THE HONG KONG POLYTECHNIC UNIVERSITY

INSTITUTE OF TEXTILES AND CLOTHING

Study the relationship between UV protection and knitted fabric structure

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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CHONG HANG KEI (Name of student)

Abstract

The main purpose of this research was to study the relationship between the structure of knitted fabric and the ultraviolet (UV) protection of cotton fabrics.

For studying the UV protection ability of cotton knitted fabric, a total of 7 types of knitted fabric were produced. The single knit fabrics were: (1) Cross Tuck (Knit + Tuck), (2) Cross Miss (Knit + Miss), (3) Double Cross Tuck (Knit + Tuck), (4) Double Cross Miss (Knit + Miss), (5) Lacoste (Knit + Tuck), (6) Weft Locknit, (7) Plain Knit (All Knit). All the fabrics were produced from combed cotton (CH series) and combed supima ESTex (MCG series) with yarn count 20Ne and FUKUHARA Circular knitting machine was selected.

In this research, different kinds of testing methods were used to evaluate the performance of the knitted cotton fabric. Fabric weight measurement, fabric thickness measurement, fabric count (stitch density) measurement, fabric shrinkage, air permeability, Kawabata Evaluation System, and ultraviolet protection factor measurement, were studied in this research. The result revealed that the Double Cross Miss has the highest UPF value but its fabric weight was also the highest. The single knit fabric with knit and miss could perform a better UV blocking ability than the fabric with all knit or knit and tuck.

LIST OF PUBLICATIONS

1. H.K.S. Chong, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu and C.W.M. Yuen, "Study the Relationship between UV Protection Property and Knitted Fabric Structure", Journal of Textile Engineering (Submitted)

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Recently, an increasing number of skin cancer cases have been observed worldwide (Grant-Kels, 1993). Although the recommendation of textiles as a means of sun protection has previously been published (USEPA 1999, WHO 1995, Hacker et.al 1993, Akaydın et.al 2009, Das 2010, Lam et.al 2009), there is still an inadequate supply of suitable clothing that offers simple and effective protection against the sun. Many government, medical, education, and volunteer groups applied a set of resources and working to increase public awareness of the potential hazard of sun damage to the skin and methods of prevention (Wong et.al 2006, Xin and Daoud, 2004). Healthy People 2010 (U. S. Health and Human Services) suggest limiting sun exposure, seek shade whenever possible, wear sunscreen, wear protective clothing and accessories, and avoid tanning beds, all these methods are effective in protecting human from the hazards of UV radiation. While textile research continues to improve methods of producing fabrics with better UV blocking ability (Gamlichler et.al, 2002, Gies et.al 1998, Diffey et.al, 1997, Song and Stone, 2005), perseverance in sun protection education, motivation incentives and behavior interventions must place at a higher priority (Center for Disease Control and Prevention [CDC], 2006; Jackson and Aiken, 2000; U.S. Health and Human Services, 2005). Nevertheless, several studies have revealed, differing from those popular expected, that some textiles provide only limited Utlraviolet (UV) protection (Gies et.al, 1998, Gambichles et.al, 2001 and Osterwalder and Rohwer, 2002). Clothing, as a principal means to protect people from the harmful UV radiaton has many advantages over sunscreen. It cannot be washed off and once you wear, you do not need to reapply. It is also reusable ad stable. Although clothing has many advantages over sunscreen, some researchers found that about one-third of commercial summer clothing items provided a UPF less than 15 (Gies et.al. 1998, Gambichler et.al, 2001, Osterwalder and Rohwer, 2002). The direct and diffused UV transmittance through fabric is an important factor determining the UV protection of the fabric (Alvarez and Lipp, 2003, Akaydin, 2010). Moreover, spaces between yarns are generally larger in a knitted fabric than in a woven fabric. Since knitted fabric is more common in summer because it is more comfortable to wear, therefore it is important to increase the UV blocking ability of knitted fabric. On the other hand, an increase in weight per unit area will result in a decrease in fabric porosity. The yarns are closer to each other in the heavier fabric which will reduce the transmission of UV radiation. Since the fabric structure, fabric weight and fabric thickness are the three major factors of fabric porosity, these factors will be investigated in this study.

1.2 Scope and Background of Research

Due to an increasing interest in UV protection, recreationally and occupationally, test methods and a rating scheme for clothing were needed to ensure sufficient UV protection. Ultraviolet radiation constitutes part of the sun energy arriving at the earth. UV is composed of about 5 per cent of sun radiation arriving at the earth and the wavelengths are between 100 – 400 nm. UVR is classified as three types, namely UVA, UVB and UVC (Mutlu & Toros, 2003). UVA radiation (320 – 400 nm), UVB radiation (280 – 320 nm) and UVC radiation (100 – 280 nm). In order to measure the UV transmission through the fabric, a spectrophotometer is used to detect the percentage transmission in wavelength of 5nm interval from 290nm to 400nm and the protection factor is known as Ultraviolet Protection Factor (UPF). Besides, thickness is another useful factor for understanding differences in UV protection between fabrics. It is clear that the thicker, tighter the fabrics, the less UV radiation can be penetrated. It is concluded that thickness is useful in explaining differences in UV transmission. Although it is clear that UV protection is important in protecting human from the hazard of UV radiation, seldom report focuses on the knitted fabrics concerning fabric structure. Most of the previous studies were focused on the woven fabric (Gies et.al, 1998), however knitted fabric is much more popular in summer time while UV radiation is high in summer, therefore in this project, knitted fabric with UV protection will be investigated. In this project the most important context is the fabric structure, cover factor, tightness factor, fabric weight and fabric weight, a comprehensive study in this field is needed. In order to produce a textile material with a high UPF rating, other than chemical approach, the manufacturer can also be focused on the fabric structure in producing the textile materials in a controlled condition with a fixed ranged of cover factor.

1.3 Objective

The purpose of this research is to study the relationship between the different knitted fabrics structure and the UPF. The parameters of different fabrics were measured, they are fabric weight, fabric thickness, fabric density, air permeability, tightness factor and surface properties. These factors are also examined in order to further understand the effect of different factors on the UPF. In this research, different kinds of statistical tools were used to study the relationship between the knitted fabric structure and the UPF. They are Multiple Linear Regression (MLR) and Factor Analysis (FA). MLR was used to study the effects of different parameters on the UPF. It is widely used to model the mean of the response variables a function of the independent. It allows for the prediction of mean of a dependent variable in terms of regression coefficients (Ramsey and Schafer, 1997). On the other hand, Factor analysis was used for understanding the relationship among factors. It also helps to know about the correlation and correlation matrix. Using few factors to represent lots of original variables with little loss of information. These two statistical tools can help to understand the relationship between the structural parameters and the UPF and also predict the UPF by using the fabric parameters before the fabric being made.

1.4 Methodology

In this research in vitro measuring methods were used and ASTM, AATCC methods and spectrophotometric methods are the main approaches under in vitro testing. The spectrophotometric method measures “the total transmission of UVR through the test sample as a function of wavelength, weighting this transmission measurement with the expected distribution of solar radiation in a geographic location of interest and the relative erythemal resonse of the skin to each wavelength of radiation” (Capjack et.al, 1994). The advantage of this spectrophotometric measurement technique is that it is repeatable and reproducible test method for determining the UPF blocking ability (Gies, Roy and Holmes, 2000). Also it can account for any spectral variations in the absorption spectrum of the sample. However, frequent calibration is needed during the measurement process and the fluorescence induced by UV have to be blocked by filters in order to ensure the accuracy of the measurements. As studied by Laperre et.al, eight laboratories using nine different measuring instruments located in five different locations, have measured fourteen samples. The results showed that the variations of measurements between laboratories increased with higher UPF but within each laboratory, the differences varied little in the UPF ranged from 1-70. The laboratory setting of the UPF measurement is generally considered the “worst” condition. The collimated beam used in the laboratory is directed. It is more intense and less likely to be absorbed by fabric than the actual sunlight, which contains a considerable amount of diffuse light. As spectrophotometric measurement and different kinds of international standard are used in this research, the use of the spectrophotometer and standards are discussed later.

1.5 Summary

This chapter showed the scope and background of this research, as there is a general awareness that UV is harmful, people started to seek more protection other than traditional methods. Although sun cream is a good method which can be applied to everyone, frequently apply of sun cream is needed which is quite annoying. Therefore textile materials with good UV blocking ability become more and more important. The objective of this research is to study the relationship between knitted fabric structure and UPF, by understanding the relationship we can predict the UPF of the knitted fabric before production, also we can obtain a textile materials with better UV blocking ability by only changing the fabric parameters.

CHAPTER 2 LITERATURE REVIEW

2. 1 Introduction

This section would review related work which is relevant to this study. Brief background information of Ultraviolet (UV) radiation will be presented. In addition, related equipments machine and materials will be introduced. The factors affecting the UV blocking ability of the fabric, different kinds of fabric structure and measurement methods will also be discussed.

2.2 Ultraviolet Radiation

UV radiation is the wavelength region from 100-400 nm in the electromagnetic spectrum. Due to the different biological effects that the radiation causes, UV radiation is subdivided into three regions, which are UVA (315-400nm), UVB (280-315nm), and UVC (100-280nm) (Diffey, 2002). As a result of the absorption by ozone in the upper atmosphere, approximately half of the UVB and no UVC will reach the earth surface (Gies et.al., 1992).

Since UVB is the main cause of the skin related problems, around 80% of the biological damage is caused by UVB and 20% is caused by UVA (Diffey, 2002) The 280-300nm portion of the UVB spectrum is 1000 times more erythmogenic than the 340-400nm portion of the UVA spectrum (Wang et.al 2001). For UVC, since it is blocked by the ozone layer therefore it is difficult to reach the earth. However, it is the most dangerous and harmful to our eyes and skin (Algaba and Riva, 2002, Palacin, 1997, Akaydin et.al., 2009). The maximum erythemal effectiveness occurs at 308nm reported by Reinert, (1997). It is believed that UVA is much less in inducing erythema than UVB (McKinlay and Diffey, 1987) so that the immediate effects of UVA are not easily been seen. Even in a moderately high dose, UVA does not cause sunburn even though it results in biologic damage. UVA reacts with endogenous photosensitizes producing reactive oxygen free radicals that damage DNA (Ananthaswamy and Pierceall, 1990) and may play a role in the pathogenesis of melanoma and nonmelanoma skin cancer (Runger, 1999) Figure 2.1 shows the absorption of UV radiation by ozone layer while Table 2-1 shows the types and properties of UV Radiation

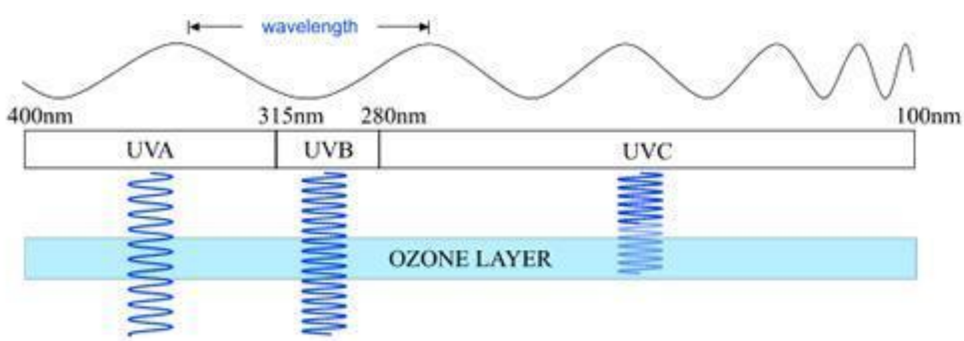


Figure 2.1 The absorption of UV radiation by ozone.(ARPANS, 1999)

