# INFLUENCE OF SILVER YARN DISTRIBUTION ON ANTIBACTERIAL PROPERTIES OF POLYESTER WOVEN FABRIC

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# ABSTRACT


In this research, mechanical properties and antibacterial properties of woven fabric containing polyester and silver yarns were determined. The results found that the amount of silver yarns per square inch affected tensile and tearing strength of the fabric. Adding silver yarn in fabric increased the tensile strength of fabric but tearing strength got decreased compared to normal fabric. In addition, the antibacterial properties of fabrics were also investigated by using *Staphylococcus aureus* and *Klebsiella pneumoniae*. The antibacterial results showed that the polyester fabrics containing silver yarns exhibited excellent activities against both bacterial species which are more than 99.93 and 99.94% reductions of *Staphylococcus aureus* and *Klebsiella pneumoniae*, respectively when compared to the normal fabric. This developed fabric can be used as guideline that silver yarn is compatible with common textile processing, which are weaving, dyeing and finishing processes. In addition, it can help to develop the fabric for medical textile, which is one of the interesting segments in technical textile.

# ACKNOWLEDGEMENTS

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| | |
|---|---|
| Silver yarn | Silver coated polyester yarn |

# CHAPTER I

# INTRODUCTION

## 1.1 Statement and significance of the problems

Hospital Acquired Infection (HAI) is the definition that explains the infection that everyone can be got from hospital. It can be transmitted in both direct and indirect with the patients. From indirect transmission, everyone should avoid microbial contaminated reusable objects such as towels, bed sheets, etc. From the information of the Centers for Disease Control and Prevention, in the United States, approximately 1.7 million hospital-associated infections contribute to 99,000 deaths each year [1]. As the increasing and developing of bacteria and virus, many businesses launch the products to satisfy this market, e.g. antibacterial and antiviral tissue, antibacterial detergent [2-3], antibacterial and antiviral wipes [3], and antibacterial sock [4]. In addition, it is known that health related business is highly concerned in the global market. Many people have more awareness and concern on their health and it tends to get more and more popularity in market.

As the increasing of health related business, medical business and the requirement of number of medical staff also increase in the positive correlation. In Thailand, The Medical Council of Thailand forecasts that in the next 4 years the number of doctor will increase to 2,500 per year [5].

Refer to the indirect transmission of HAI, since medical staff move from patient to patient, their uniforms can be the disease agent. While medical equipment in the hospital is developed to reduce HAI problem even disposable product, the uniforms of medical staff are treated not good enough. Doctors and patients' uniforms are also the important reusable objects which are washed by following the regulation of washing inside the hospital. On the other hand, nurses and medical staffs' uniforms are ignored because they are treated by household cleaning product.

To create antibacterial uniform fabric, there are various chemical and physical possibilities that can be considered. In physical treatment, using bamboo [6], charcoal [7], and silver [8] yarn are concerned. Different types of yarn provide the different effect to bacteria but they are not widely used due to the cost. On the other side, using antibacterial chemical finishing on fabric is not durable. So, this research would like to study fabric that can help to reduce the number of Hospital Acquired Infection in achievable price.

## 1.2 Research objectives

1) To study the effect of fabric density of silver yarn on bacteriostatic properties
2) To determine the cost effectiveness of antibacterial fabric compared to current fabric

## 1.3 Significance of the research

The results of this study will be very useful to increase the understanding and knowledge of antibacterial fabric from silver yarn. The antibacterial activity of fabric might be used as alternative fabric for medical staffs' uniforms.

# CHAPTER II
# LITERATURE REVIEW

## 2.1 Technical textile

Technical textiles are considered as the fastest growing sector in the textile and clothing industries. The definition of technical textiles adopted by the Textile Terms and Definitions, which published by the Textile Institute, is “textile materials and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics” [9].

### 2.1.1 Classification of technical textile

Technical textile is textiles and products that are produced for the specific characteristics in order to serve the specific purposes. It can be categorized into 12 segments according to their main end-use markets: Agrotech, Buildtech, Clothtech, Geotech, Hometech, Indutech, Medtech, Mobitech, Oekotech, Packtech, Protech, and Sporttech [10].

The market for technical textile has been consistency gaining traction for its diverse application areas such as sport, aerospace, agriculture, and healthcare (Figure 1) [11].

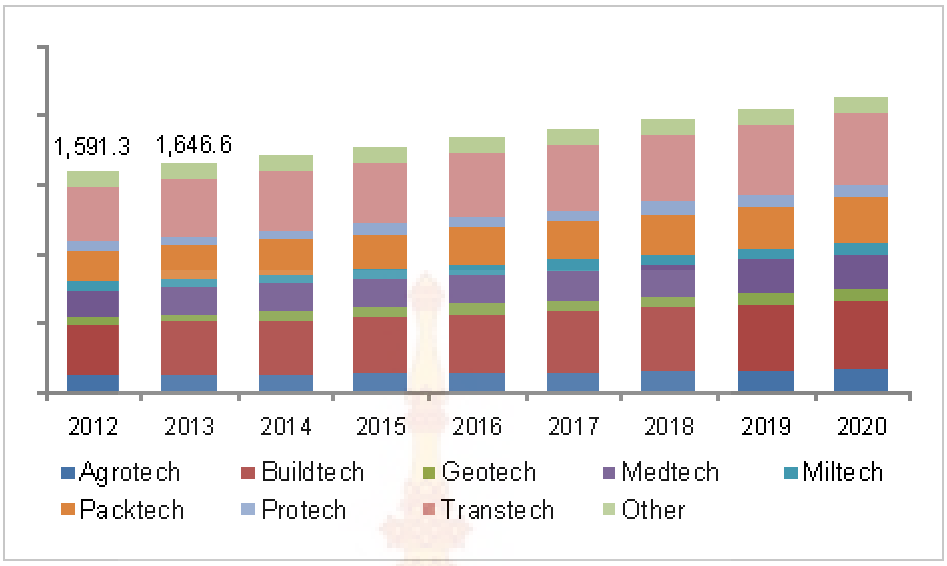



**Figure 2.1** Technical textile chemicals market volume by application, 2012-2020 (kilo tons) [12]

<u>Agrotech</u>

Textiles that are used in agriculture are called as Agrotech. The important properties are the strength and durability. The examples of the product are nets, conveyor belt, and hoses.

<u>Buildtech</u>

Textiles are used in the construction of permanent and temporary buildings as well as structures including, for example, concrete reinforcement, interior construction, insulations, proofing materials, air conditioning, and noise prevention.

<u>Clothtech</u>

Clothtech mainly comprises of textile components used in apparel and shoe industry. Typical applications are interlinings in shirts, lining fabrics, sewing threads, etc [13].

Geotech

Geotech is any material used in the earth or soil for technical purpose. The application areas include civil engineering, earth and road construction, dam engineering, soil sealing and in drainage systems [14].

Hometech

Hometech is one of the segments of technical textile, comprises of the textile components of furniture, household textiles, and floorcoverings [15].

Indutech

Textiles are used as products and solutions for filtration, purification, chemical industry, and many other industrial applications. Products under Indutech include filters, wipes, felts and three dimensional textile products [16].

Medtech

A segment of technical textiles comprises the range of innovations in the manufacture, processing, and application of medical and hygiene products [16].

Mobiltech

Textiles are used in the construction of automobiles, railways, ships, aircraft, and spacecraft. In the manufacture of cars, textiles have numerous different applications: seats, ceilings, door paneling, and carpets [16].

Oekotech

An application for textiles in environmental protection is called as Oekotech. For example, applications in floor sealing, erosion protection, air cleaning, prevention of water pollution, water cleaning, and waste treatment.

Packtech

Packtech includes many packing materials that made of textiles in various goods for industrial, agricultural and other consumer goods.

Protech

Protection against heat and radiation for fire fighter clothing, against molten metals for welder, for bullet proof jacket, etc. are the examples of using textiles in Protech category. Clothing that is used by the astronauts in the space is also in Protech category.

Sporttech

Sporttech is developed by using sophisticated technologies to produce sportswear. The examples are sport shoes, artificial turf used in sports surfaces, advanced carbon fiber composites, balloon fabrics including parachute and paraglider's fabrics and sailcloth.

### 2.1.2 Medical textile

In medical textile market, it is a niche market but having high market value and continuously growth. Medical applications of technical textiles have resulted in one of the fastest growing segments in the global technical textiles market [17]. Market size of medical textile is increasing continuously according to information shown in Figure 2.2.

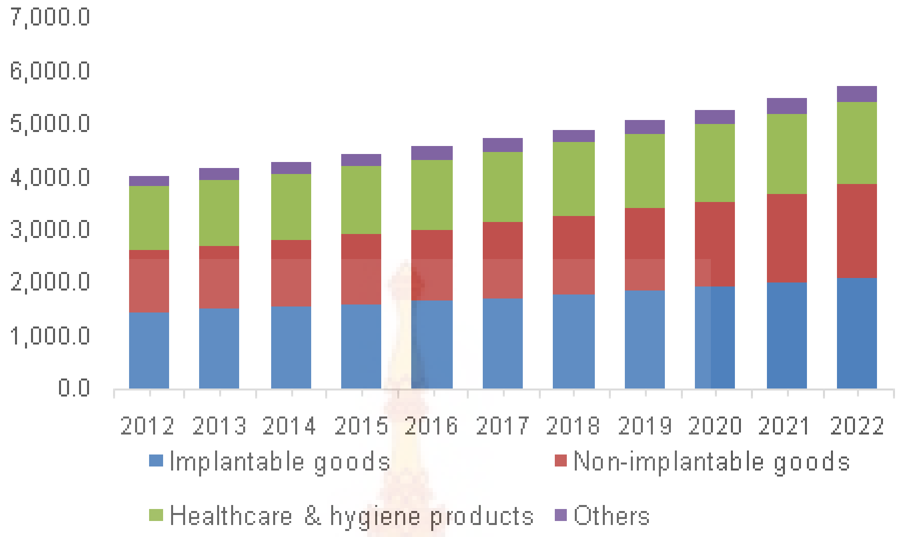



**Figure 2.2** Europe medical textiles revenue, by application, 2012-2022 (USD Million) [18]

Manufacturers can provide sophisticated textile in order to produce many specific products for serving this market such as operating gowns and drapes, sterilisation packs, dressing, sutures and orthopaedic pads, etc.

<u>Classification of medical textile</u>

The textiles used in medical and surgical proposes can be classified as follows (Figure 2.3) [17]:

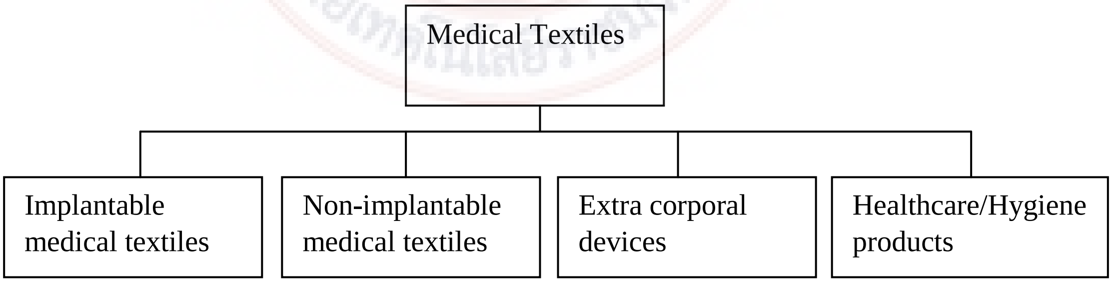



**Figure 2.3** Classification of medical textile [19]

1) Non implantable materials

Non implantable materials refer to those used outside the human body to assist the recovery of wounds. These include wound dressing, bandages and plasters (Table 2.1).

**Table 2.1** Non implantable materials [20]

| Product application | Fiber type | Manufacture system |
|---|---|---|
| Wound contact layer | Polyamide, Polyethylene | Knitting, Weaving, Non-weaving |
| Simple bandages | Polyamide | Weaving, Knitting |
| Compression | Polyamide | Weaving, Knitting |
| Plasters | Polyester, Polypropylene | Knitting, Weaving, Non-weaving |

2) Extracorporeal devices

Extracorporeal devices are the artificial organs that will be used to replace the diseased ones e.g. artificial kidney, liver and lung (Table 2.2).

**Table 2.2** Extracorporeal devices [20]

| Product application | Fiber type | Function |
|---|---|---|
| Artificial kidney | Hollow polyester | Remove waste products from patients' blood |
| Mechanical lung | Hollow polypropylene, Hollow silicone | Remove carbon dioxide from patients' blood and supply fresh oxygen |

3) Implantable materials

Implantable materials are the textile structures that can be used inside the human body of various purposes, such as closure, repair and replacement (Table 2.3). Available products are sutures, vascular grafts, artificial ligaments, artificial joints, scaffolds for tissue growth, and so on that providing suitable properties for the end-use.

