10.35
		Total cost yarn			18.67

Table G-5 Costing of fabric containing ply twist yarn 300D/288 with 120 TPM

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	300D/288F	195.6	1.65	52.89	10.35
	Twist cost/kg				30.00
		Total cost yarn			48.67

Table G-6 Costing of fabric containing ply twist yarn 300D/288 with 200 TPM

Direction	Yarn type	Weight (g/yard)	Yarn cost (USD/ kg)	Yarn cost (THB/ kg)	Yarn cost (THB/yard)
Warp	150D/2/96F	173.5	1.50	48.00	8.33
Weft	300D/288F	195.6	1.65	52.89	10.35
	Twist cost/kg				30.00
		Total cost yarn			48.67