TABLE 2-1 TYPES AND PROPERTIES OF UV RADIATION

Name	Wavelength range in Nanometers	Energy per photon	Property
Ultraviolet A UVA	400nm-315nm	3.10-3.94eV	-premature Ageing -wrinkling of the skin -implicated in skin cancer
Ultraviolet B UVB	315nm-280nm	3.94eV-4.43eV	-skin cancer -cataracts -sunburn
Ultraviolet C UVC	280nm-100nm	4.43eV-12.4eV	-extremely dangerous -blocked by ozone layer

(ISO 21348 , Process for determining solar irradiances, 2007)

Other than the direct sunlight, people can still receive substantial UVR exposure from the open sky and reflective surface. Also some building with white paint or metallic surfaces can reflect UVR onto the skin or eyes even if people are shaded from the direct sunlight. Generally speaking, clothing can provide a good UV protection and it is obvious that wearing clothing can give us a better protection against the sunlight when compare to bare skin (Osterwalder, et.al., 2000, Robson and Diffey, 1990). It is believed that wearing clothing can give at least five times better which means less than 20% of the UVR can penetrate clothes (Menter et.al, 1994). Premature skin ageing will be resulted by this amount of UV radiation (Ream and Devillez, 1978, O'Quinn and Wagner, 1998). In order to make a good sun protective garment, several factors should be concerned (Resource guide for UV protective products, 2003) :

1. Fibre content: Different types of fibre such as cotton, polyester and nylon have different natural UVR absoring properties.
2. Fabric density: With tighter the fabric structure, less UVR passes through the fabric.
3. Colour: Darker the colour will absorb UVR more than lighter shades and consequently will have a higher UPF rating.
4. Tension: While stretching the knitted fabric, the fabric may deform and causing the hole of the fabric becomes bigger and so the UPF rating will be decreased. Therefore care should be taken to select the correct size for the wearer.
5. Weight: Heavier weight textiles generally have a higher UPF rating than lighter materials of the same type.
6. Wetness: When the fabrics get wet, the UPF rating will be lower. The decrease in UPF rating depends on the type of fabric and the amount of moisture absorbed.
7. Design: The garment design also plays a major role in determining the UPF rating. A shirt with long sleeve offers higher protection than a short sleeve shirt. Tight fitting garments will have lower UPF rating than loose fitting garments.
8. Condition: The UPF rating of a brand new cotton fabric is different from a used one. Shrinkage in these fabrics closes small gaps between the yarns and less UVR can pass through. However, old and faded fabric may has a lower UPF rating.

9. UV absorbers: Treatment with a UVR absorber during manufacturing process, can increase the UPF rating of the fabrics while retaining the comfort property of the fabric.

2.3 Ultraviolet Protection Factor (UPF)

Ultraviolet Protection Factor (UPF) is the ratio of the average effective UV radiation irradiance calculated for unprotected skin to the average effective UV radiation irradiance calculated for skin protected by the test fabric. In addition, UPF is also known as the ability of a fabric to against UV radiation, there are three factors in determining UPF of a fabric.

(a) Fabric's spectral transmittance: it represents the energy amount passing through the fabric per wavelength.

(b) Sun's spectral radiation: it is a function of sun energy amount arriving to the earth surface per wavelength.

(c) Erythema effect spectrum: it is value spectrum of UV radiation effect on the skin per wavelength

The equation of UPF= $\frac{\sum_{\lambda=280}^{400} E\lambda \text{ x } S\lambda \text{ x } \Delta\lambda}{\sum_{\lambda=280}^{400} E\lambda \text{ x } S\lambda \text{ x } T\lambda \text{ x } \Delta\lambda}$ …… Equation 2-1

McKinlay and Diffey's (1987) erythemal spectral effectiveness function published by the International Commission on Illumination (CIE) (1987). Based on Equation 2-1 where λ is the wavelength in nm; E_λ, relative erythemal spectral effectiveness; S_λ, solar spectral irradiance of the source in watts per square meter; Δ_λ, bandwidth in nanometer; and T_λ, spectral transmission of the sample. The integrals (e) are calculated over the wavelength range of 280 to 400 nm (Gies et.al, 1999). The UPF value is calculated based on the transmission in the UVB region. Some of the UV radiation is absorbed, reflected and some is transmitted through the fibres and the fabric porosity reduces its ability to provide protection against UV Radiation. The UPF increases with fabric density and thickness for similar construction, and depends on porosity (UPF = (100%) / (100%-porosity)). The UV protection ability of fabric is also affected by the cover factor. (UPF = (100%)/(100%-cover factor)). (Australian/New Zealand Standard, 1996).

2.4 Sun Protection Factor (SPF)

Sun protection factor (SPF) is similar but not the same as Ultraviolet protection factor (UPF). SPF used in the Australian / New Zealand Standard AS/NSS 2604 1997 to describe in vivo testing of sunscreens while UPF used for garment. Human testing is used to determine the values of SPF, on the other hand, instrumental measurement of UVR transmission is used to determine the values of UPF. For studying the UV blocking rating of fabrics, UPF will be used while SPF used for rating sunscreens. (Crews, et.al, 1999)

2.5 Standard for UV protection

UV transmission measurement is one of the most important evaluations in this project. There were several UV testing standards in the textile industry: i.e. Australia/ New Zealand standard (AS/NZS 4399:1996), USA standard (AATCC 183) and (ASTM 6603) and British & European standards (EN 13758-1). There are some similarities and differences among the standards. The calculation and expression of results are similar in EN 13758-1, AATCC-183 and AS/NZS 4399. All three standards used UPF rating as a result. If the fabric has a UPF rating higher than 50, ASTM 6603 and AS/NZS4399 report them as 50+ while EN 13758-1 report them as >50.

EN 13758-1 stipulates that fabric samples are to be conditioned at a specified temperature and humidity before. AS/NZS4399 does not require any conditioning and ASTM 6603 require that the fabric samples needed to launder.

EN 13758-1 and AATCC 183 provide fabrics for reporting of measurements when the fabrics are wet or stretched while AS/NZS 4399 specifies testing in the dry and relaxed state only.

2.5.1 Australia/New Zealand standard

In this project, Australia/New Zealand standard: AS/NZS 4399:1996 “Sun protective Clothing- Evaluation and Classification” was used and Varian Cary 300 UV-VIS Spectrophotometer was used for measurement.

Table.2.2 shows brief information of the UV blocking testing standard for textiles which is based on Australia/ New Zealand standard, Sun protective clothing—Evaluation and classification 1996. (http://www.saiglobal.com/online (accessed on 28-6-2011))

TABLE 2-2 BRIEF INFORMATION OF THE UV BLOCKING TESTING STANDARDS FOR TEXTILES

Country	Australia/ New Zealand
Standard number	AS/NZS 4399:1996
Results expression	UPF rating
Calculation method	Calculate mean UPF value and average of UVA & UVB transmission, to classify UPF level
Testing condition	normally 20℃ ± 5℃ and 50% ± 10% relative humidity (RH)
Wavelength range	290-400nm
Samples required	4 samples test required
Samples state	Only specifies testing in dry and relaxed state

The AS/NZS 4399:1996 sets requirements for determining and labeling the UPF of sun protective textiles and other items that are worn next to the skin. The UPF index only determines the protection factor for the fabric but not for the degree of protection which is provided by the design of the garment. (Hoffmann, et.al, 2001). The other factors such as wetness, stretch, uses and wearing condition are not considered. Based on AS/NZS

4399:1996, UPF are classified in 3 categories: UPF of 15 to 24 (ratings 15 and 20) provides good protection; UPF of 25 to 39 (ratings 25, 30, and 35), provides very good protection; and UPF of 40-49 (ratings 40, 45, and 50), provides excellent protection; and UPF of 50+ (rating 50+) considered the ultimate in UV sun protection. Textiles with a UPF of less than 15 are not labeled. Table 2.3 shows the UPF Ratings and Protection Categories (Australia/ New Zealand standard, Sun protective clothing—Evaluation and classification 1996). (http://www.saiglobal.com/online (access on 28-6-2011))

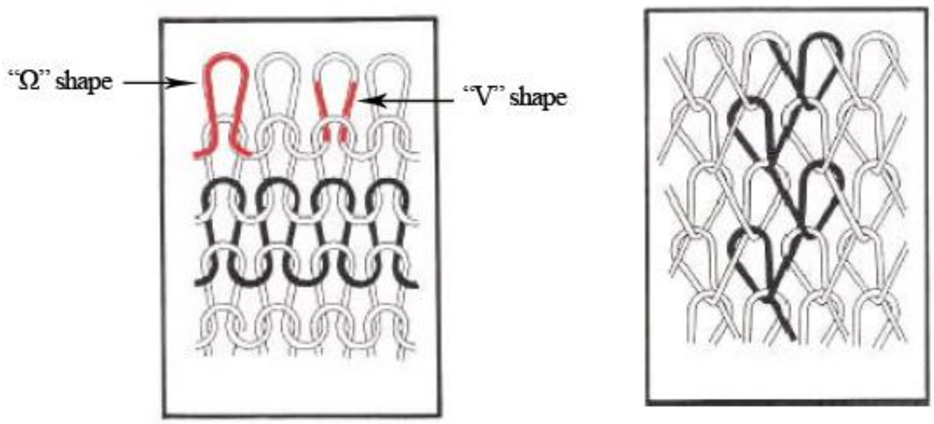
TABLE 2-3 UPF RATINGS AND PROTECTION CATEGORIES

UPF Rating	Protection Category	% UV radiation Blocked
UPF 15 - 24	Good	93.3 - 95.9
UPF 25 - 39	Very Good	96.0 - 97.4
UPF 40 - 49	Excellent	97.5 or more
UPF50+	Considered the Ultimate in UV Sun Protection	

Source from ((http://www.saiglobal.com/online (access on 28-6-2011))

2.6 Knitting Fundamentals

Knitted fabric is a manufactured assembly of yarn that has substantial surface area in relation to its thickness and sufficient cohesion given to the assembly enough mechanical strength (Denton and Daniels 2002). Knitting is the interloping of yarns to form a textile fabric. There are two basic types of knits-weft and warp. The yarns of weft knitting are knitted across the width of the fabric while the yarns of warp knitting are knitted along the length of the fabric (Spencer, 2001). Fabric is produced by several parallel yarns that form one stitch for each yarn in each course. Each stitch in a course is made of different yarns (Gioello, 1982). Figures 2-2a and 2-2b showed the structure of weft knitting and warp knitting respectively.



Figures 2-2 (a) Weft knit structure and (b) Warp knit structure

2.6.1 General Characteristics of Single Knit Fabrics

[1] Fabric Elasticity

Since the shape of a loop can easily be changed by stretching the fabric on all directions, the distorted loop can recover their relaxed shape afterwards. This ability makes the fabric elastic and comfortable to wear.

[2] Fabric Porosity

Generally speaking, the space between the yarns of a knitted fabric is larger than the space of a woven fabric, because a “Ω” shape of a loop is a single unit to form a knitted fabric. Therefore, the porosity of the knitted fabric provides better air permeability performance. However, with increasing in porosity, more holes can be found on a knitted fabric, the UV radiation can pass through the fabric and reach the skin directly, therefore the UV blocking ability of the knitted fabric will be decreased (Curiskis et.al, 1983) This special features on knitted fabric shows the biggest difference from the woven fabric which is composed of almost straight warp and weft yarns.