**Table 2.3** Implantable materials [20]

| Product application | Fiber type | Manufacture system |
|---|---|---|
| Artificial ligament | Polyester | Braiding |
| Heart valves | Polyester | Weaving, Knitting |
| Vascular grafts | Polyester | Weaving, Knitting |

4) Health care and hygiene products

Health care and hygiene products are one of the important areas of medical textiles. The range of products in healthcare and hygiene product is vast but they are typically used either in the operating theatre or in the hospital wards for hygienic, care and safely of the staff and patients (Table 2.4).

**Table 2.4** Health care and hygiene products [20]

| Product application | Fiber type | Manufacture system |
|---|---|---|
| Surgical clothing | | |
| Gowns | Polyester, Polypropylene | Non-weaving, weaving |
| Masks | Polyester | Non-weaving |
| Bedding | Polyester | Weaving, Knitting |
| Clothing | | |
| Uniforms | Polyester | Weaving |
| Protection clothing | Polyester, Polypropylene | Non-weaving |

The prevention and control of infections in hospital

A possible source of infection to the patient is the pollutant particles shed by the nursing staff, which carries bacteria. Surgical gowns should act as a barrier to prevent the release of pollutant particles into the air. Traditionally, surgical gowns are woven cotton goods that not only allow the release of particles from the surgeon but are also a source of contamination generating high level of dust. Moreover, clothing products, which include articles worn by nurses, medical staffs, and patients have no specific requirements other than comfort, durability and smart. These clothing products are always made from conventional fabrics which can be easily found in the market.

Infection prevention and control use epidemiological principles and statistical analysis in order to prevent the transmission of infections from one patient to another. The key concepts in preventing infections involve these three links in the chain of infection as below [21].

1) Potential sources of infection

2) The routes of transmission of infection

3) The role of host factors such as patient

The point is to utilize this information to break the chain of transmission of infection by targeting any or all of the links of the chain (Figure 2.4).

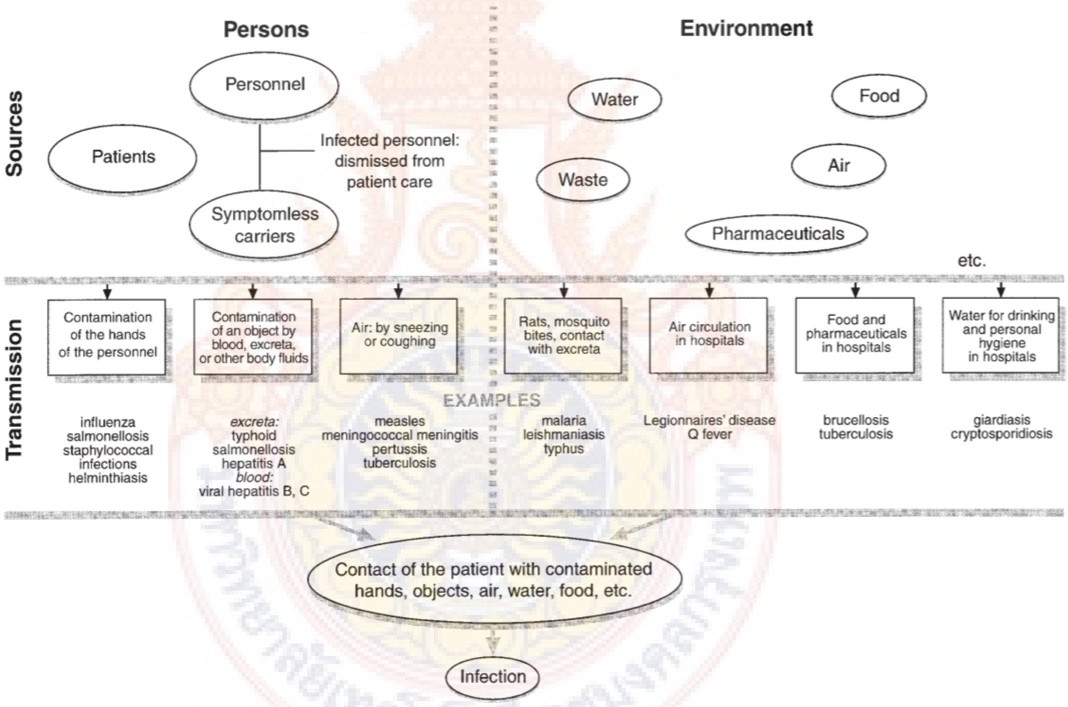



**Figure 2.4** The spread of infections [22]

In sources of infection, possible sources of infection are patients who are carriers of an infectious organism, such as MRSA in the nose or *C. difficile* in the gastrointestinal tract; or patients who are infected. There are also potential environmental sources such as surfaces in a hospital ward, door handles, or toilets in communal areas used by patients that are contaminated with body fluids. It is possible to show that pathogenic bacteria such as MRSA can be recovered by sampling the hospital environment.

In routes of transmission of infection, it can be transferred from the source of infection to the host can be either airborne; by contact; or percutaneous. Airborne transmission involves the spread of infections such as influenza and TB via water droplets. Contact transmission can involve direct person-to-person transmission from the source to susceptible host (as with MRSA), or can involve contact with body fluids such as faecal material (*C. Difficile*), epuipment such as endoscopes, or food. Percutaneous transmission can occur via insect vectors (malaria); intravascular lines (MRSA); or as a result of sharps injuries (hepatitis B, HIV) [17].

In the role of host factors, patients in hospital may have a serious underlying medical condition that reduces their normal defenses against infection. Patients in intensive cate, or having a history of recurrent admissions or prolonged hospital stays, have a higher incidence of HAIs.

The chain of infection is vulnerable at each of the three links in the chain. Sources of infection can be minimized by a high standard of cleaning such as cleaning and sterilizing all surgical equipment, and controlling the standard of food given to patients. Transmission of infections can be blocked by the provision of suitable protective clothing, including medical textiles, for both healthcare workers and patients [17].

Life cycles of disposal and reusable textile [17]

Both disposable and reusable medical textiles are made of polymeric fibers but they have different fabric constructions. Disposables, usually nonwoven fabric, are produced by closely entangling fibers into a web and then layering the resulting material into sheets. Disposable textiles generally serve only as single-use products in healthcare facilities and many other institutional protective clothing applications. After usage, it has to be immediately discarded as hazardous materials. The disposal of biologically contaminated nonwoven materials has been traditionally done by incineration, which cause air pollution problem. Another way of medical waste disposal is to use landfill, which is very costly.

On the other hand, reusable textiles, which traditionally made of cotton fiber and currently are made of polyester, can be repeatedly used in healthcare facilities. After each usage, the textiles should be professionally laundered following the CDC’s guidelines. When laundered, the used textiles are not only cleaned but it also disinfected with bleaching agents such as diluted sodium hypochlorite solution or concentrated hydrogen peroxide solution. So, laundering is a very necessary process in the life cycle of reusable textiles. This process consumes large amounts of water and consequently produces the same amount of waste water. Even if the resulting waste water is fully treated and recycled to reduce deleterious effects to the environment, there is still the problem of energy consumption during the laundry operation.

From the material life cycle perspective, reusable textiles have the advantages of a longer lifetime. Comparing these two choices, it seems that reusable textiles may have advantages over disposable materials in term of environmental concern and sustainability. The superior durability of reusable textiles made of polyester fibers means more repeated uses and significant environmental advantages over disposable materials in the amount of waste produced.

Both disposable and reusable textiles can be designed to provide a defensive barrier to liquids and particles. These barrier textiles cannot completely protect healthcare worker and patients from infections because bacteria can survive on textiles for days or even months. The only solution to reduce material-related infections while maintaining comfort properties is to develop and employ biocidal textiles that can completely inactivate any micro-organisms upon surface contact. Theoretical risk assessment study has shown that the use of biocidal textiles can reduce risk of transmission on infectious diseases in hospitals.

## 2.2 Antimicrobial agent

### 2.2.1 Classification

Classification in several ways, including

Spectrum of activity [23]

In spectrum of activity, it depends on the range of bacterial species susceptible to these agents as below.

1) Broad spectrum

It is antibacterial that is active against both gram-positive and gram-negative organisms. For example, tetracyclines, phenicols, fluoroquinolones, “thirdo-generation” and “fourth-generation” cephalosporins.

2) Narrow spectrum

It is antibacterial that is active against particular group of microorganisms. For example, glycopeptides and bacitracin are only effective against gram-positive bacteria, whereas polymixins are usually only effective against gram-negative bacteria.

Effect on bacteria [24]

Due to the differences of antibiotics' mechanisms effect on bacteria, it causes different effects on bacterial agents and can be divided into 2 categories as follows:

1) Bactericidal drugs can kill target organisms such as aminoglycosides, cephalosporins, penicillins, and quinolones.

2) Bacteriostatic drugs inhibit or delay bacteria's growth and replication such as tetracyclines, sulfonamides, and macrolides.

Mode of action

A large number of antimicrobial drugs have been developed to target points of vulnerability within bacteria. As illustrated in Figure 2.5, these drugs can be grouped into five broad categories based upon their mechanism of action: [25-26]

1) Inhibitors of cell wall synthesis
2) Inhibitors of cell membrane function
3) Inhibitors of protein synthesis
4) Inhibitors of nucleic acid synthesis
5) Inhibitors of other metabolic processes

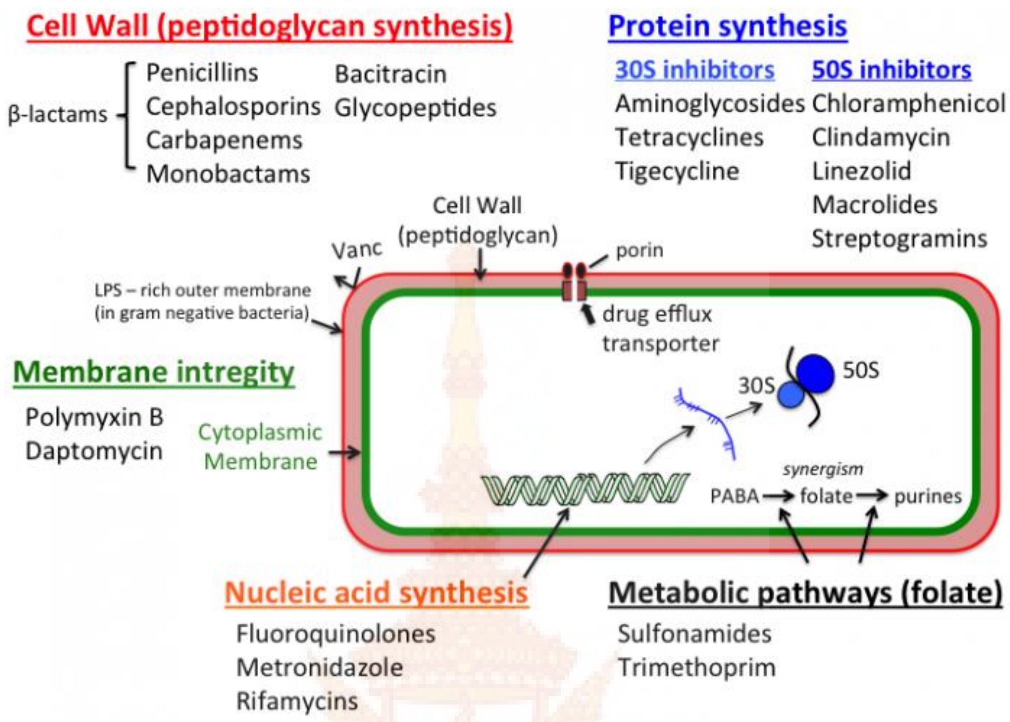



**Figure 2.5** Bacterial structure and mechanism of action of antibacterial drugs [25]

### 2.2.2 Antimicrobial metals

General aspects

In antimicrobial, there are two distinct roles of the antimicrobial finishes which are given below [27].

1) The prevention of the growth of disease causing microorganisms on textiles which not cause biodeterioration of textiles but can cause malodour, stains and cross- infection.

2) The protection of the textile itself from attack by the mildew, mould or rot producing microorganisms.

An antimicrobial protection for textiles would have to fulfill the following basic requirements which are as follows [20]:

1) To provide safety in form of low toxicity to the users such as it would not cause allergy or irritation to the skin.

2) Its application would not adversely affect textile's properties or its appearance.

3) It should be compatible with common textile processing and the resulting antimicrobial efficacy has to be durable against repeated laundering.

Example of antimicrobial metal

The antimicrobial activity of metals such as silver (Ag), copper (Cu), gold (Au), titanium (Ti), and zinc (Zn), each having various properties, potencies, and spectra of activity, has been known and applied for centuries [28].

1) Silver

According to literature Ag nanoparticles are the most popular inorganic nanoparticles used as antimicrobial agents [29]. Antibacterial action of Ag nanoparticles results from damage of the bacterial outer membrane [30]. Some researchers suppose that, Ag nanoparticles can induce pits and gaps in the bacterial membrane and then fragment the cell [31-32].

2) Copper

Cu nanoparticles due to their unique biological, chemical and physical properties, antimicrobial activities as well as the low cost of preparation are of great interest to the scientists [33-34]. However, rapid oxidation of the Cu nanoparticles on exposure to the air limits their application [35-36].

3) Germanium

It is used in small portions in pharmaceuticals and nutritional supplement formulations. The potential of organic germanium compounds as effective antibacterial agents has been successfully proved against some of the human pathogenic bacteria [37].

### 2.2.3 Silver

For centuries silver has been in use for the treatment of burns and chronic wounds. As early as 1000 B.C., silver was used to make water potable [38]. Varying concentrations of silver nitrate was used to treat fresh burns [39-40].

Silver ions ($Ag^+$) have long been known to have strong inhibitory and bactericidal effects as well as a broad spectrum of antimicrobial activities [41]. It has been proven that hydroxyapatite (HA) coatings on implant materials treated with silver exhibited excellent antibacterial effects [42]. Several proposals have been developed to explain the inhibitory effects of silver ions on bacteria. It is generally believed that heavy metals react with proteins by combining the SH groups, which leads to the inactivation of the proteins. Recent microbiological and chemical experiments implied that interaction of silver ions with thiol groups played and essential role in bacterial inactivation [43]. It is revealed that bulk silver in an oxygen-charged aqueous media catalyzes the complete destructive oxidation of microorganisms [44].

## 2.3 Spinning process

### 2.3.1 Stages of spinning process

There are three stages of the spinning process [45].

In the first stage, solid fiber-forming polyester is produced from polymer chips. These polymer chips can be converted to dope by heating or dissolving by some solvents.

Polymer chips —Conversion→ Dope (viscoelastic fluid or spinning fluid)

In the second stage, dope fluid is extruded through a spinneret and converted to viscoelastic filament, which known as the originally extruded filament. Then the viscoelastic filament is solidified into solid filament fiber, which is called filament.

Dope —Spinning→ Viscoelastic filament —Solidification→ Solid filament fiber

Moreover, in the solidification process, there are three methods of spinning as shown below.

Melt spinning

Polymer chips —Conversion by heat→ Dope —Spinning→ Viscoelastic filament —Solidification by cooling→ Solid filament fiber

Wet spinning

Polymer chips —Conversion by dissolving in solvent→ Dope —Spinning→ Viscoelastic filament —Solidification by submerging in coagulation bath→ Solid filament fiber

Dry spinning

Polymer chips —Conversion by dissolving in solvent→ Dope —Spinning→ Viscoelastic filament —Solidification by curing in the heating chamber→ Solid filament fiber

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 PET, polyamide, polyurethane, polypropylene, etc. [45]. 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.

### 2.3.2 Melt spinning

The diagram shown in the Figure 2.6 explains the melt spinning process of PET fiber. PET fibers are formed by extrusion of the molten polymer [45]. 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.

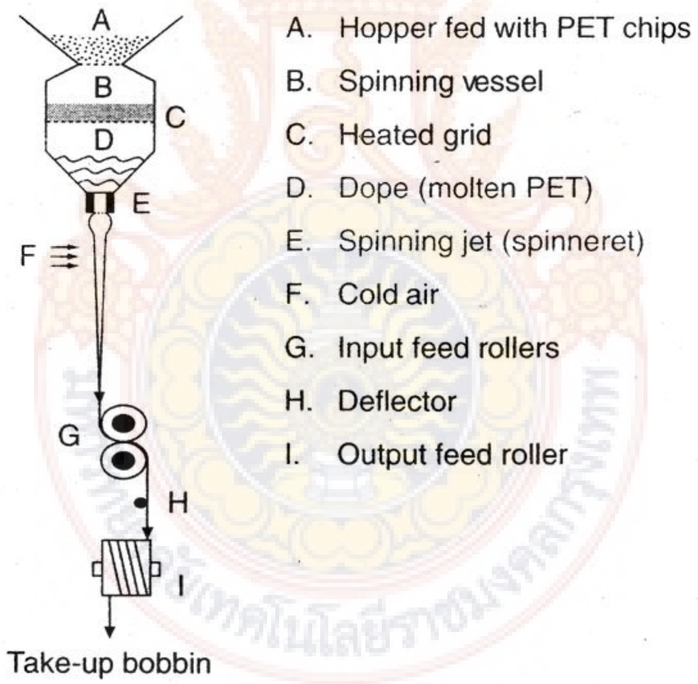



**Figure 2.6** Process of melt spinning [45]

The dope fluid (viscoelastic fluid) that flows through the spinning jet (E), can be explained in Figure 2.7.

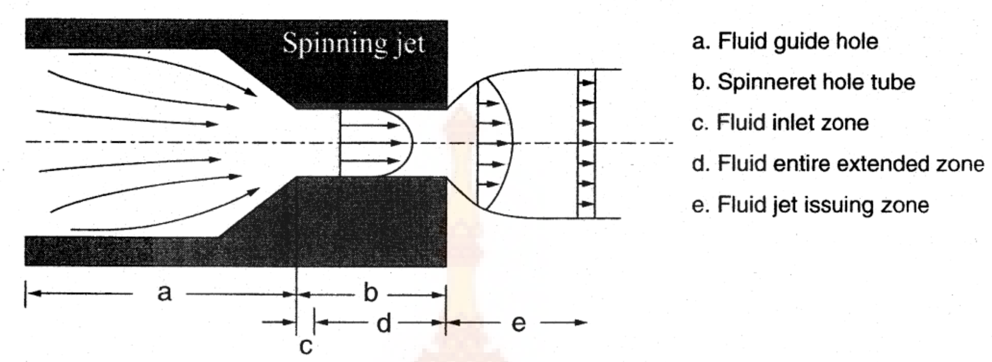



**Figure 2.7** The model of spinning jet [45]

From Figure 2.7, in the fluid inlet zone (c), the dope fluid is contracted then the polymer chain in the dope fluid produces elastic deformation. 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 2.8.

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.

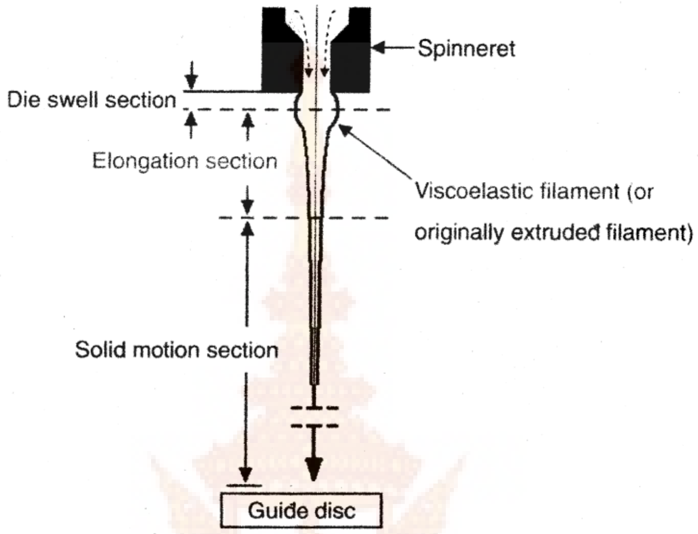



**Figure 2.8** The deformation of viscoelastic filament by elongation strain [45]

During solidification, there are two temperature gradients. The first temperature gradient is along the spinning axial line, while the other is radial which expresses the radial differential temperature from the outer layers to the inner layers of viscoelastic filament.

### 2.3.3 Heat setting and textured yarn of filament

Due to the short time of fiber-forming during the spinning process, it results in different relaxing states of polymer chain in the PET fiber and also causes the non-uniform internal stresses within fibers. It also affects to many crystal defects appear. Moreover, the unstable structure would cause fiber shrinkage that will create more difficulty in further finishing process. Therefore, in order to achieve a stable fiber structure, heat setting should be controlled before the fibers are used.

Heat setting determines the morphology and dimensional stability of thermoplastic fibers. It includes three fundamental factors, which are temperature, time and speed. Heat setting causes the movement of polymer chains in fiber, which releases the internal stress, finally producing a complete and stable structure of fibers as shown in Figure 2.9.

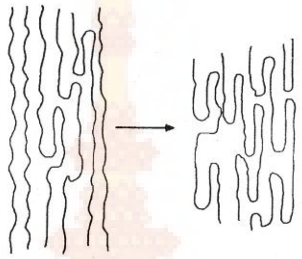


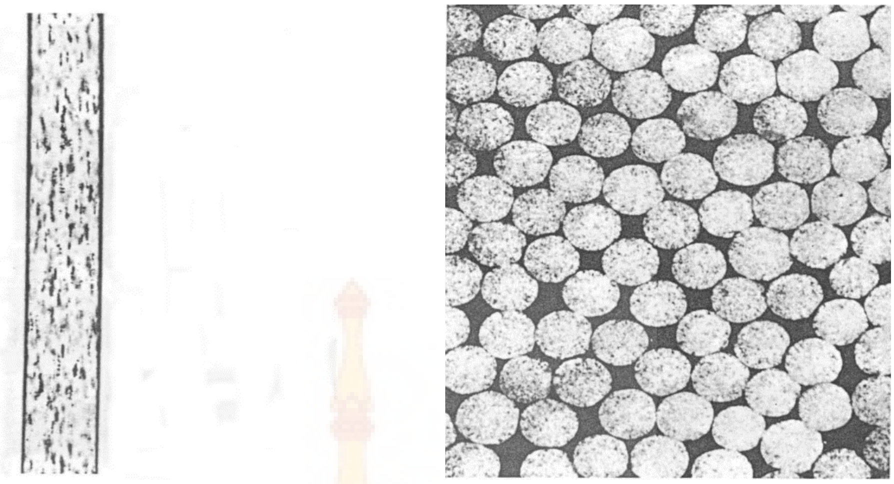

**Figure 2.9** Effect of heat setting on fiber structure [45]

## 2.4 Polyester

Polyesters are broadly classified into two types, which are thermoplastic polyesters and unsaturated polyesters that upon curing form highly cross-linked thermosets.

### 2.4.1 Shape of polyester fiber

Polyester is a very important manmade fiber produced by melt spinning process. Polyester has circular cross-sectional shape and yarn evenness (Figure 2.10).



(a) (b)

**Figure 2.10** Polyester fiber (a) long-sectional shape (b) cross-sectional shape [45]

**2.4.2 Properties of polyester fiber**

Properties of polyester include the following [10]:

1) Hydrophobic with a low moisture regain value of 0.4%

2) Excellent tensile strength

3) Resiatance to stretching

4) Wrinkle resistance

5) Excellent abrasion resistance

6) Easy care

7) Resistance to chemicals

8) Resistance to mildews

**2.4.3 Functional finishing of polyester**

There are many positive attributes of polyester fibers such as strength, wrinkle resistance, good wash and wear properties, durability, and many more but it also has poor moisture regain property. So, blending polyester with natural or man-made fibers help to increase higher moisture regain property. Nowadays, there is the increasing in demand of technical textiles that can serve other functionalities such as water-repellence, water-proof breathability, gas barrier, flame retardant, UV protection.

These are basically four approaches to impart functionality to the textiles made from polyester and polyamide textiles.

1) By incorporating a suitable additive in the melt or dope of the fiber polymer to produce intrinsically functional filaments such as Trevira, the intrinsically flame retardant polyester fiber.

2) By applying a suitable chemical or mechanical finish to the textile.

3) By applying a coating of a functional chemical formulation on the textile substrate.

4) By laminating the textile with a preformed film or layer.

## 2.5 Previous research

Qin, Y. et al [46] studied the antibacterial effect of chitosan fibers and silver containing chitosan fibers against bacteria. The results showed that the silver containing chitosan fibers is more effective in controlling bacteria growth than the original chitosan fibers.

Pollini, M et al [47] developed the silver-coated fibers by using an innovative and low-cost silver deposition technique. The silver coating stability was tested with several industrial washing.

Eremonko, A.M. et al [48] impregnated cotton fabric in aqueous solutions of silver and copper salts followed by a certain regime of heat treatment. The results found that textiles materials with silver demonstrated high antibacterial activity, while fabrics doped with bimetallic composite silver/copper showed antimycotic properties. Batericidal and antifungal properties of materials remain the properties after washing.

# CHAPTER III

# EXPERIMENTAL

## 3.1 Materials

1) Polyester yarn (300 denier) (Kanwal Textile Co., Ltd., Thailand). Specifications of this yarn are given in appendix A

2) Silver yarn (72/36/2 yarn count) (Maw Chawg Enterprise Co., Ltd., Taiwan)

3) ECE phosphate detergent (SDC Enterprises Limited, UK)

## 3.2 Weaving

In this experiment, three types of fabric were weaved by controlling other factors of every fabric except the number of silver yarn in each fabric. For normal fabric, there was no silver yarn used in the fabric. Moreover, there were some different amount of silvery yarn in sample A and sample B as shown in the Table 3.1. In addition, all kinds of fabric in the study were weaved by water jet LW551 210 weaving machine (Nissa, Japan). The structure of the woven fabric can be varied by altering the warp yarns. The 4 and 5% of silver yarn in the fabric showed 5 and 6 silver yarn per square inch, repectively.