[3] Fabric Appearance

All single jersey fabrics have different appearance on the two sides. Looking on the face side, the fabric seems to be composed by “V” shape loop; while on the back side, the loops appeared to be “semi-circle”, depending on the structure. For a weft knitted fabric, the basic elements are knit loop, tuck loop and miss loop. The formation of a weft knitted fabric is totally based on the knit loops, while the tuck loops and miss loops cannot be used to produce any fabric alone. Therefore single knit fabrics can either be composed of (Yue, 1991):

1. All knit loops,

2. Knit + miss loops

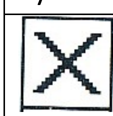
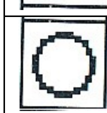
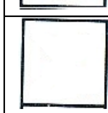
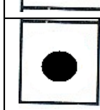
3. Knit + tuck loops, or

4. Knit + tuck + miss loops.

2.6.2 Notation Diagram

In order to simplify and shorten the drawing procedure, the knitter use simple symbols to represent the different type of loops, these symbols are called the “Notation”. However there is yet no international standard for the symbols and only mutual agreement between the knitter and the buyer. Table 2.4 shows common knitting symbols used in many countries (Raz, 1993):

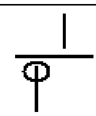
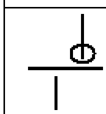
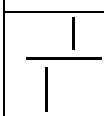
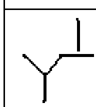
TABLE 2-4 SYMBOLS OF DIFFERENT TYPES OF LOOP

Symbols	Loop
	A face loop
	A back loop
	A miss loop
	A tuck loop

2.6.3 Yarn Path Diagram

The “yarn path diagram” is a different method to show the knitting process. It simulates the knitting process on the knitting machine rather than showing the appearance of the loop. Table 2-5 shows the symbols used in the yarn path diagram (Raz, 1993)

TABLE 2-5 SYMBOLS USED IN THE YARN PATH DIAGRAM

Symbols	Loop
	A face loop
	A back loop
	A miss loop
	A tuck loop

2.7 Basic Knit Structures

All weft knitted structures can be classified into three primary groups based on the arrangement of loops. The three classifications are the Plain knit (single jersey), Rib (double jersey) and Purl. Plain knit is the simplest and the most basic structure. It is a single sided fabric, therefore “Plain knit” is also called “Single knit”. Rib, also called “Double Knit” is a double sided fabric which formed by two sides of knitted structure.

Lastly, Purl is also a double knit fabric which requires both front and rear needles beds for the production of the structure.

2.7.1 Plain knit

Plain knit or single jersey is a general term for knitted fabric produced by the knitting machines using one set of needles either front or rear. The fabric could be composed of different patterns, stitches, materials or different weight and thickness.

2.7.2 Rib

Rib or double knit is knitted fabric produced by knitting machines using two sets of needles both front and rear. Each set of needles produce their own loops on one side of the fabric, therefore both sides of the fabric are composed of technical face loops

2.7.3 Purl

As with rib, two sets of needles are required to produce the purl structure. Purl can be determined as a knit structure in which front and reverse loops appear in the same wale. It also required special equipment to produce. However, in this paper, only plain knit and rib will be discussed.

2.8 Yarn Type

In this study, a total of two types of yarns would be selected for making into fabric, they are combed cotton (CH) and combed cotton Supima ESTex (MCG) yarns. It is because these two types of cotton yarn are mostly used for making knitted fabric. For CH yarn, the texture of combed cotton yarn is softer because it lacks short threads to stick out and prickle, and all dirt and impurities have been removed from the thread. CH yarn is also stronger, because shorter and breakable fibres have been removed through combing (Hargrave, 2008). For MCG yarn, Supima cotton yarns that are known for their fibre length, strength and natural lustre. The staple length of Supima is 35% longer than regular cotton fibre. The longer staple enhances the softness and lustre. Since less fibre ends are exposed, it can minimize the effects of abrasion and resulting in less pilling. Supima is up to 45% stronger than regular cotton fibre. This makes Supima products extraordinarily resilient. Even light-weight Supima fabrics are more durable, without compromising drape and comfort (General Information about Supima. Supima:World's Finest Cottons. Accessed on 24-10-2012). While ESTex is a torque-free ring-spun yarn, it is a new spinning technology that has produced yarns with low twist, balanced torque high bulkiness and softness (Xu and Tao, 2008). It can also produce single ring yarns with a low twist and relatively high strength at the same time. (Tao et.al., 2007). With softer feel and higher bulkiness, the MCG yarns can provide the wearer with a more comfortable feeling.

2.9 Fabric Structure

The tightness of woven or knitted fabric is proposed as one of the major factors in determining the UPF of a textile fabric (Menzies, et.al, 1991, Robson and Diffey, 1990, Hutchinson and Hall, 1984, Zhang et.al, 1997). A tighter woven or knitted fabric usually has a higher UPF. It is because the UV radiation is either scattered or transmitted through the pores of the fabric structure but not pass through the yarns (Welsh and Diffey, 1981) Comparing a knitted fabric to a woven fabric, knitted fabric usually has a larger space between yarns due to the structure of the fabric. Therefore the pores between yarns tended to reduce the level of cover and increase the UV transmission (Taylor, 1981). Moreover, Knitted fabric is the most common fabric structure for the base layer, as it has high elasticity, providing greater freedom of movement and shape retention. Knitted fabrics also have relatively uneven surfaces, which make them feel more comfortable than smooth-surfaced woven fabrics of similar fibre compositions. This effect results from the fact that fabric that has uneven surfaces has less direct contact with the skin (Higgins and Anand, 2003).

Even though UV protection of knitted fabric is lower than woven fabric, and most of the previous studies were focused on the woven fabric, only few studies focused on the knitted fabric especially lightweight knitted fabric (Crews et.al., 1999, Davis, et.al., 1997, Gies et.al., 1997). However lightweight knitted fabric is much more popular in summer while UV radiation is high at that season, if the mass per unit area of the knitted fabric can be increased while keeping other factors constant, the ability of UV protection of the knitted fabric will also be increased (Pailthorpe, 1994). Since the yarns are closely packed together and smaller holes will be resulted, therefore more UV radiation is blocked (Böhringer, 1998). Other study showed UPF has a high correlation with fabric weight and thickness (Singh, 2005), fabric with higher number of loops in course and wale gives higher UPF. Therefore double knit structures give significantly higher UV protection than single knit structures. In double knit structures; interlock gives the highest level of UV protection, followed by 1x1 rib structure, full milano and full cardigan (Lam et.al, 2009). It is believed that increasing in fabric density and thickness will decrease the fabric porosity for similar construction and also fibre arrangement within yarns surely influence the fabric porosity (Yoon, 1984), hence, the value of UPF will be increased (Achwal, 1997). Since the fabric structure, fabric weight and fabric thickness are the three major factors of fabric porosity (Wilson and Parisi, 2006, Khazova et.al, 2007), the fabric porosity, including the cover factor, tightness factor and fabric openness, will be investigated in this study.

2.10 Fabric Cover Factor, Weight and Thickness

Fabric cover factor depends not only on the course per inch, wale per inch and linear density, it should also included their regularity, hairiness, fiber composition, twist, yarn count and even finishing process (Taylor, 1981). Since cover factor can be defined as the percentage area occupied by warp and filling yarns in a given fabric area. (Capjack et.al, 1994) It also indicates the relative looseness or tightness of a knitted fabric. It is clear that the cover factor will directly affect the UV transmission and absorption of a fabric (Dobnik, 2006). Thus a fabric with a loose structure will provide lower UV protection than denser one (Hilfiker, et.al, 1996, Reiner, et.al, 1997, Haerri et.al, 2000).

In order to understand the relationship between UV transmission and fabric structure and cover factor, an “ideal “fabric with closely packed yarns which is opaque to UV radiation. Since the yarns are closely packed and the spaces between the yarns are very small, so that UV radiation can be blocked by the fabric. The relationship between UV transmission and the cover factor of the “ideal” fabric can be explained as following Equation 2-2:

% cover factor=100 - % UVR transmission (Pailthorpe, 1994)…… Equation 2-2

In reality, UPF of real fabric is lower than those of an ideal fabric because yarns are usually not opaque to UV radiation. In order to reach a minimum UPF rating of 15, the cover factor of the fabric must be at least 93%, when the cover factor of the fabric above 95%, even a small increase in cover factor leads to a higher UPF of the fabric (Saravanan, 2007).

Other than cover factor, thickness will also affect the UV transmission. The decrease in the size of fabric porosity per unit area, in return, the weight will increase per unit area (Sliney et.al, 1987). Since the holes between the yarns are smaller in heavier fabric, which allowing less UV radiation to pass through and hence, higher UPF will be resulted.

Although in the previous study (Welsh and Diffey, 1981) thickness was considered to be less important than porosity or weight of fabric, its significant should not be neglected because it can help us to understand the differences of UV protection among fabrics (Srinivasan and Gatewood, 2000). With thicker and denser fabric, more UV radiation will be blocked by the yarns. Therefore thickness is also useful in explaining the relationship between UV transmission and fabric structure (Crews et.al, 1999). In order to produce textile materials with a high UPF rating, the production system must be maintained under controlled conditions, minimizing the variations and producing the materials with a consistent cover factor.

2.11 Tightness factor

Since Tightness factor is very useful in setting up knitting machine and it is the ratio between yarn count and loop length, the higher the value means tighter the fabric. As a result, tightness factor will also be studied experimentally in this project. Tightness Factor (TF) is calculated based on Munden's Theory:

$$TF=\frac{\sqrt{\mathrm{tex}}}{\mathrm{l}} \quad \text{…… Equation 2-3}$$

where Tex is yarn tex and l is loop length (mm)

2.12 Washing

Most fabrics will undergo the process of shrinkage after knitting process, the surface fibre and yarns will be twisted into the open area during washing. These kinds of physical changes will decrease the space between the yarns, in return, the UV transmission will be reduced accordingly, thus improving UV blocking ability of the fabric (Menzies et.al, 1991, Zhou and Crews, 1998, Sliney et.al., 1987; Clark et.al, 2000). It was also found that wash and wear cycle improves the UV blocking ability significantly. As pure cotton Tshirts were selected to wear 4-8 hours a week and washed once a week by 20 subjects for 10 weeks. The UPF increased from 15 to 35 approximately after 10 weeks of washing and wearing (Standford et.al, 1995). Clark et.al, (2000) also used a cotton T-shirt in a wash and wear trial. After 6 wash and wear cycles, the UPF increased from 15 initially to about 25. And it was found that no increases in UPF after the first time wearing, which means that the increases of UPF were due to washing.

2.13 Fabric colour

The dye molecules absorb a certain range of visible light waves in order to produce a colour. The rest of the light reflected is the colour we see. (Zollinger, 1987). The absorption bands for some dyes extend into the UVR spectral region and thereby reduce the total UV transmission. As a result, dyestuff can improve the UV blocking ability of the fabrics (Clarks et.al., 2000). It is believed that darker the colour will provide better the UV blocking ability than the lighter colour (Pailthorpe, 1993 and Reinert et al., 1997). Enhanced UV protection of a dye depends on the concentration of the dye in the textiles, and the absorption bands of the dye. It was claimed that dark colour provides better UV blocking ability than light colour only valid when the dyes have the same absorbence and same concentration (Reinert et.al., 1997). Other fabric parameters should be the same, such as fabric weight, fabric thickness and construction. In addition, the colour fastness to washing, light, bleaching of the dyestuff should also be achieved certain level in order to maintain the UPF for the life of the fabric or garment (Pailthorpe, 1998)

2. 14 UV absorbers

Although it is found that shrinkage can increase UPF of cotton fabric, it is unlikely that shrinkage can cause sufficient increase in UPF. However, with the use of UV absorbers can significantly enhance the UV blocking ability of fabrics, especially for cotton and cotton / polyester blends which are very common to find in summer clothing (Zhou and Crews, 1998). UV absorbers are also referred to "colourless dyes" because they do not absorb in the visible region of electromagnetic spectrum. UV absorbers are compatible with most of the fibre except acrylics (Reinert et.al, 1997). One of the examples is called Rayson® which was developed by Clariant. This absorber can develop covalent bond with the fibre and so has a good washing fastness and light fastness. Rayson® increases the UPF rating of a summer-weight cotton fabric by 300% (Standford et.al., 1997). On the other hand, Optical Brightening Agents (OBAs) can also absorb the UV radiation in the UVA range but not effective as UV absorbers in the UVB range which is the most dangerous UV radiation to the human since it plays a major role in the development of skin related diseases. Therefore it is not enough to prevent the hazards from the UV radiation only relying on the OBAs (Osterwalder and Rohwer, 2002).