**Table 3.1** The specification of fabrics

| Fabric | Weave | Polyester yarn | Silver yarn 72/36/2 | Warp density | Weft density |
|---|---|---|---|---|---|
| Normal fabric | 2/2 twill | 300 denier | no | 69 | 64 |
| Sample A | 2/2 twill | 300 denier | 4% of silver yarn | 69 | 64 |
| Sample B | 2/2 twill | 300 denier | 5% of silver yarn | 69 | 64 |

## 3.3 Fiber characterization

Cross-sectional shapes of fibers were characterized with Olympus BX41 Light microscope (Olympus Corporation, Japan) with 200× magnification. The morphologies of longitudinal direction of polyester and silver yarn were observed under a JSM-5410LV scanning electron microscope, SEM (JEOL Ltd, Japan) at 2,000× magnification.

## 3.4 Mechanical properties

### 3.4.1 Tensile strength

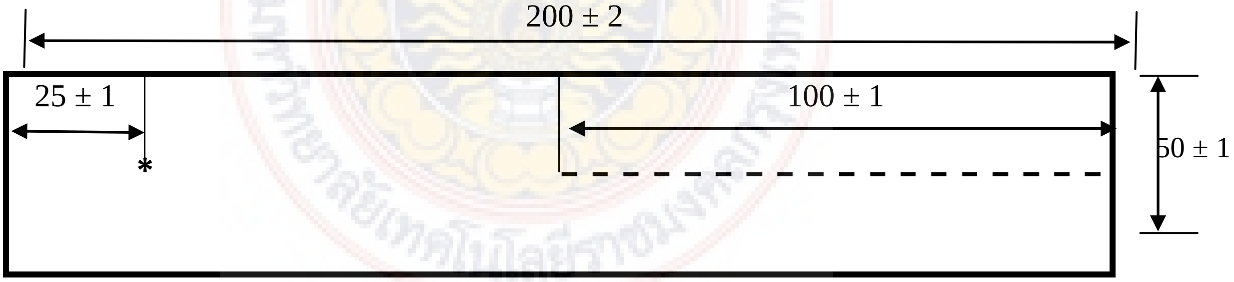
For tensile strength, it was tested according to ISO 13934-1: 1999(E) by using tensile testing machine Instron Model 5566 (Instron (Thailand) Limited, Thailand). According to the standard, for the preparation of test, each test sample was cut into two sets of test specimens, one set in the warp direction and the other in the weft direction.

The width dimension of each test specimen was 50 ± 0.5 mm with 200 mm gauge length. Therefore, the actual sample size of this specimen was 50 mm ×

300 mm. Rate of extension was 100 mm/min under the testing condition at 20 ± 2˚C with 65 ± 4% relative humidity.

### 3.4.2 Tearing strength

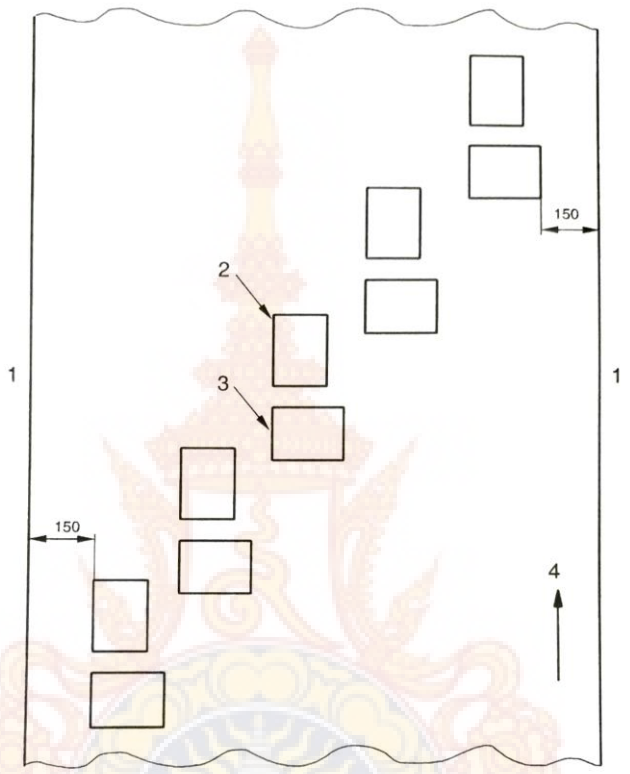
For tearing strength, it was tested under the standard of ISO 13937-2: 2000(E) by using testing machine Instron Model 5566 (Instron (Thailand) Limited, Thailand). Each laboratory sample, two sets of test specimens were cut: one set in the warp direction and the other in the weft direction. The dimension of test specimens was 50 mm × 200 mm (Figure 3.1) which was tested under testing condition of 20 ± 2 °C with 65 ± 4% relative humidity. The clamps of the tensile testing machine were adjusted at a distance of 100 mm apart, taking care that the clamps were properly aligned and parallel to each other. The tensile testing machine was adjusted to give a constant rate of jaw separation of 100 mm/min. The legs of the samples were fastened to the clamps of the device along a straight line and pulled to tear the fabric. Applied force to continue the tear was recorded up to a specified length.




* = Mark for end of tear length    Dimension in millimetres
- - - - = Cut

**Figure 3.1** Test specimen shape

For woven fabrics, each test specimen was cut out with its length parallel to the warp or the weft of the fabric. For test specimens where the longer side was parallel to the warp, the direction of the tear was qualified as "across weft" and for test specimens where the longer side of the test specimen was parallel to the direction of the weft, the tear is qualified "across warp" shown in Figure 3.2.




Where, 1 = edge

2 = specimen for tear "across weft"

3 = specimen for tear "across warp"

4 = warp

**Figure 3.2** Pattern for cutting out test specimens from the test sample

### 3.4.3 Stiffness

The stiffness is the observation of the tendency of fabric, which mostly used to judge bending rigidity and fabric handling. It is because the degree of fabric stiffness is related to properties of fabric including fiber, yarn, and fabric construction.

The procedure of testing was firstly three samples of materials in warp direction and three samples of material in weft direction were cut into the size of 22 cm × 2.5 cm. All of 6 samples were tested one by one slowly moving sample forward until it reached 41.5° of the instruments according to ASTM D-1388-08. The bending length was measured and recorded in order to calculate the mean of each direction.

$$G = 0.10MC^3$$

Where, G = stiffness

M = mass of fabric (gsm)

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

## 3.5 Abrasion resistance

Abrasion resistance was tested using in-house test method. The material was cut into circle shape with the size of 5 inches diameter together with the small hole in the middle. Then, each specimen was weighed and recorded as weight before testing. After that, the sand wheel on both left and right sides was set. The testing process was started by putting each specimen on the rubber plate. The specimen was locked and the sand wheel was placed down on the specimen. Then, setting time of abrasion, for this study 20 times was set. The vacuum behind the abrasion machine was turned on before starting the abrasion machine. After testing, each specimen was weighed again and recorded as weight after abrasion. The formula of weight loss index was:

$$\text{Weight loss index} = \frac{\text{weight before abrasion - weight after abrasion}}{\text{number of abrasion time}} \times 1000$$

Moreover, fabric surfaces after test were studied using a JSM-5410LV scanning electron microscope (JEOL Ltd, Japan) at 50× magnifications.

## 3.6 Antibacterial testing

For antibacterial finishes on textile materials, it was tested under the standard of AATCC 100: 2004. This test method provided a quantitative procedure for the evaluation of the degree of antibacterial activity. Assessment of antibacterial finishes on textile materials was determined by the degree of antibacterial activity intended in the use of such materials. Test organisms were *Staphylococcus aureus*, American Type Culture Collection No. 6538 as gram positive organism and *Klebsiella pneumoniae*, American Type Culture Collection No. 4352 as gram negative organism.

This test was performed with polyester and silver yarn/polyester fabric with contact time at 24 h. Percent reduction of bacteria was calculated:

$$R = [(B – A)/B] \times 100$$

Where, R = percent reduction

A = number of bacteria recovered from inoculated treated test specimen swatches in the bottle incubated over desired contact.

B = number of bacteria recovered from inoculated untreated test specimen swatches in the bottle incubated over desired contact.

### 3.7 Antibacterial efficiency of washed fabrics

Fabrics were cut into 10 cm × 15 cm in size, and then each specimen was put in the pot together with 5 steel balls in each pot. The 150 ml of ECE detergent with a concentration of 4 g/L was added in each pot. The fabrics were washed at temperature of 50°C for 30 min. After that, the fabrics were washed several times with water and allowed to line dry. Then, the antibacterial test was conducted with all after washed fabrics, which were 5, 10, 15, and 20 washes. The fabrics were tested according to AATCC 100: 2004 using *S. aureus* and *E. coli* as the intended test bacteria.

### 3.8 Statistical analysis

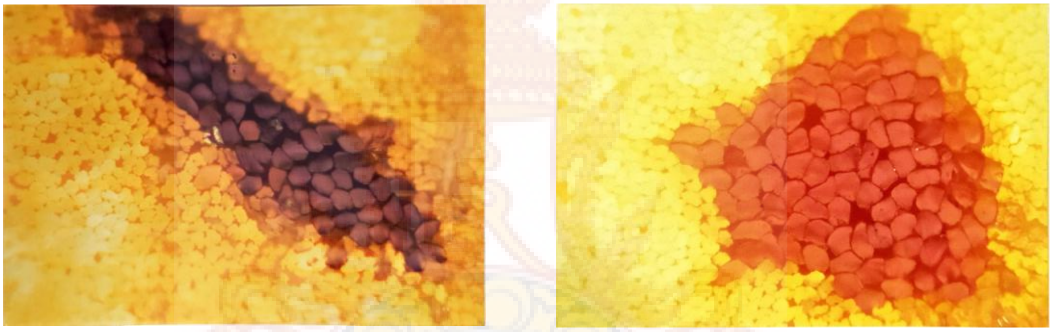
ANOVA was performed to determine the significant interactions between breaking load amd tear strength for woven fabrics.

# CHAPTER IV

# RESULTS AND DISCUSSION

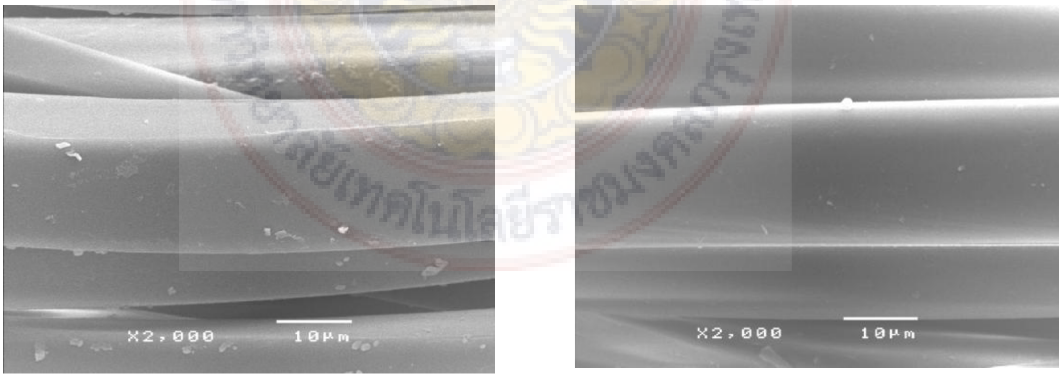
## 4.1 Fiber characterization

Optical micrographs of the cross section of silver yarn and polyester yarn were taken using Olympus BX41 light microscope and displayed in Figure 4.1. Also, the SEM micrographs of the longitudinal surfaces of fibers are shown in Figure 4.2.



(a) (b)

**Figure 4.1** Cross-section of (a) silver yarn (b) polyester yarn




(a) (b)

**Figure 4.2** SEM images of longitudinal section of (a) silver yarn (b) polyester yarn

Fiber cross sections for use in textiles and composites are becoming more and more complex. Shape impacts fiber or filaments properties and therefore the yarn and fabric characteristics. Silver fibers were round shaped cross section similar to polyester fibers. In addition, the silver fibers were thinner than polyester fibers (Figure 4.1). SEM images of the longitudinal section of polyester fibers exhibited a smooth surface as illustrated in Figure 4.2(b). Compared with polyester yarn, silver yarn showed the white particles that was the silver layer on fiber (Figure 4.1(a)).