2.15 Conclusion

In summary, basic introductions to different kinds of knitted fabric were presented. On the other hand, the UPF and SPF and the standard of measurement used in this study were also presented. The factors affecting the UPF of the knitted fabrics were discussed and the effect of fabric structure will be evaluated. The influences of weight, thickness, fabric cover factor, the tightness factor, washing cycle, fabric colour and UV absorber would also be examined in order to further understand the different effects on UPF.

CHAPTER 3 EXPERIMENTAL DETAILS

The purpose of this study is to examine the effect of different fabric parameters on the protection against UV radiation. Fabric weight, thickness, shrinkage, stitch density, air permeability, tightness factor and UVR transmission are measured after fabrics were scoured and bleached. UPF values were calculated based on measured UVR transmission.

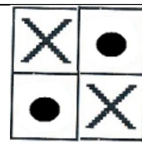
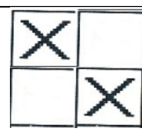
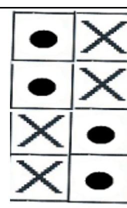
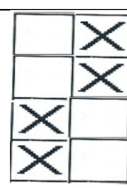
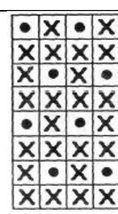
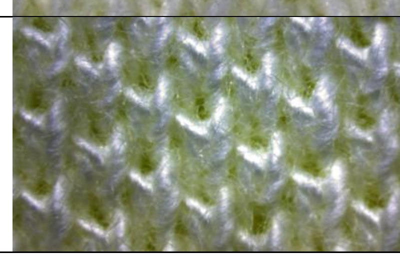
A total 7 sets of knitted fabric were produced on circular knitting machine (Fukuhara circular knitting machine) using cotton yarn. They were produced in order to study the effectiveness of the structure of the knitted fabric as protection against ultraviolet radiation. The fabrics were: (1) Cross Tuck (Knit + Tuck), (2) Cross Miss (Knit + Miss), (3) Double Cross Tuck (Knit + Tuck), (4) Double Cross Miss (Knit + Miss), (5) Lacoste (Knit + Tuck), (6)Weft Locknit (7) Plain Knit (All Knit).

3.1 Knitting Procedure

7 sets of single knit fabric were produced on FUKUHARA Circular knitting machine (JAPAN) from using cotton yarn (CH and MCG). The single knit structures were produced in order to study the effectiveness of the structure of the knitted fabric as protection against ultraviolet radiation. The single knit fabrics were: (1) Cross Tuck (Knit + Tuck), (2) Cross Miss (Knit + Miss), (3) Double Cross Tuck (Knit + Tuck), (4) Double

Cross Miss (Knit + Miss), (5) Lacoste (Knit + Tuck), (6) Weft Locknit (7) Plain Knit (All Knit), all images were taken by Leica M125 stereomicroscope. The details of the fabrics structure and machine are showed in Tables 3-1 and 3-2 respectively.

TABLE 3-1 DETAILS OF THE FABRICS STRUCTURE

Knitting Structure	**Notation Diagram**	**Picture**
1. Cross Tuck (Knit + Tuck)		
2. Cross Miss (Knit + Miss)		
3. Double Cross Tuck (Knit + Tuck)		
4. Double Cross Miss (Knit + Miss)		
5. Lacoste (Knit + Tuck)		

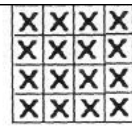
6. Weft Locknit		
7. Plain Knit (All Knit)		

TABLE 3-2 DETAILS OF KNITTING MACHINE

Fabric type	**Machine**	**Gauge**	**Material**	**Yarn**
- Single Jersey	FUKUHARA Circular knitting machine(JAPAN)	20G	Cotton	***-Combed cotton (CH series):*** 20Ne(CH20K) - Conventional Ring Spun ***- Combed Supima Cotton ESTex (MCG series) :*** 20Ne(MCG20) - Torque - Free Ring Spun

The details of sample no. were listed in Appendix A, “CH” representing Combed cotton with conventional ring spun, MCG representing Combed cotton Suipma ESTex with Torque - free ring spun, the first digit representing type of fabric structure and the last digit representing number of washing cycles, e.g. CH2-3, “2” means structure of cross miss and “3” means three washing cycles.

3.1.1 Materials

100% cotton yarns sponsored by Central Textiles Limited were used for knitting the fabric. The yarns were in raw stage and all the fabrics would be scoured after knitted into fabrics. All data would be collected from the fabric after scouring.

3.1.2 Single Knit

[1] Cross Tuck (K+T 1:1)

This structure combined with knit and tuck. Tuck loop produces a small hole on fabric. Figure 3-1 shows the notation diagram of a repeat of the Knit + Tuck fabric.

[2] Cross Miss (K+M 1:1)

This structure combined with knit and miss. Miss loop will stretch the adjacent loop closer together and the fabric will become denser, tighter and shorter in width. Figure 3-2 shows the notation diagram of a repeat of the Knit + Miss fabric.

[3] Double Cross Tuck (K+T 2:2)

This structure combined with knit and tuck and tuck on the same needle for two times. Tuck loop produce a small hole on fabric. Figure 3-3 shows the notation diagram of a repeat of the K+T 2:2 C fabric.

[4] Double Cross Miss (K+M 2:2)

This structure combined with two knit and two miss loops on the same needles. Miss loops will float at the back and stretch the fabric, so that the fabric will be shorter in width and length. The fabric will become denser and the loop will be closer together. Figure 3-4 shows the notation diagram of a repeat of the K+M 2:2 fabric.

[5] Lacoste

Compare with plain knit, Lacoste contains tuck loops which the fabric will be thicker and heavier, this is because there are extra yarns at the back. Figure 3-5 shows the notation diagram of two repeats of the Lacoste fabric.

[6] Weft Locknit

A four-course knit-miss jersey fabric produced by the odd-numbered needles missing at the first course, the even-numbered needles missing at the third course, and all needles knitting at the second and fourth courses. Figure 3-6 shows two repeats of Weft Locknit.

[7] Plain knit

The simplest and most basic structure is the “Plain Knit”. Each side of the fabric is made of a single type of loop, either face side or reverse side (Raz, 1993). Figure 3-7 shows the notation diagram of the face side of the plain knitted fabric.

3.2 Sample Treatment

All fabric samples were scoured and bleached with sandopan DTC paste, caustic soda, stabilizer AWN, water glass and hydrogen peroxide in the bath at boil for 60 minutes with liquor ratio 20:1 and then neutralized with cold dilute acid solution (0.5% H_2SO_4). After that, the fabrics were dried at room temperature. After that the samples were conditioned under the standard atmospheric pressure at 65% ± 2% relative humidity and 21℃ ± 1℃ for at least 24 hours prior to further evaluation. The scouring and bleaching recipe was shown in Table 3-3.

TABLE 3-3 RECIPE OF THE SCOURING AND BLEACHING SOLUTION

Chemical	**Required Concentration**	**Volume to be taken from stock solution**
Sandopan DTC paste	5 g/L	Depends on total fabric weight
Caustic Soda (10%)	10 g/L	Depends on total fabric weight
Stabilizer AWN	1 ml/L	Depends on total fabric weight
Water glass (38°Be')	10 ml/L	Depends on total fabric weight
Hydrogen Peroxide (35%)	25 ml/L	Depends on total fabric weight

3.3 Fabric weight

Fabric weight was measured according to ASTM D3776 - 96(2002) Standard Test Methods for Mass Per Unit Area (Weight) of Fabric and electronic weight was used. Scoured sample were cut with a die cutter and weighed.

3.4 Fabric Thickness

Thickness was measured following ASTM D1777 - 96(2007) Standard Test Method for Thickness of Textile Materials was used. A specimen was placed on the base of a thickness gauge and a weighted presser foot lowered. The displacement between the base and the presser foot was measured as the thickness of the specimen. The specimen was measured five times with five different spots. The mean of the five measurements was recorded as the thickness of this specimen.

3.5 Fabric Count

Fabric count was measured according to the test methods, ASTM D3887 Standard Specification for Tolerances for Knitted Fabrics (Fabric count). The measurement were recorded as “wales/inch” and “courses/inch”. And then the stitch density will be calculated by the equation: WPI x CPI.

3.6 Ultraviolet Protection Factor (UPF)

Spectrophotometric measurement is the main approaches to evaluate (UPF). The spectrophotometric method was measured according to Australia/New Zealand standard: AS/NZS 4399:1996 “Sun protective Clothing- Evaluation and Classification”. The fabric samples were measured with Varian Cary 300 UV-VIS Spectrophotometer. The equation for the UPF calculation is expressd as Equation 2-1, where λ is the wavelength in nm; E_λ, relative erythemal spectral effectiveness; S_λ, solar spectral irradiance of the source in watts per square meter; d_λ, bandwidth in nanometer; and T_λ, spectral transmission of the sample. The integrals (e) are calculated over the wavelength range of 290 to 400 nm. (Gies, et.al., 1997). A fabric UPF was calculated from four single measurement of transmission for each sample. Four specimens were cut from every sample.

3.7 Air Permeability

Air permeability was measured according to KES-F8 air permeability and using the air permeability tester. All samples were tested with “Small” size hole with $0.2\pi cm^{2,}$ and the flow rate is 0.4m/s. The permeating resistance "R" of the sample is directly measured, and then displayed on the digital panel meter as R = kPa s/m.

The permeating resistance was calculated from five single measurements for each sample. The pressure loss is averaged over three seconds for each half cycle. The averages for the two half cycles are further averaged to increase the measurement accuracy.

3.8 Tightness Factor

Tightness Factor (TF) is the ratio between yarn count and loop length and it is calculated based on Munden’s Theory: Equation 2-3 where Tex is yarn tex and l is loop length (mm).

3.9 Kawabata Evaluation System for Fabrics

The Kawabata Evaluation System for Fabrics was employed to test the physical properties of the knitted fabrics. In this research, Compressional Property and Surface Property are chosen as test parameters for studying their relationship with UPF.

The KES-F System could measure the tensile, compression, shear and bending properties of the fabric together with the surface roughness and friction (Kawabata, 1980, Kawabata and Niwa, 1988). The measured parameters as obtained from the hysteresis curves are listed in Appendix B.

3.9.1 Compression Properties

Compression properties includes the fabric thickness at 0.5(T_0) and 50 (T_m) gf/cm^2 pressure respectively, compressional energy (WC) defined as the energy in compressing fabric under 50 gf/cm^2, and compressional resilience (RC) determines the recoverability of fabric after being compressed. The compressional properties are measured by placing the sample between two plates and increasing the pressure while continuously monitoring the sample thickness up to a maximum pressure of 50gf/cm^2 (0.49N/cm^2).

3.9.2 Surface Properties

The surface roughness is measured by pulling across the surface a steel wire 0.5mm in diameter which is bent into a U shape shown in Figure 3-1 the contact force that the wire makes the surface is 10gf (98.1mN). MIU means the fabric smoothness, roughness and crispness. The higher the MIU value, the less smooth and rougher the surface is. Geometrical roughness (SMD) means the evenness characteristics of the fabric surface. The greater the SMD value, the less evenness of the fabric surface will be. A plot of the height variation against distance is shown in Figure 3-2. The value measured is SMD which is mean deviation of surface roughness. A plot of friction against distance travelled is shown in Figure 3-3

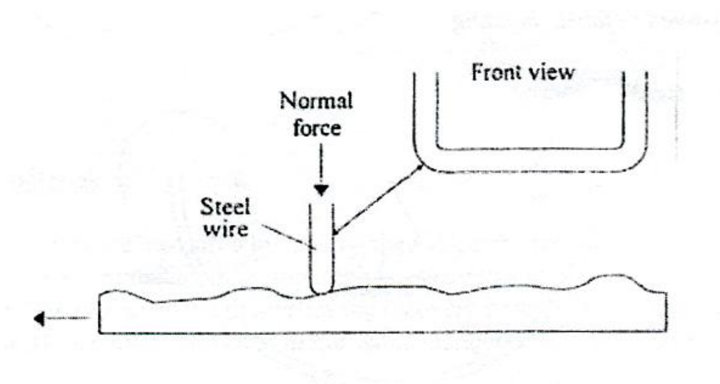


Figure.3-1 Surface roughness measurement

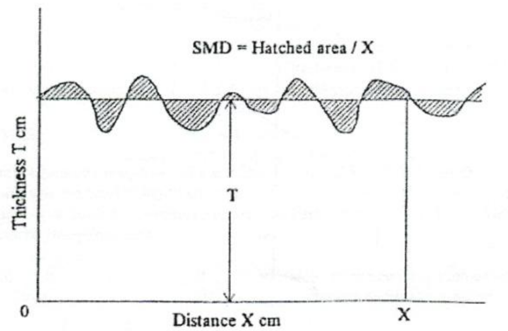


Figure.3-2 Surface thickness variation

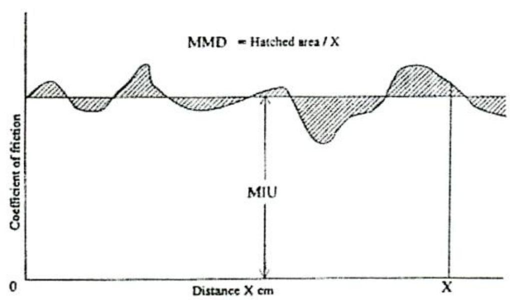


Figure 3-3 Surface friction variation. MIU is the mean value of the coefficient of friction

3.10 Washing Procedure

The washing procedure was following AATCC Test Method 135-2010: Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics. The distances between benchmarks on the top of each sample were measured at 0, 1, 3, 5 washing cycles and AATCC Standard Reference Detergent was used.

3.11 Statistical Analysis

Statistical data were analyzed using SPSS 16 for Windows. SPSS is a computer program used for survey authoring and deployment, data mining, text analytics, statistical analysis, and collaboration (http://www.ibm.com/software/analytics/spss/ accessed on 28-10-2012). There were five independent variables and one dependent variable in this research. The independent variables were:

1. Fabric weight
2. Fabric thickness
3. Fabric count (Stitch Density)
4. Tightness factor
5. Washing cycles

The dependent variable was UPF.

The measured variables in this study were fabric weight (g/m^2), fabric thickness (mm), fabric count, fabric shrinkage (cm^2), air permeability (kPa S/m), tightness factor and UV transmission. The corresponding UPF values were calculated using the Equation 2-1, the fabric shrinkage was showed in area shrinkage of the measured fabric. Also the mean of the measured variables was used in the statistical analysis. Since the statistical analysis only indicates the significance effect of the variables, with larger the sample size standard error will be smaller, so the performance of individual specimen will not be focused on.

3.11.1 A Multiple Linear Regression Model (MLR)

A multiple linear regression model (MLR) was used to analyze the effects of different parameters on the UPF. The MLR model is widely used to model the mean of the response variables a function of the independent. It allows for the prediction of mean of a dependent variable in terms of regression coefficients (Ramsey and Schafer, 1997).

3.11.2 Factor Analysis

Factor analysis was used to study the relationship among factors. It also helps to know about the correlation and correlation matrix. Using few factors to represent lots of original variables with little loss of information, Factor Analysis is a methodology used for Data Reduction and replacing redundant variables by a smaller number of underlying factors (Gorsuch, 1983, Kim and Mueller, 1978, Dennis 2006).

3.12 Conclusion

In this chapter, the procedure of making the fabric and sample treatment were introduced. In addition, different kinds of testing methods were also selected to measure different parameters of the knitted fabrics in order to have further analysis. For the statically analysis, MLR and Factor Analysis were selected. MLR is a method used for modeling the relationship between a scalar dependent variable *y* (UPF) and explanatory variables (fabric weight, fabric thickness, fabric count, tightness factor and washing cycles). Besides, by using MLR, predication or forecasting can be achieved if such a model can be developed from the observed data. While factor analysis can be used to reduce the number of variables, by combining two or more variables into a single factor or identify groups of inter-related variables, to see how they are related to each other. Therefore the relationship between different factors can be explained.

CHAPTER 4 EFFECT OF FABRIC STRUCTURE ON UPF

4.1 Data and Linear Regression Results

In this section, data was analyzed using Statistical Product and Service Solutions **(**SPSS) also known as Statistical Package for the Social Sciences. Multiple Linear Regression (MLR) and factor analysis have been selected to analyze the data. For MLR, there are 5 independent variables and 1 dependent variable in this research. Since the 5 independent variables are basic knitting parameters, the fabric properties are mainly affected by these independent, therefore they were selected to be studied. The independent variables are:

1. Fabric weight
2. Fabric thickness
3. Fabric count (Stitch Density)
4. Tightness factor
5. Washing cycles

And the dependent variable is UPF. Table 4-1 lists the data of the independent variables and dependent variables.

TABLE 4-1 LINEAR REGRESSION RESULTS SHOWING RELATIONSHIP BETWEEN FABRIC PROPERTIES AND UPF OF CH AND MCG

Independent variables	Correlation Coefficient (r)
Fabric weight	0.819
Fabric thickness	0.245
Stitch density	0.640
Tightness factor	0.870
Washing cycles	0.298

Correlation coefficient between two variables is defined as the covariance of the two variables divided by the product of their standard deviations. The form of the definition involves a "product moment", that is, the mean (the first moment about the origin) of the product of the mean-adjusted random variables; hence the modifier product-moment in the name (Stephen, 1989). The correlation coefficient ranges from −1 to 1. A value of 1 means that a linear relationship e.g. $Y = a + bX$ exists between X and Y perfectly, with all data points lying on a line for which Y increases as X increases. A value of −1 means that all data points lying on a line for which Y decreases as X increases. A value of 0 implies that there is no linear correlation between the variables. More generally, note that $(X_i - \overline{X})\ (Y_i - \overline{Y})$ is positive if and only if X_i and Y_i lie on the same side of their respective means where $\overline{X}$ and $\overline{Y}$ are the mean of $\sum X$ and $\sum Y$ respectively. Thus the correlation coefficient is positive if X_i and Y_i tend to be simultaneously greater than, or simultaneously less than, their respective means. The correlation coefficient is negative if X_i and Y_i tend to lie on opposite sides of their respective means.

Referring to the Table 4-1, it shows that the Correlation Coefficient between UPF and different fabric properties. It implies that heavier and tighter the fabric will provide higher UPF value. Since the pore size of the knitted fabric is affected by the tightness factor, while a tighter and denser fabric will increase the fabric weight because more yarns with are packed per unit area (Pailthorpe, 1994). On the other hand, the fabric thickness and washing cycles have relatively low correlation coefficient, which have the similar results with Welsh and Diffey‘s study (Welsh and Diffey, 1981). But the importance of fabric thickness should not be neglected, for the fabrics with same knitting structure, with thicker and denser fabric, more UV radiation will be blocked by the yarn. Therefore thickness is also useful in explaining the relationship between UV transmissions and fabric structure (Crews et.al, 1999).

By using SPSS, all of the data from the fabric parameters (Appendix C) were used to establish the MLR equation and interpret the regression coefficients and calculate the predicted the values of UPF. It can also used to explain how well the model is and evaluate overall significance of the regression model and evaluate the significance of individual independent variables. The validity of the assumptions can be checked through SPSS.

For Factor Analysis, it can find out the physical meaning of the factor for further use and the relationship between original data and underlying factors.

4.2 MLR Analysis on the Effect of Weight, Thickness, Density, Tightness and Washing Cycles on UPF

The effect of mass, thickness, density, tightness and washing cycles on UPF were analyzed using a linear regression model, graphs and descriptive statistics. The purpose of this part is to examine how fabric weight, thickness, density, and tightness affect the UPF.

4.2.1 Model Summary of MLR

The assumptions of simple linear regression model including:

1. <u>Linearity</u>, the underlying relationship between X and Y is linear;
2. <u>Normality of Error</u>, error values are normally distributed for any given value of X;
3. <u>Constant Error Variance</u>, the probability distribution of error s has constant variance that does not depend on the value of X;
4. <u>Independence of Errors</u>, error values are statistically independent from each other so that the model can be used.

The normality assumption was checked by the normal probability plot (P-P plot). The points in the P-P plot are clustered along the 45^{o} line, meaning that the normality assumption of the model is reasonably satisfied. The spreads of (UPF) residuals are relatively equal around the zero line, and the residuals do not show any specific pattern. Therefore, linearity, constant error variance and independence of error are not violated.

The multiple correlation coefficient R, is a measure of the linear correlation between the observed and the model-predicted values of the UPF. Higher the R value means a stronger the correlation and of the model to the data.

The significant P-value ($p<0.05$) provides a very strong justification for the use of the model. Based on the independent variables (fabric weight, fabric thickness, stitch density, tightness factor and washing cycles), at least one of the independent has a significant effect on UPF. The variation of the dependent variable (UPF) explained by the model is not random occurrence or a chance. Therefore, the change in UPF can be predicated by the independent variables. (fabric weight, fabric thickness, stitch density, tightness factor and washing cycles)

TABLE 4-2 TABLE OF MODEL SUMMARY OF MLR ANALYSIS ON FABRIC PARAMETERS AND UPF

Model	r	r^2	Adjusted r^2
1	0.978	0.956	0.951

Coefficient of determination r^2 is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. r^2 is most often seen as a number between 0 and 1.0, used to describe how well a regression line fits a set of data. An r^2 near 1.0 indicates that a regression line fits the data well, while an r^2 closer to 0 indicates a regression line does not fit the data very well. It is the proportion of variability in a data set that is accounted for by the statistical model (Steel, 1960). It provides a measure of how well future outcomes are likely to be predicted by the model. From the Table 4-2, the coefficient of determination r^2 is 95.1 %. This means that 95.1 % of the variation in the UPF can be explained by the variables of fabric weight, fabric thickness, stitch density, tightness factor and washing cycles.

F test is used to evaluate the overall linear significance of the model, i.e. if there is a linear relationship between UPF and all the independent variables considered together.

1. The null hypothesis claims that all independent variables considered together do not have a linear relationship with UPF, i.e. all regression coefficients are 0:

H_0: $b_1 = b_2 = \ldots = b_k = 0$

2. The alternative hypothesis claims that at least one of the independent variables has a linear relationship with UPF, i.e. at least one regression coefficient is not 0:

H_1: at least one of $b_1, b_2, \ldots, b_k \neq 0$

if $p < a$, then reject H_0 and conclude that the regression model contains a significant linear relationship (a is the significance level and its typical value is 0.05).

4.2.2 ANOVA of MLR

TABLE 4-3 ANOVA OF DEPENDENT VARIABLE

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1742.572	5	348.533	214.832	0.000
	Residual	81.212	50	1.887		

Total	1823.784	55			

From the Table 4-3, the p-value of the F test is 0.000 which less than 0.05, reject the H_0 that all regression coefficients are zeros. Therefore the regression model has a significant linear relationship at a significance level of 0.05

t tests are used to evaluate the significance of each variables of X, i.e. if the *i*th *X* variable (*X*i) has a significant linear relationship with *Y*, holding the other *X* variables constant. t tests should be used only if F test is significant.