## 4.2 Tensile Strength

The breaking load and elongation of both warp and weft direction of all kinds of the fabric, which were normal fabric, sample A, and sample B are exhibited in Table 4.1- 4.2, Figure 4.3-4.4, and appendix B.

**Table 4.1** Breaking load of fabrics

| Direction | Normal fabric | Sample A (4% of silver yarn) | Sample B (5% of silver yarn) |
|---|---|---|---|
| Warp | 1,843.01 ± 43.83 N | 1,844.23 ± 19.50 N | 1,888.58 ± 63.28 N |
| Weft | 1,747.88 ± 99.41 N | 1,708.92 ± 29.76 N | 1,678.48 ± 33.15 N |

**Table 4.2** Percentage elongation at break of fabrics

| Direction | Normal fabric | Sample A (4% of silver yarn) | Sample B (5% of silver yarn) |
|---|---|---|---|
| Warp | 47.20 ± 0.77 | 44.03 ± 1.02 | 46.02 ± 1.97 |
| Weft | 53.20 ± 1.10 | 52.13 ± 0.82 | 52.20 ± 1.36 |

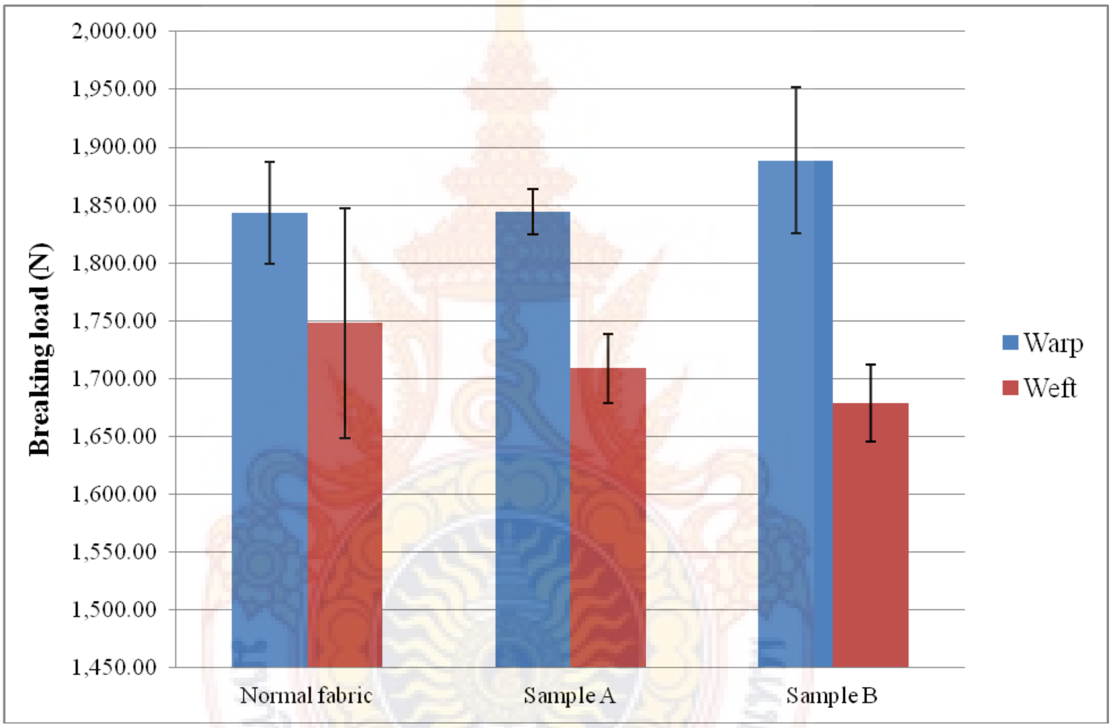



**Figure 4.3** Breaking load of fabrics

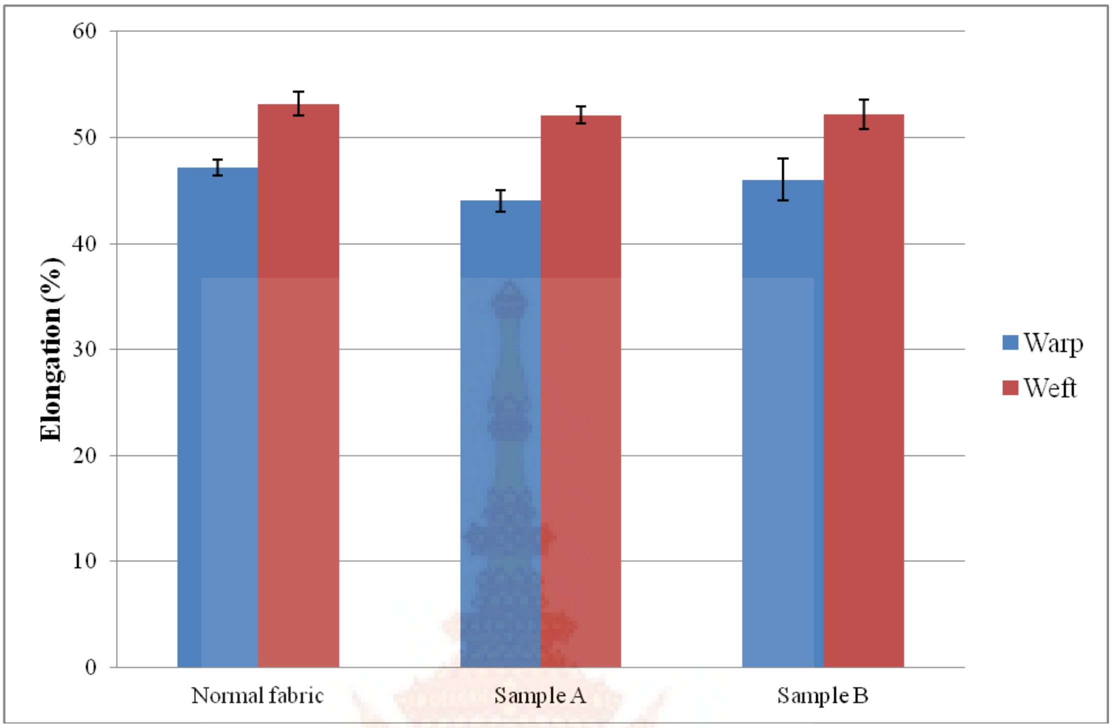
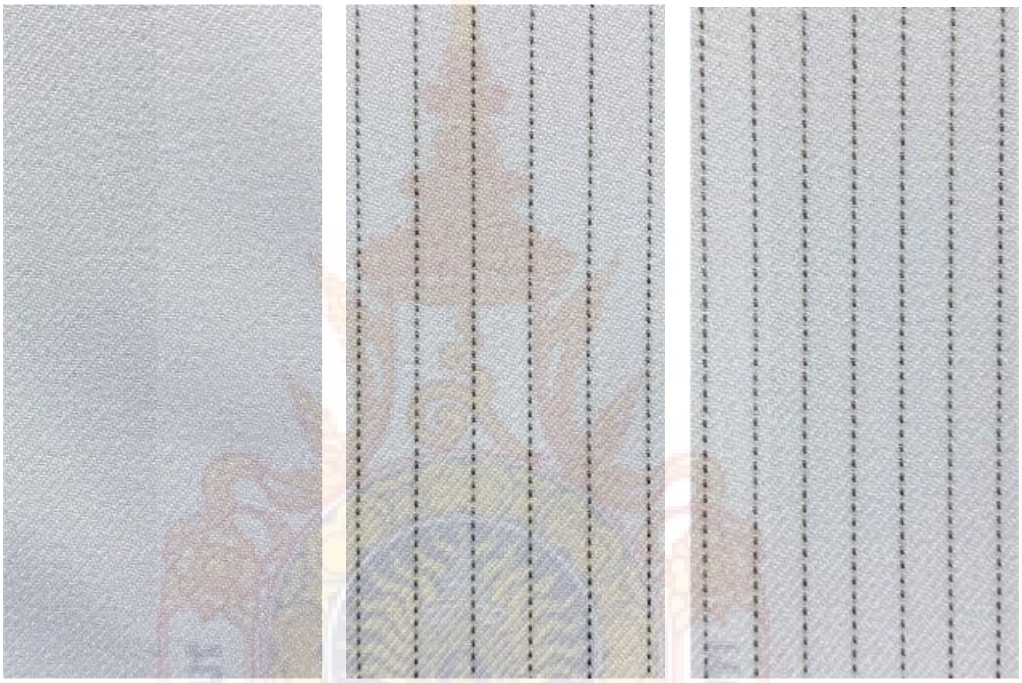



**Figure 4.4** Percentage elongation of fabrics

From the Table 4.1 and Figure 4.3, the results showed that in warp direction, the breaking load of sample A and sample B increased while the breaking load of weft direction decreased when comparing with normal fabric. It implied that the increasing of tensile strength in both sample A and sample B is the result of adding some silver yarns in warp direction at the different percentage (Figure 4.5). It showed the positive relationship that if there was the increasing in silver yarn, the tensile strength increased. On the other hand, the weft direction showed negative relationship that adding more silver yarn, the tensile strength decreased. The elongation at break did not show any considerable differences when adding silver yarn to fabric in both warp and weft directions (Table 4.2 and Figure 4.4).

According to ANOVA results, factors which have a P value below 0.05 are statistically significant on breaking load with 95% confidence. Otherwise, P values above 0.05 indicate an insignificant factor. However, Anova results for both warp and weft directional breaking load of samples gave P values of 0.241 for warp direction and 0.256 for weft direction. The effect of silver yarn on fabric breaking load was generally found to statistically insignificant.



(a) (b) (c)

**Figure 4.5** Samples of all fabrics in the study (a) normal fabric (b) sample A (c) sample B

All the sample fabrics, as shown in Figure 4.5, had the same construction. Since, the core component's mechanical/tensile properties in any hybrid yarn structure dominate the yarn's mechanical/tensile properties [50]. Therefore, incorporating the metallic filaments as core deteriorates the mechanical/tensile properties of textile yarns and ultimately the fabrics.

### 4.3 Tearing strength

The tearing load in both warp and weft direction of all kinds of the fabric that were normal fabric, sample A and sample B are shown in Table 4.3, Figure 4.6, and appendix C.

**Table 4.3** Tearing load of fabrics

| Direction | Normal fabric | Sample A (4% of silver yarn) | Sample B (5% of silver yarn) |
|---|---|---|---|
| Warp | 76.05 ± 1.28 N | 72.10 ± 2.46 N | 70.00 ± 3.84 N |
| Weft | 82.83 ± 1.40 N | 64.51 ± 1.93 N | 63.44 ± 3.21 N |

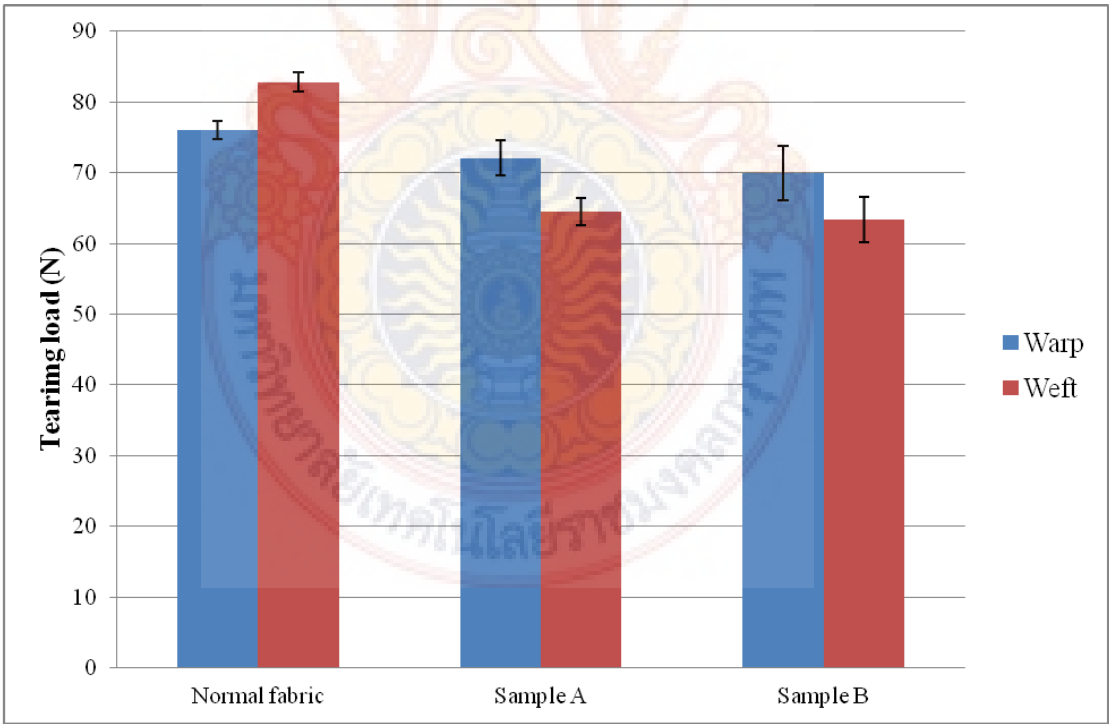



**Figure 4.6** Tearing load of fabrics

Refer to Table 4.3 and Figure 4.6, the results presented tearing load of sample A and sample B in both warp and weft directions decreased when comparing with normal fabric. It revealed that silver yarn showed negative relationship with tearing load. The increasing in silver yarn obviously decreased the tearing load of the fabric. The P values of warp and weft direction were 0.013 and 0.00001, respectively. They indicated that adding silver yarns in fabric have statistically significant effect on tearing load in both directions.