1. The null hypothesis claims that the *5* variables, fabric weight, fabric thickness, stitches density, tightness and washing cycles does not have a linear relationship with UPF, i.e. the *i*th regression coefficient is 0:

H_0: $b_i = 0$ (i=1,2,3…k)

2. The alternative hypothesis claims that the *5* variables, fabric weight, fabric thickness, stitches density, tightness and washing cycles have a linear relationship with UPF, i.e. the *i*th regression coefficient is not 0:

H_1: $b_i \neq 0$ (i=1,2,3…k)

Use the p-value of t test for evaluation: p-values of t tests if $p < a$, the p-value of the t test is 0.000 which less than 0.05, reject the H_0 that all regression coefficients are zeros which means *5* variables, fabric weight, fabric thickness, stitches density, tightness and washing cycles does not have a linear relationship with UPF. (a is the significance level and its typical value is 0.05)

4.2.3 Coefficients of Independent Variables

TABLE 4-4 COEFFICIENT OF INDEPENDENT VARIABLES

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-26.215	2.260		-11.602	0.000
	Fabric weight	0.095	0.016	0.386	5.850	0.000
	Fabric thickness	5.010	2.730	0.131	1.835	0.032
	Stitch density	0.005	0.001	0.236	4.076	0.000
	Tightness	7.681	0.767	0.488	10.009	0.000
	Washing Cycles	0.365	0.120	0.123	3.050	0.004

$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$

Dependent variable

Y: UPF

Independent variables

X_1: Fabric weight (g/m^2)

X_2: Fabric thickness (mm)

X_3: Fabric count

X_4: Tightness factor

X_5: Washing cycles

Intercept: a

Regression coefficients: b_1, b_2, b_3, b_4 and b_5 (slopes)

From the Table 4-4, the multiple regression equation is:

$$UPF=-26.215+0.095\ X_1+5.010\ X_2+0.005\ X_3 + 7.681X_4 + 0.365X_5$$

Interpretation of Regression coefficients:

UPF= -26.215+0.095 Fabric weight (g/m^2) + 5.010 Fabric thickness (mm) + 0.005 (Stitch density) + 7.681 (Tightness factor) + 0.365 (washing cycles)

Each additional fabric weight (g/m^2) will increase the UPF by 0.095.

An additional portion in the fabric thickness (mm) will increase the UPF by 5.010.

An increase in stitch density will also increase the UPF of 0.005.

Also, tighter the fabric, the UPF will be increased in 7.681.

With increasing number of washing cycles, the UPF will be increased in 0.365.

If the independent variables have higher value of the standardized coefficient, it means higher correlation with the dependent variable. From Table 4-5, Tightness factor has a standardized coefficient of 0.488, fabric weight has 0.386, stitch density has 0.236, Fabric thickness has 0131 and washing cycles has 0.123. The high standardized coefficient indicates that Tightness factor is a more dominant predictor than others independent variables.

From Table 4-4 Coefficient of independent variables, the p-values of t tests for each regression coefficients are all smaller than 0.05.

$p1<0.05$, fabric weight (g/m^2) has a significant linear relationship with UPF at a significance level of 0.05.

$p2<0.05$, fabric thickness (mm) has a significant linear relationship with UPF at a significance level of 0.05.

$p3<0.05$, stitch density has a significant linear relationship with UPF at a significance level of 0.05.

$p4<0.05$, tightness factor has a significant linear relationship with UPF at a significance level of 0.05.

$p5<0.05$, washing cycles has a significant linear relationship with UPF at a significance level of 0.05.

Therefore the significant variables are fabric weight (g/m^2) and fabric thickness (mm) stitch density, tightness factor and washing cycles.

4.2.4 Verification of the Model

From the table Measured UPF vs Predicted UPF of yarn type CH and MCG in Appendix

C, it can be found that the difference between measured UPF and predicted UPF is 5.42% of CH series and 7.62% MCG series. The variation can be explained by the different surface structure of the fibres, the proportion of crystalline and amorphous zones. In addition, some residuals could be attached on the yarn surface during the spinning process or some chemicals product added when the scouring the fabrics (Algaba, et.al, 2008).

4.2.5 Residuals Statistics of independent variables

Residual: the residual for observation i, denoted by e_i, is the difference between its observed value Y_i and predicted value

$$e_i = Y_i - \widehat{Y_i}$$

If the regression assumptions hold, the residuals should look like a random sample from a normal distribution with mean 0 and variance $\sigma^{2.}$ The scatter plot of Residual vs. predicted values is used to display how well the entire set of observed values for observation points matches the solution data. Therefore, if the residuals appear to distribute randomly, it suggests that the model fits the data well. On the other hand, if non-random structure is found in the residuals, it is claimed that the model fits the data poorly. The plot of Residuals versus each independent variable X_1: Fabric weight (g/m^2), X_2: Fabric thickness (mm), X_3: Fabric count, X_4: Tightness factor , X_5: Washing cycles is shown in Figure 4-1.

4.2.6 Residual Plots and Scatter Plot

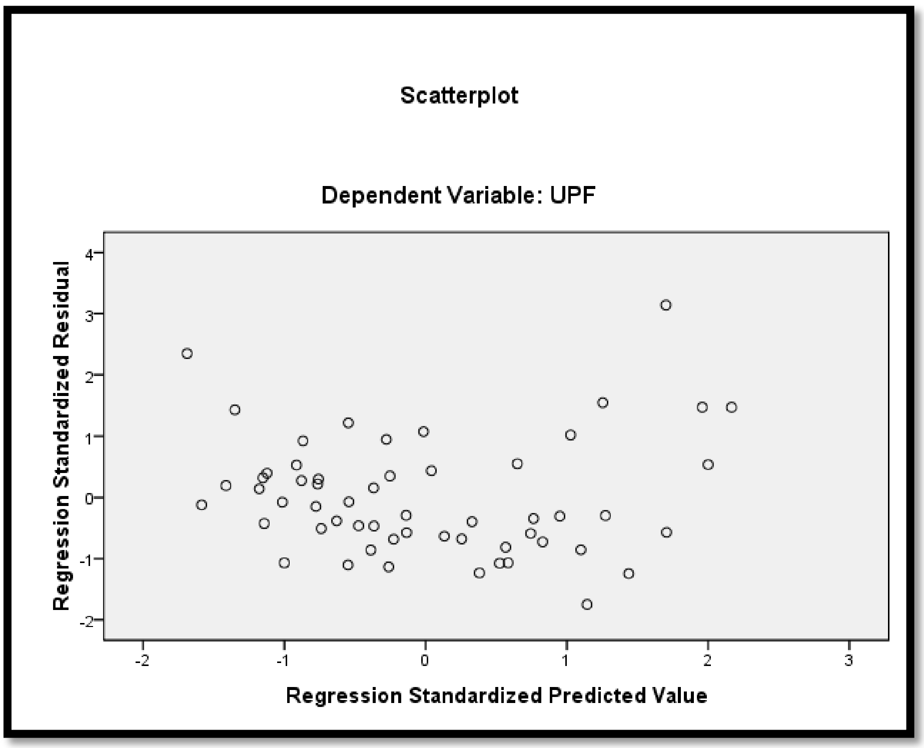


Figure 4-1 Scatter plot of residuals vs. the predicted values

From Figure 4-1 plot of residuals vs. the predicted values of UPF generated by SPSS, it appears that the residuals are randomly distributed with no pattern and with equal variance as UPF increase, therefore, linearity, constant error variance and independence of error are not violated.

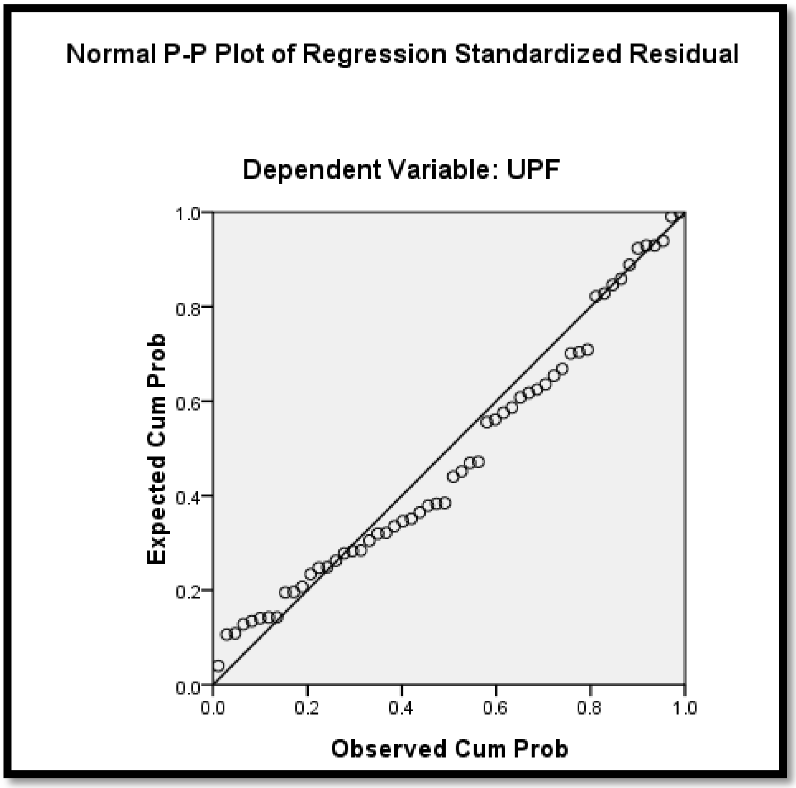


Figure 4-2 Normal P-P Plot of Regression Standardized Residual

On the other hand, the normal probability plot is a graphical technique for normality testing: assessing whether or not a data set is approximately normally distributed. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line (Chambers, 1993). Departures from this straight line indicate departures from normality. The normal probability plot is shown in Figure 4-2. From Figure 4-2, all points are approximately on a straight line, it looks fairly straight, at least when the few large and small values are ignored. Therefore the assumption of Normality of Error is not violated.

4.3 Factor Analysis of Fabric weight, Thickness, Stitch Density, Air Permeability, Tightness and Washing Cycles

4.3.1 Correlation Matrix of the Independent Variables

TABLE 4-5 CORRELATION MATRIX OF FABRIC WEIGHT, THICKNESS, STITCH DENSITY, AIR PERMEABILITY, TIGHTNESS AND WASHING CYCLES

Correlation (r)	Washing cycles	Fabric weight	Fabric thickness	Stitch density	Fabric dimension	Air permeability	Tightness
Washing cycles	1.000	0.137	0.384	0.135	-0.718	0.166	0.081
Fabric weight	0.137	1.000	0.554	0.293	-0.486	0.247	0.561
Fabric thickness	0.384	0.554	1.000	-0.416	-0.504	-0.381	-0.100
Stitch density	0.135	0.293	-0.416	1.000	-0.281	0.817	0.672
Fabric dimension	-0.718	-0.486	-0.504	-0.281	1.000	-0.167	-0.202
Air permeability	0.166	0.247	-0.381	0.817	-0.167	1.000	0.858
Tightness	0.081	0.561	-0.100	0.672	-0.202	0.858	1.000

From Table 4-5, it can be seen that many variables are highly ($r>0.8$) correlated. For instance, air permeability are highly correlated to tightness and stitch density with coefficient of r 0.858 and 0.817 respectively. While washing cycles is also correlated to fabric dimension with coefficient of r is -0.718. Therefore there are much redundancy between variables and the data set might be suitable for the factor analysis.