Adding silver yarn into the fabric leaded to the differences of yarn breaking strength, breaking elongation and crimp. These significant differences were the example of the primary factors that influencing a great many fabric properties especially in tensile and tearing strength. The integral yarn strength was a major contributing factor to both tensile and tearing strength of the fabric.

In the discussion an attempt was made to relate yarn properties to fabric properties. However, it must be emphasized that a certain amount of conflict exists as far as the tensile and tearing strengths of fabric were concerned. It showed that the cloth assistance factor increased with the increase in crossing threads per inch, but an increase in threads per inch would reduce the tear strength. Therefore, the end-use requirement plays an important role in the choice of parameters in design modification of fabrics.

Tearing strength was improved by reducing threads per inch in the opposite direction and by increasing the yarn strength in the direction of the test [51].

## 4.4 Stiffness

The bending stiffness of a fabric is an important indicator for determining its comfortability, thus influencing a person's purchase decisions. The stiffness of fabrics was investigated and the results are displayed in Table 4.4, Figure 4.7, and appendix D.

**Table 4.4** Stiffness of fabrics

| Sample | Weight (g/m$^2$) | Stiffness (g.cm) | |
|---|---|---|---|
| | | Warp | Weft |
| Normal fabric | 394 | 2,919.07 ± 0.00 | 2,054.05 ± 186.89 |
| Sample A | 395 | 1,555.19 ± 137.05 | 1,693.56 ± 0.00 |
| Sample B | 390 | 1,745.51 ± 3.55 | 1,770.43 ± 85.14 |

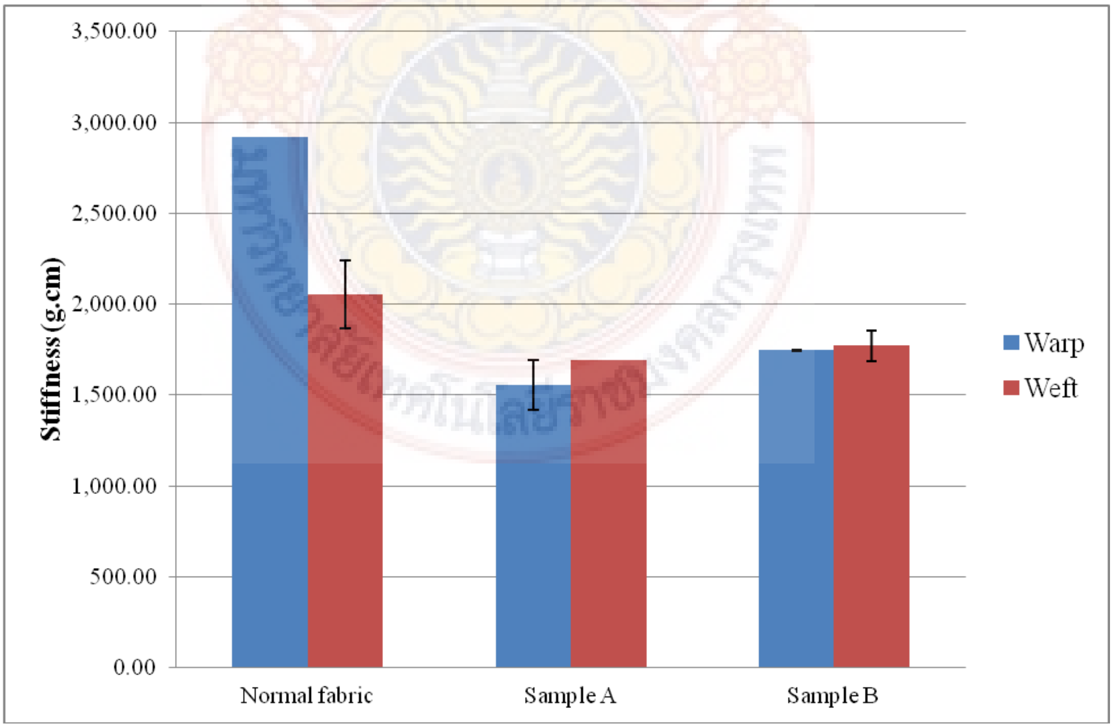



**Figure 4.7** Stiffness of fabrics

Adding silver yarn on fabric decreased the stiffness of fabric compared with normal fabric (Table 4.4 and Figure 4.7). Factors affecting the stiffness offered by fibers, yarns, and woven fabrics are considered. Yarn stiffness is usually controlled by fiber stiffness. Fiber stiffness depends upon fiber material, corss-section shape, and denier. The phenomenon can be explained that silver yarn is much lower denier than that of normal yarn causing much more flexible fabric.

### 4.5 Abrasion resistance

The abrasion resistance of fabrics is displayed in Table 4.5 and appendix E. The fabric surface after test is shown in Figure 4.8.

**Table 4.5** Abrasion resistance of fabrics

| Fabric | Weight loss index |
|---|---|
| Normal fabric | 0.0867 ± 0.0012 |
| Sample A | 0.0783 ± 0.0076 |
| Sample B | 0.0667 ± 0.0076 |

(a) (b) (c)

**Figure 4.8** SEM images of fabrics after abrasion test (a) normal fabric (b) sample A (c) sample B

Weight loss index indicates rate of weight loss and is calculated by measuring the loss of weight per cycles of abrasion. When the weight loss index is lower, the abrasion resistance quality of the material is better. From Table 4.5 and Figure 4.8, it was found that weight loss index decreased with increasing silver yarn in fabrics. This could be because silver coated on fiber helped improving abrasion resistance.

## 4.6 Antibacterial efficiency

The prepared fabrics were evaluated for antibacterial activity against *S. aureus* and *K. pneumoniae* according AATCC 100: 2004 standard. The percentage reduction in the antibacterial activity of silver yarn and fabrics is revealed in Table 4.6-4.7.

**Table 4.6** The percentage bacterial reduction of silver yarn

| Testes microorganisms | Silver yarn |
|---|---|
| *S. aureus* | > 99.93 |
| *K. pneumoniae* | > 99.94 |

**Table 4.7** The percentage bacterial reduction of fabrics

| Testes microorganisms | Normal fabric | Sample A (4% of silver yarn) | Sample B (5% of silver yarn) |
|---|---|---|---|
| *S. aureus* | 0 | > 99.93 | > 99.93 |
| *K. pneumoniae* | 0 | > 99.94 | > 99.94 |

The antibacterial property of normal fabric did not show any reduction, while silver yarn has strongly provided the high percentage reduction of antibacterial (Table

4.6-4.7). There are various mechanisms about how silver kills bacteria. Most of the proposed mechanisms involve silver entering the cell in order to cause damage [52]. Our results are also in line with those reported by Hipler *et al*.[53] that found that silver-loaded cellulosic fiber is found to be effective against *S. aureus*. Furthermore, the cotton fabrics impregnated with silver and silver/copper nanoparticles were prepared by Eremenko *et al*. [54]. The results show high antimicrobial properties of materials with low concentration of silver and silver/copper nanoparticles is confirmed with a wide range of multidrug-resistant bacteria and fungi: *Escherichia coli*, *Enterobacter aerogenes*, *Proteus mirabilis*, *Klebsiella pneumoniae*, *Candida albicans* yeasts, and micromycetes.

## 4.7 Antibacterial efficiency of washed fabrics

In this section, *E. coli* and *S. aureus* were chosen to test the efficiency of the fabrics. The difference between *E. coli* and *S. aureus* is that *E. coli* is a gram negative bacteria, while *S. aureus* is a gram positive bacteria (Figure 4.9).

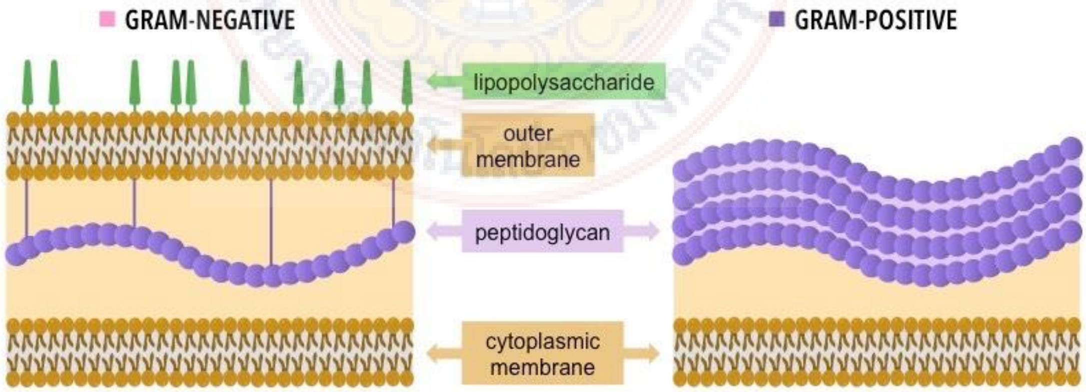
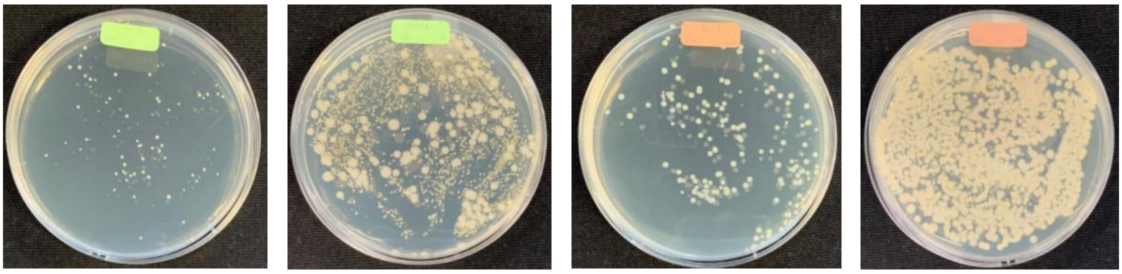



**Figure 4.9** Gram-negative versus Gram-positive cell walls [55]

Gram negative bacteria have an outer membrane for protecting the bacteria from various antibiotics, dyes, and detergents which would normally damage the inner membrane or cell wall. Gram positive bacteria lack this outer membrane. The standard used for testing the efficiency of fabrics was AATCC 100. The percentage reduction results of antibacterial fabrics are shown in Table 4.8 and Figure 4.10-4.18. In addition, inhibition zone of antibacterial fabrics is displayed in Table 4.9 and Figure 4.19-4.20.

**Table 4.8** The percentage bacterial reduction of fabrics after washing

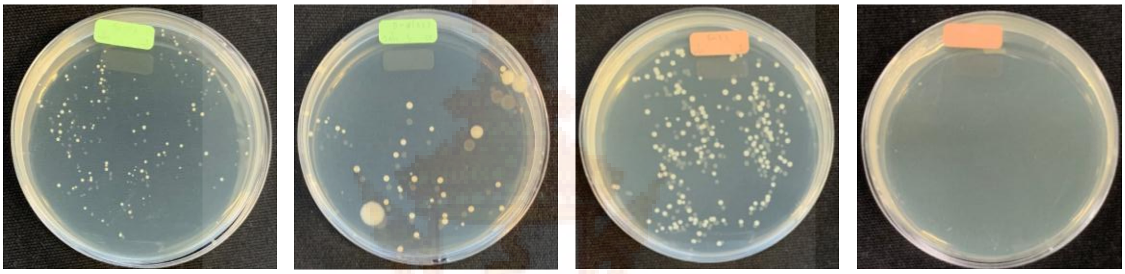
| Sample | Wash (cycles) | Testes microorganisms | |
|---|---|---|---|
| | | *S. aureus* | *E. coli* |
| Normal fabric | 0 | 0 | 0 |
| Sample A | 5 | 58.98 | 100 |
| | 10 | 42.62 | 100 |
| | 15 | 51.27 | 100 |
| | 20 | 53.65 | 100 |
| Sample B | 5 | 55.83 | 100 |
| | 10 | 47.18 | 100 |
| | 15 | 52.44 | 100 |
| | 20 | 52.97 | 100 |



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

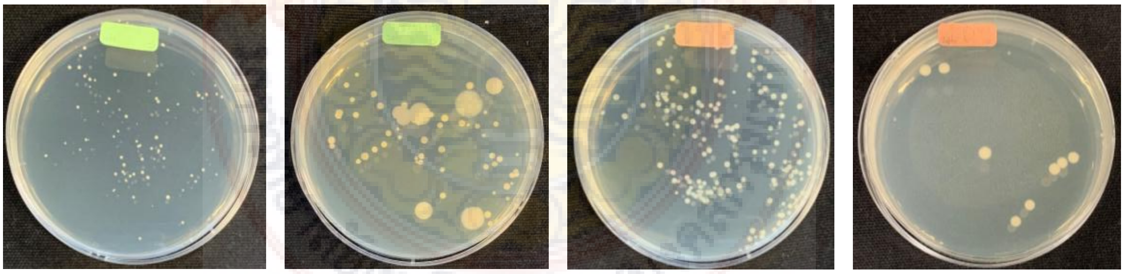
**Figure 4.10** The number of bacteria on normal fabric



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

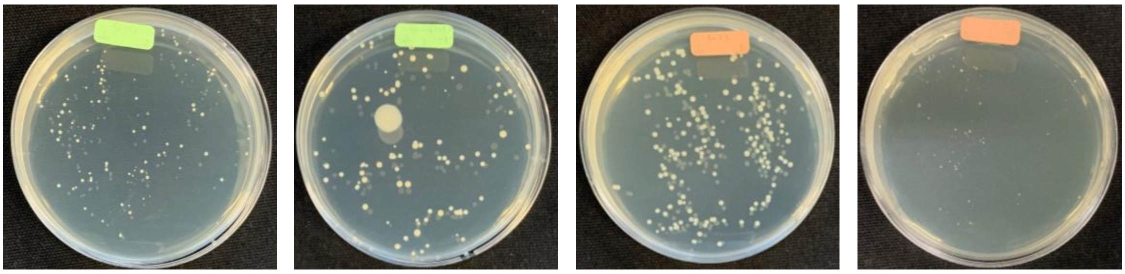
**Figure 4.11** The number of bacteria on sample A after washing 5 times



0 h 24 h *0 h* 24 h

*S. aureus* *E. coli*

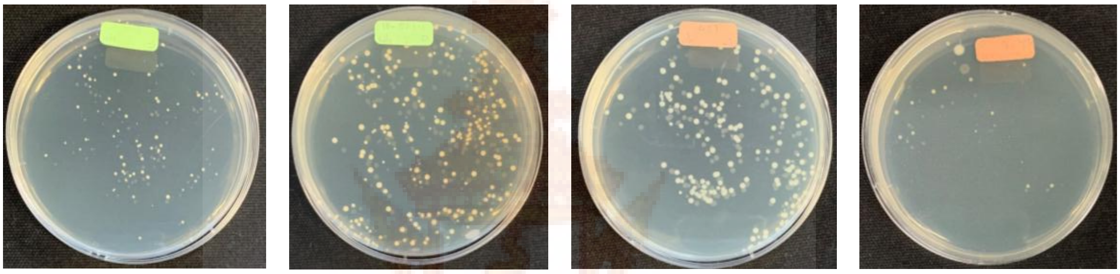
**Figure 4.12** The number of bacteria on sample B after washing 5 times



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

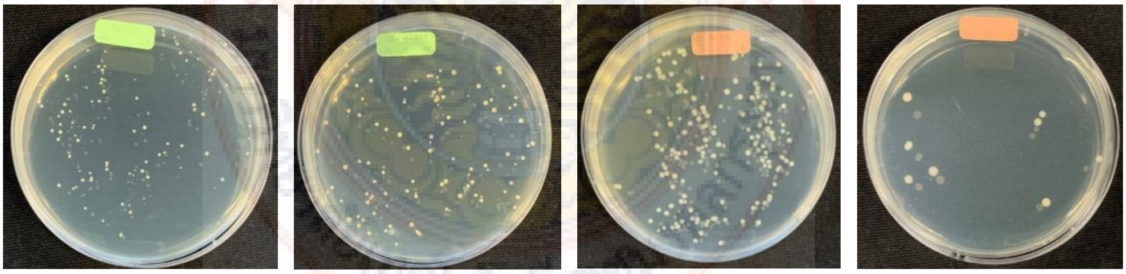
**Figure 4.13** The number of bacteria on sample A after washing 10 times



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

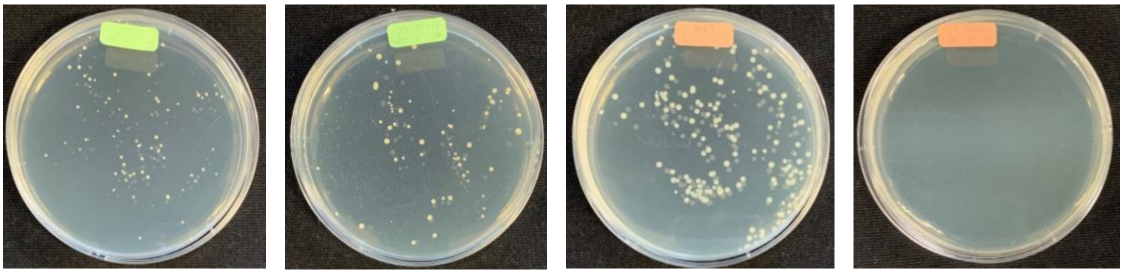
**Figure 4.14** The number of bacteria on sample B after washing 10 times



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

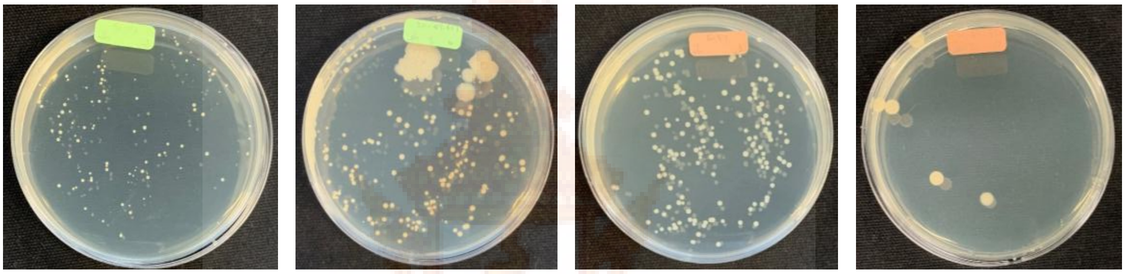
**Figure 4.15** The number of bacteria on sample A after washing 15 times



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

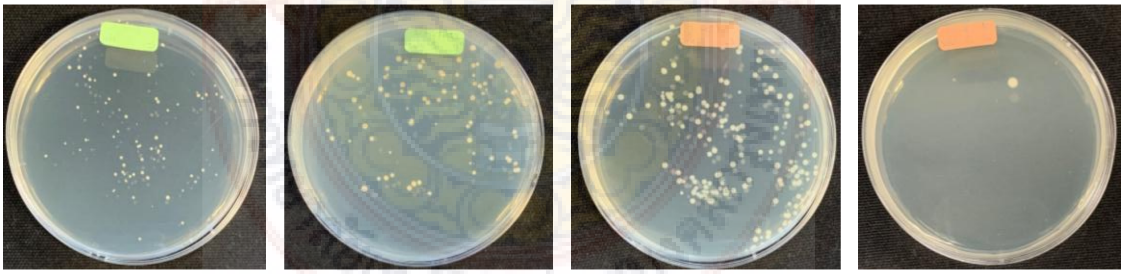
**Figure 4.16** The number of bacteria on sample B after washing 15 times



0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

**Figure 4.17** The number of bacteria on sample A after washing 20 times



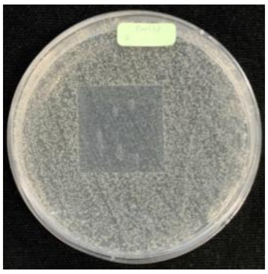
0 h 24 h 0 h 24 h

*S. aureus* *E. coli*

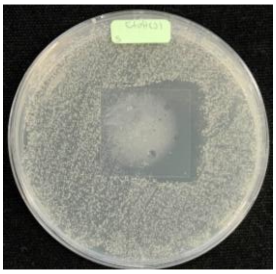
**Figure 4.18** The number of bacteria on sample B after washing 20 times

**Table 4.9** Efficacy of sample on growth inhibition of bacteria

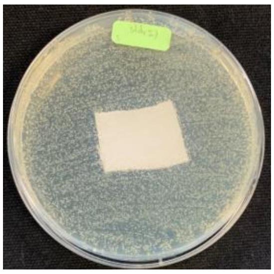
| Sample | Wash (cycles) | Clear zone of inhibition (mm) | |
|---|---|---|---|
| | | *S. aureus* | *E. coli* |
| Negative control (DW) | - | 0.0 ± 0.0 | 0.0 ± 0.0 |
| Positive control (Ethanol) | - | 3.12 ± 0.76 | 1.83 ± 0.29 |
| Normal fabric | 0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| Sample A | 5 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 10 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 15 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 20 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| Sample B | 5 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 10 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 15 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| | 20 | 0.0 ± 0.0 | 0.0 ± 0.0 |



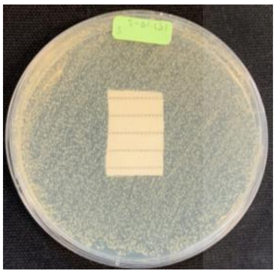
Negative control (DW)



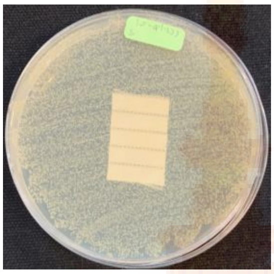
Positive control (Ethanol)