4.3.2 Sample Adequacy and Correlation Matrix of Independent Variables

TABLE 4-6 KMO AND BARLETT'S TEST OF THE INDEPENDENT VARIABLES

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.562
Bartlett's Test of Sphericity	Approx. Chi-Square	335.884
	df	21
	Sig.	0.000

The Kaiser-Meyer-Olkin (KMO) measures the sampling adequacy tests whether the partial correlations of both overall and each variables are small (Kaiser, 1970). Bartlett's test of sphericity tests whether the correlation matrix is an identity matrix, which would indicate that the factor model is inappropriate (Snedecor and Cochran, 1983). The KMO measures the sampling adequacy which should be greater than 0.5 for a satisfactory factor analysis to proceed. From Table 4-6 KMO and Barlett's Test table of SPSS, it can be seen that:

- The KMO measure is 0.562 > 0.5, so there is a satisfactory amount of variance in original variables that might be caused by underlying factors.
- Barlett's Test of Sphericity is 0.000 < 0.05, so the original variables are not unrelated.

Combining the results from the Correlation Matrix, and KMO and Barrlett's Test, the data set are suitable for the factor analysis

TABLE 4-7 TOTAL VARIANCE EXPLAINED

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.036	43.378	43.378	3.036	43.378	43.378	2.844	40.624	40.624
2	2.274	32.489	75.867	2.274	32.489	75.867	1.815	25.926	66.549
3	1.043	14.899	90.766	1.043	14.899	90.766	1.695	24.217	90.766
4	0.370	5.288	96.054						
5	0.143	2.038	98.092						
6	0.087	1.249	99.341						
7	0.046	0.659	100.00						

Table 4-7 shows the Total Variance Explained, it measures the proportion to which a mathematical model explains the variation of a measured data set. From Table 4-7, it can be seen that three underlying factors are extracted with their Eigenvalues of 3.036 (>1), 2.274 (>1) and 1.043 (>1). They together account for 90.766% (>60%) of the total variance of all variables, therefore we considerably reduce the complexity of the data set by using just three factor (from 7 variables to 3 factors), with about 9.234% loss of information. Therefore the factor extraction results are satisfactory

4.3.3 Component Matrix and Rotated Component Matrix of the Independent Variables

From Component Matrix and Rotated Component Matrix in Appendix C, it can be seen that the air permeability, tightness factor and stitch density have their highest factor loadings on component 1, since the openness of the fabric is largely depend on the structure and the tightness, with tighter the fabric, smaller the loop and more loops will come closer together and so the air permeability will decreased. While fabric weight and fabric thickness have their highest loadings on Component 2, it is because with heavier the fabric, there will be more yarn per unit area and the fabric will become thicker and vice versa. On the other hand, fabric dimension and washing cycles have their highest loadings on Component 3. It is believed that the shrinkage will occur after the washing process, therefore washing cycles and fabric dimension are highly correlated and can be grouped into the same component. As a result, air permeability, tightness factor and stitch density can be represented by Component 1 while fabric weight, and fabric thickness can be represented by component 2. Moreover, fabric dimension and washing cycles can be represented by component 3.

We can further define a summary name for each factor by analyzing the common meanings of the variance that the factor represents:

Component 1: Loop factor

Component 2: Fabric parameters

Component 3: Washing effect

TABLE 4-8 COMPONENT TRANSFORMATION MATRIX COMPONENT

Component	1	2	3
1	0.864	0.367	0.344
2	-0.503	0.639	0.582
3	-0.006	-0.676	0.737

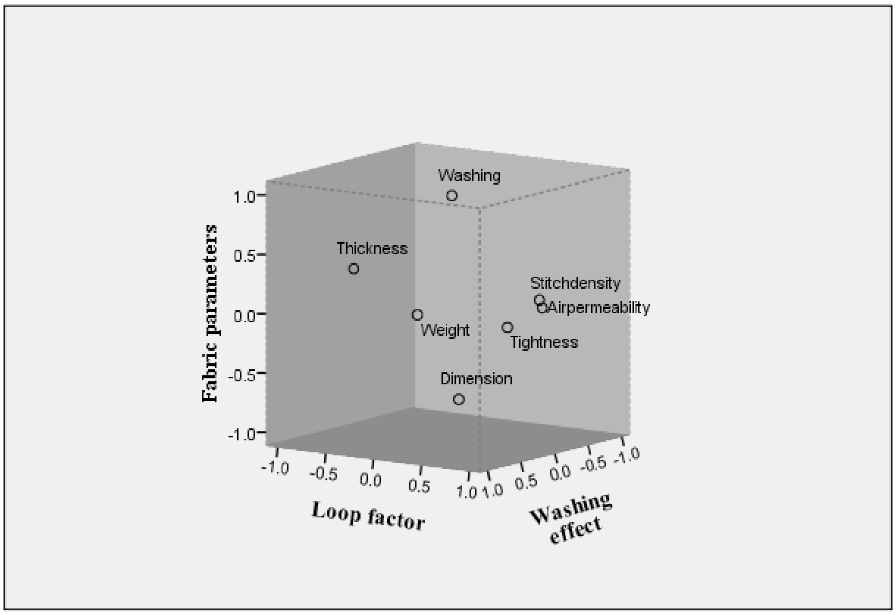


Figure 4-3 Component Plot in Rotated Space

From Table 4-8 and Figure 4-3 (Component Plot in Rotated Space of SPSS), it is visually verified that the component rotation make a better association of the variables with the component. For instance, tightness factor closer to component 1 while fabric thickness (mm) and dimension closer to Component 2 after rotation.

Based on the result from the factor analysis of SPSS, it can be found that 7 variables which are air permeability, tightness factor, stitch density, fabric thickness, fabric weight fabric dimension and washing cycles can be represented by three factors only. The three factors are loops factor, fabric parameter and washing effect. Since an ‘Omega’ shape loop is a single unit of a knitted fabric, by changing the loop size, shape or even the materials used, the whole structure of the knitted fabric will also be changed, thus the UV blocking ability of the knitted will be affected. in addition, for consumer after they bought the product, the laundry process would also affect the UV blocking ability of the product. Therefore in order to produce a fabric with better UV protection, the manufacturer should focus on the loop factor, the fabric parameter and the washing effect. Since these the three factors already represented 90.766% of all variable of the fabric. By changing these two factors, the UV protection ability of the fabric can be greatly affected.

4.4 Structural Properties of the Knitted Fabrics

Knitting structures are important because they provide different advantages through their structural properties. The three basic loops, which are knit loop, tuck loop and miss loop plays a major role of the fabric. By combining three types of loops, it makes many kinds of knitted fabric structure becomes possible. Physically, they present properties of comfort such as high elasticity, conformity with the shape of the body, softer and better touches. Porosity is one of the important physical properties which has an influence on the comfort and the aspect of use.

In this part, a total of 7 types of knitted fabrics structure were examined through images. The images of the face side and the back side of the fabrics will be presented and discussed. The images were taken by Leica M125 stereomicroscope.

4.4.1 Cross Tuck

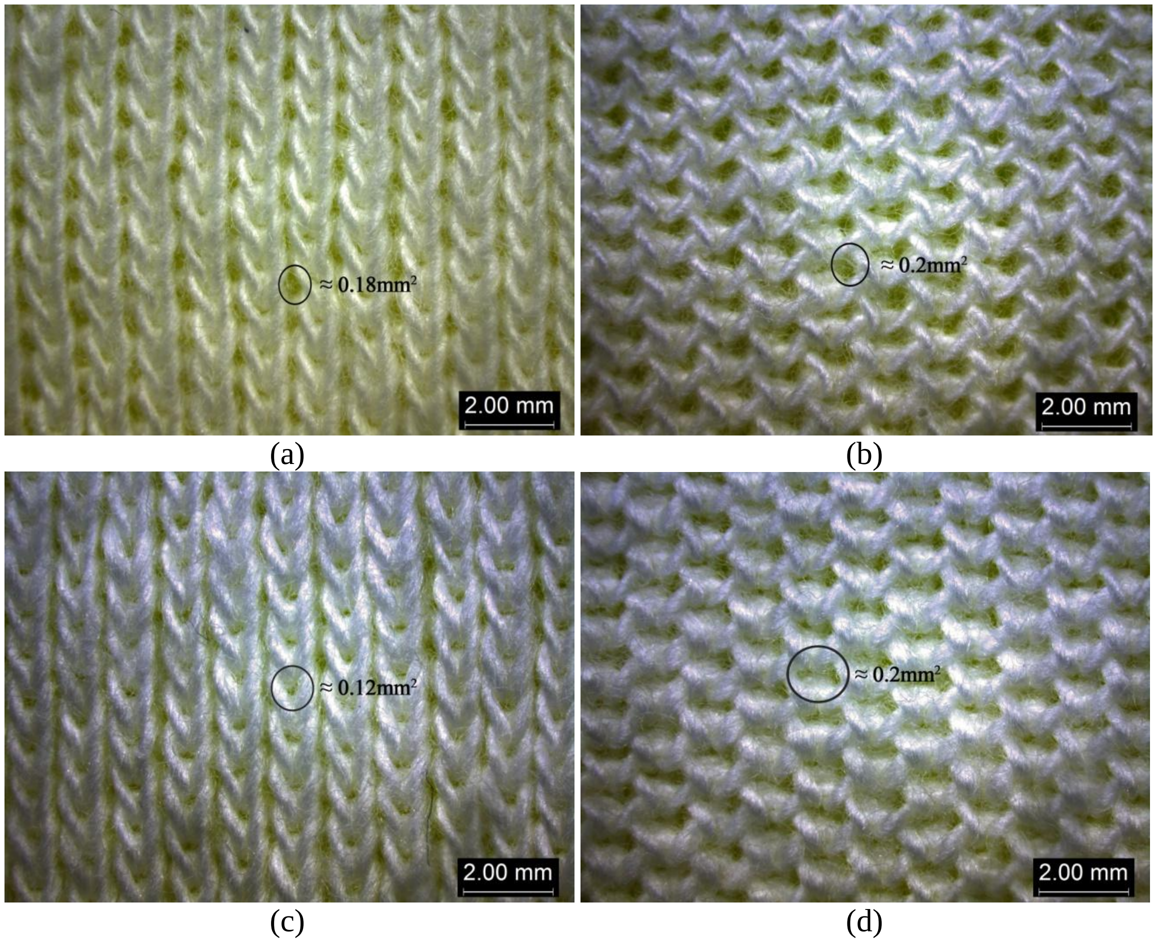


Figure 4-4 (a) Face side of CH Cross Tuck, (b) Back side of the CH Cross Tuck, (c) Face side of MCG Cross Tuck, (d) Back side of the MCG Cross Tuck

Based on the image of Figures 4-4 (a), (b), (c) and (d), the pore size and different type of loops are shown. Figures 4-4 (a) and (c) show the face side of the CH and MCG fabric with pore size 0.18 mm^2 and 0.12mm^2 respectively while Figures (b) and (d) showing the back side of the fabric with pore size 0.2 mm^2. On the face side, the pore is clearly being seen and an ‘Omega’ shape of a loop is clearly found. It is because the tuck loop presented on the fabric only formed half of a normal loop, therefore a larger pore will be resulted. From the back side, the pore size even bigger than the face side, as we can see that there are one knit loop and one tuck loop on one needle position, therefore the pore size within the loops becomes bigger and the fabric will also be thicker since more yarns were held at the same needle position.