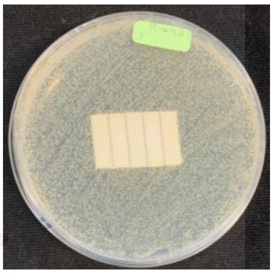
Normal fabric



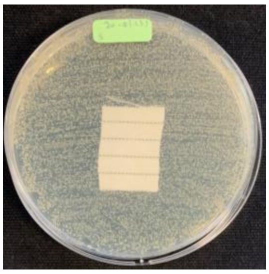
5 times washing



10 times washing

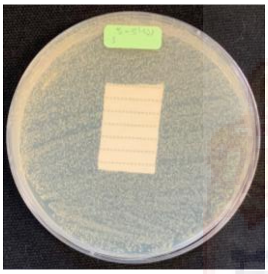


15 times washing

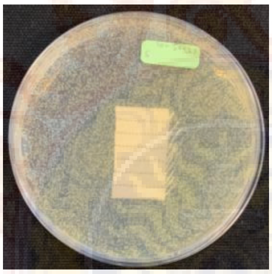


20 times washing

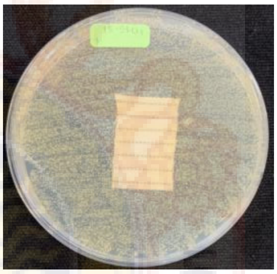
Sample A



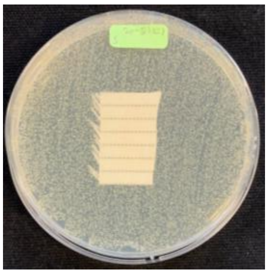
5 times washing



10 times washing



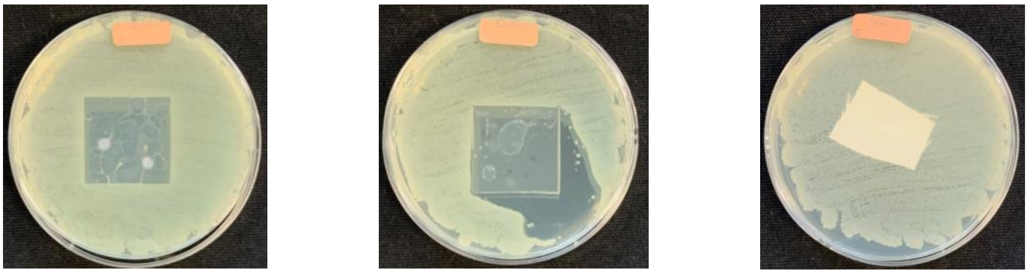
15 times washing



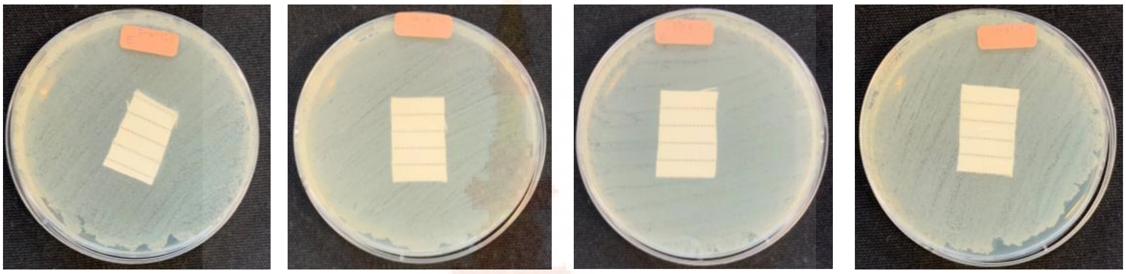
20 times washing

Sample B

**Figure 4.19** Inhibit bacteria *Staphylococcus aureus*

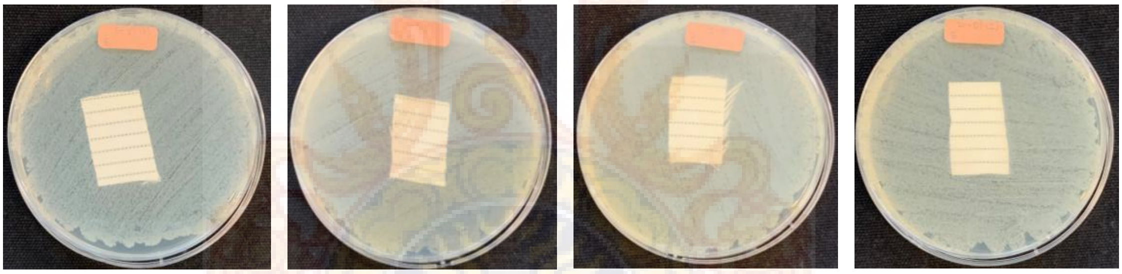


Negative control (DW) Positive control (Ethanol) Normal fabric



5 times washing 10 times washing 15 times washing 20 times washing

Sample A



5 times washing 10 times washing 15 times washing 20 times washing

Sample B

**Figure 4.20** Inhibit bacteria *Escherichia coli*

*S. aureus* and *E. coli* are among the most prevalent species of gram-positive and gram-negative bacteria, respectively. Table 4.8 and Figure 4.10-4.18 showed the percentage reduction results of antibacterial fabrics after washing 5, 10, 15, and 20 times. It could be seen that the percentage reduction of *S. aureus* decreased after washing, while the percentage reduction of *E. coli* did not decrease. The percentage reduction of *S. aureus* bacteria was lower than *E. coli* bacteria because the cell wall for gram-positive consisted of linear polysaccharide chains cross-linked by short peptides to form a three-dimensional rigid structure [56].

After washing, the fabrics against *S. aureus* gave an antibacterial pencentage of around 50%. This phenomenon is associated with the weak physical bonding between the silver particles and fabric surface (Figure 4.21). The presence of silver layer on fibres can clearly be seen on these SEM images. However, the antibacterial percentage against S. *aureus* and *E. coli* bacteria was around 50% and 100%, respectively. Therefore, the durability of antibacterial fabric is satisfied [56].


(a) (b)

**Figure 4.21** Silver yarn (a) before washing (b) after washing 20 times

In the case of zone of inhibition, it was observed that no zones of inhibition of all fabrics (Table 4.9 and Figure 4.19-4.20). This could be implied that the silver, an antimicrobial agent, did not leach from fabrics.

## 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 4.10 and appendix F.

**Table 4.10** Costing of fabrics

| Fabric type | Cost (THB/yarn) |
|---|---|
| Normal fabric | 17.85 |
| Sample A (4% of silver yarn) | 18.25 |
| Sample B (5% of silver yarn) | 18.31 |

The cost of fabrics increased with increasing amount of silver yarn presented in Table 4.10. However, the cost of fabrics constituting silver yarn slightly higher than that of normal fabric with having antibacterial properties.

# CHAPTER V

# CONCLUSION

Silver yarn obviously had antibacterial property in both gram-positive bacteria and gram-negative bacteria. The different amount of using silver yarn in the fabric, which was 5 and 6 silver yarns in square inch, was not affect to the percentage reduction of antibacterial within 24 h. For further study, the speed of antibacterial by increasing in different amount of silver yarn should be concerned in order to find the appropriate amount of silver yarn that should be used in the proper fabric.

In term of mechanical property, silver yarn directly affected strength of fabric in both tensile strength and tearing strength. From the results, it implied that if the developer needs to maintain or increase tensile strength of the fabric, the increasing in silver yarn in both warp and weft direction will be concerned to reach the objective. It was because the results revealed that the increasing of silver yarn in warp direction increased tensile strength of the fabric. Moreover, the optimal point of antibacterial effectiveness in term of percentage reduction or timing of prevention of the growth should be considered as the significant factor in order to develop fabric that compatible to be produced in textile industry and meet the customer’s satisfaction.

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# APPENDICES

# APPENDIX A

# SPECIFICATION OF POLYESTER YARN

Product name Draw texture yarn

Denier (150/48)×2 SD (IL 1H)

Lot 310

Grade A

Type Semi dull

| Property | unit | specification | Avergage result | Test methods |
|---|---|---|---|---|
| Denier | De. | 306 ± 3 | 305.99 | W-QA-02-400 |
| Tenacity | g/den | ≥ 4.2 | 4.65 | W-QA-02-402 |
| Elongation | % | 24 ± 3 | 24.72 | W-QA-02-402 |
| Shrinkage | % | 4.2 ± 1 | 4.42 | W-QA-02-401 |
| Oil pick up | % | 1.5 ± 0.5 | 1.55 | W-QA-02-300 |
| intermingling | Knots/M | 105 ± 10 | 102 | W-QA-02-404 |
| Bobbin weight | kg | 5.5 ± 0.1 | 5.50 | - |
| Carton weight | kg | 33.0 | 33.0 | - |
| Type of twist | - | S + Z twist | S + Z | |

# APPENDIX B

# BREAKING LOAD AND ELONGATION

**Table B-1** Breaking load of normal fabric

| 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 B-2** Breaking load of sample A (4% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 1833.77 | 1686.21 |
| 2 | 1848.12 | 1679.71 |
| 3 | 1818.51 | 1744.52 |
| 4 | 1870.69 | 1736.75 |
| 5 | 1850.07 | 1697.41 |
| Avg | 1844.23 | 1708.92 |
| SD | 19.50 | 29.76 |

**Table B-3** Breaking load of sample B (5% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 1906.68 | 1673.21 |
| 2 | 1879.86 | 1711.63 |
| 3 | 1783.55 | 1710.74 |
| 4 | 1937.97 | 1633.91 |
| 5 | 1934.85 | 1662.90 |
| Avg | 1888.58 | 1678.48 |
| SD | 63.28 | 33.15 |

**Table B-4** Percentage elongation of normal fabric

| 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 B-5** Percentage elongation of sample A (4% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 45.67 | 52.67 |
| 2 | 43.33 | 50.92 |
| 3 | 43.08 | 53.08 |
| 4 | 43.83 | 52.08 |
| 5 | 44.25 | 51.92 |
| Avg | 44.03 | 52.13 |
| SD | 1.02 | 0.82 |

**Table B-6** Percentage elongation of sample B (5% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 47.17 | 53.00 |
| 2 | 44.92 | 52.75 |
| 3 | 43.17 | 53.50 |
| 4 | 46.75 | 50.08 |
| 5 | 48.08 | 51.67 |
| Avg | 46.02 | 52.20 |
| SD | 1.92 | 1.36 |

# APPENDIX C

# TEARING LOAD

**Table C-1** Tearing load of normal fabric

| 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 C-2** Tearing load of sample A (4% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 75.08 | 63.91 |
| 2 | 73.99 | 66.75 |
| 3 | 70.69 | 65.56 |
| 4 | 68.99 | 61.62 |
| 5 | 71.76 | 64.71 |
| Avg | 72.10 | 64.51 |
| SD | 2.46 | 1.93 |

**Table C-3** Tearing load of Sample B (5% of silver yarn)

| Sample No. | Direction | |
|---|---|---|
| | Warp | Weft |
| 1 | 74.59 | 64.46 |
| 2 | 73.25 | 62.95 |
| 3 | 67.97 | 61.90 |
| 4 | 68.85 | 61.43 |
| 5 | 65.32 | 66.43 |
| Avg | 70.00 | 63.44 |
| SD | 3.84 | 3.21 |

# APPENDIX D

# STIFFNESS

**Table D-1** Stiffness of normal fabric

| 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 D-2** Stiffness of Sample A

| Sample No. | Warp direction | | Weft direction | |
|---|---|---|---|---|
| | Length (cm) | Stiffness (g.cm) | Length (cm) | Stiffness (g.cm) |
| 1 | 3.50 | 1693.56 | 3.50 | 1693.56 |
| 2 | 3.40 | 1552.51 | 3.50 | 1693.56 |
| 3 | 3.30 | 1419.51 | 3.50 | 1693.56 |
| Avg | 3.40 | 1555.19 | 3.50 | 1693.56 |
| SD | 0.10 | 137.05 | 0.00 | 0.00 |

**Table D-3** Stiffness of Sample B

| Sample No. | Warp direction | | Weft direction | |
|---|---|---|---|---|
| | Length (cm) | Stiffness (g.cm) | Length (cm) | Stiffness (g.cm) |
| 1 | 3.50 | 1672.13 | 3.60 | 1819.58 |
| 2 | 3.55 | 1744.82 | 3.50 | 1672.13 |
| 3 | 3.60 | 1819.58 | 3.60 | 1819.58 |
| Avg | 3.55 | 1745.51 | 3.57 | 1770.43 |
| SD | 0.05 | 73.73 | 0.06 | 85.14 |

# APPENDIX E

# ABRASION RESISTANCE

**Table E-1** Abrasion resistance of normal fabric

| Sample No. | Before weight (g) | After weight (g) | Weight loss index |
|---|---|---|---|
| 1 | 3.3889 | 3.3845 | 0.0880 |
| 2 | 3.3787 | 3.3744 | 0.0860 |
| 3 | 3.3877 | 3.3834 | 0.0860 |
| Avg | 3.3851 | 3.3808 | 0.0867 |
| SD | 0.0056 | 0.0055 | 0.0012 |

**Table E-2** Abrasion resistance of sample A

| Sample No. | Before weight (g) | After weight (g) | Weight loss index |
|---|---|---|---|
| 1 | 3.5247 | 3.5233 | 0.0700 |
| 2 | 3.5454 | 3.5437 | 0.0850 |
| 3 | 3.4641 | 3.4625 | 0.0800 |
| Avg | 3.5114 | 3.5098 | 0.0783 |
| SD | 0.0422 | 0.0422 | 0.0076 |

**Table E-3** Abrasion resistance of sample B

| Sample No. | Before weight (g) | After weight (g) | Weight loss index |
|---|---|---|---|
| 1 | 3.458 | 3.4567 | 0.0650 |
| 2 | 3.4574 | 3.4562 | 0.0600 |
| 3 | 3.4187 | 3.4172 | 0.0750 |
| Avg | 3.4447 | 3.4434 | 0.0667 |
| SD | 0.0225 | 0.0227 | 0.0076 |

# APPENDIX F

# COSTING OF FABRICS

**Table F-1** Costing of normal fabric

| Direction | Yarn type | Weight (g/yard) | Yarn cost (USD/ kg) | Yarn cost (THB/ kg) | Yarn cost (THB/yard) |
|---|---|---|---|---|---|
| Warp | 150/48/2 | 188.56 | 1.50 | 48.00 | 9.05 |
| Weft | 150/48/2 | 183.36 | 1.50 | 48.00 | 8.80 |
| | | Total cost yarn | | | 17.85 |

**Table F-2** Costing of sample A (4% of silver yarn)

| Direction | Yarn type | Weight (g/yard) | Yarn cost (USD/ kg) | Yarn cost (THB/ kg) | Yarn cost (THB/yard) |
|---|---|---|---|---|---|
| Warp1 | 150/48/2 | 183.34 | 1.50 | 48.00 | 8.80 |
| Warp2 | 75/36/2 | 4.42 | 4.62 | 147.84 | 0.65 |
| Weft | 150/48/2 | 183.36 | 1.50 | 48.00 | 8.80 |
| | | Total cost yarn | | | 18.25 |

**Table F-3** Costing of sample B (5% of silver yarn)

| Direction | Yarn type | Weight (g/yard) | Yarn cost (USD/ kg) | Yarn cost (THB/ kg) | Yarn cost (THB/yard) |
|---|---|---|---|---|---|
| Warp1 | 150/48/2 | 180.17 | 1.50 | 48.00 | 8.65 |
| Warp2 | 75/36/2 | 5.82 | 4.62 | 147.84 | 0.86 |
| Weft | 150/48/2 | 183.36 | 1.50 | 48.00 | 8.80 |
| | | Total cost yarn | | | 18.31 |

**Ramark**:

1) Price of yarn is converted on April 26, 2019 at the exchange rate of THB 32.00/ 1 USD.

2) Cost of yarn is excluded tariff, import customs clearance and other transportation cost of delivery to manufacturing company.

3) Weaving, dyeing, and finishing cost are varied according to each manufacturer.