4.4.2 Cross Miss

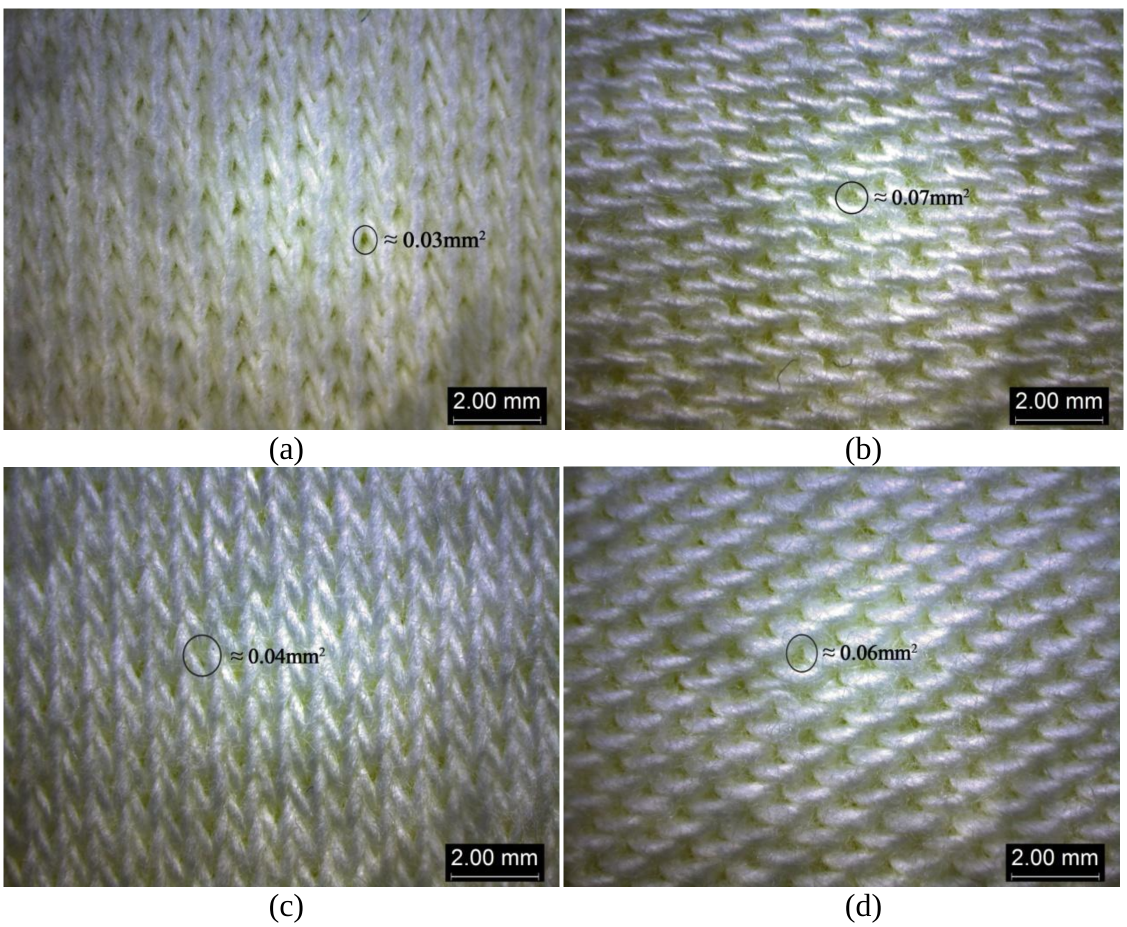
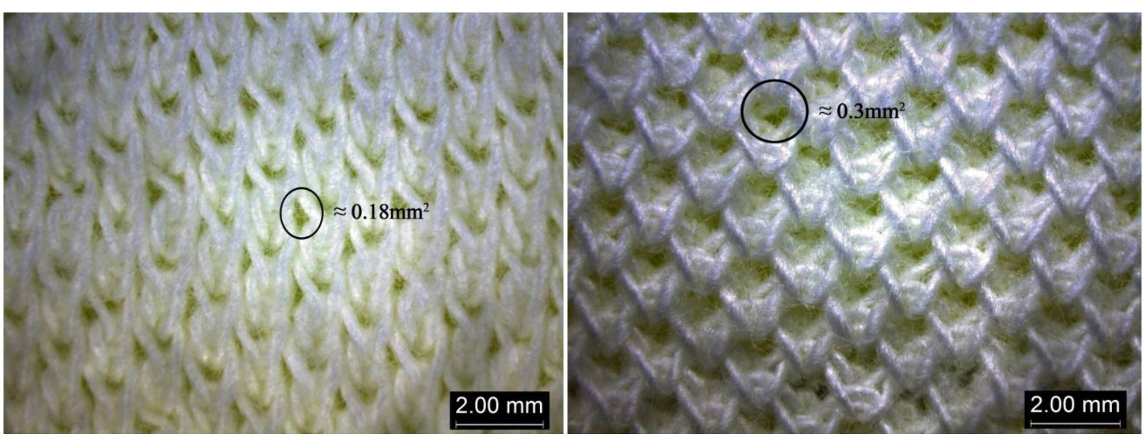


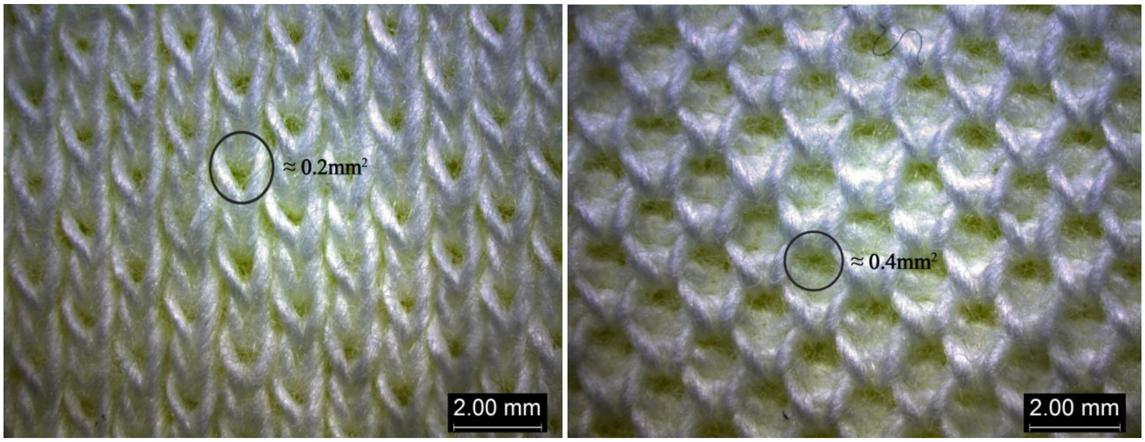
Figure 4-5 (a) Face side of CH Cross Miss, (b) Back side of the CH Cross Miss, (c) Face side of MCG Cross Miss, (d) Back side of the MCG Cross Miss

Based on the image of Figures 4-5 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-5 (a) and (c) showing the face side of the CH and MCG fabric with pore size 0.03mm^2 and 0.04mm^2 respectively while Figures (b) and (d) show the back side of CH and MCG fabric with pore size 0.07mm^2 and 0.06mm^2 respectively. From the face side of the Cross Miss fabric, the loops can be seen clearly and the pore size is very small. We can see that the loops are closely packed together and not much space can be found in between the loops. Since the fabric is composed by knit and miss loop, therefore we cannot find the miss loop from the face side, and the miss loop will not be knitted but presented as a float yarn at the back of the fabric. From the Figures 4-5 (b) and (d), there are many horizontal lines shown at the back which are the miss loop. The miss loop float at the back will also pull the loop closer together and make the fabric become tighter, therefore the pore size will also be smaller and less UVR can pass through the fabric.

4.4.3 Double Cross Tuck



(a) (b)



(c) (d)

Figure 4-6 (a) Face side of CH Double Cross Tuck, (b) Back side of the CH Double Cross Tuck, (c) Face side of MCG Double Cross Tuck, (d) Back side of the MCG Double Cross Tuck

Based on the images of Figures 4-6 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-6 (a) and (c) show the face side of CH and MCG fabric with pore size 0.18mm^2 and 0.2mm^2 respectively while Figures (b) and (d) show the back side of the CH and MCG fabric with pore size 0.3mm^2 and 0.4mm^2 respectively. The Double Cross Tuck fabric has a similar structure to the Cross Tuck fabric, the pore size on the face side can be found easily while the loops can clearly be seen. As there is tuck loop presented, a hole will be created on the fabric. Since the tuck loops stay on the same position of the knit loop, the fabric will become thicker. From Figures 4-6 (b) and (d), it is clear that several loops were knitted together at the same position and some spaces were created by the tuck loop.

4.4.4 Double Cross Miss

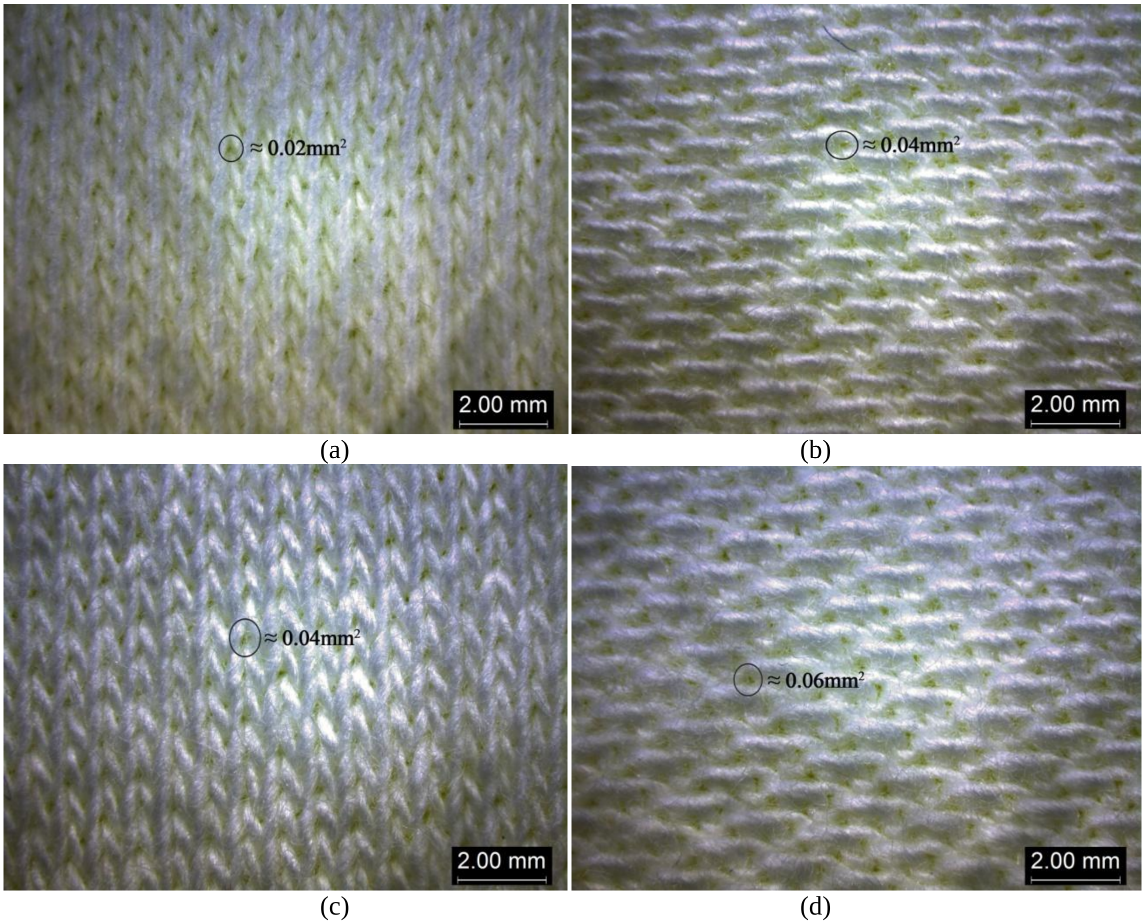


Figure 4-7 (a) Face side of CH Double Cross Miss, (b) Back side of the CH Double Cross Miss, (c) Face side of MCG Double Cross Miss, (d) Back side of the MCG Double Cross Miss

Based on the images of Figures 4-7 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-7 (a) and (c) show the face side of the CH and MCG fabric with pore size 0.02mm^2 and 0.04mm^2 respectively while Figures 4-7 (b) and (d) show the back side of the CH and MCG fabric with pore size 0.04mm^2 and 0.06mm^2 respectively. The loops can be found clearly on the face side, they are closely and regularly packed together. Since the Double Cross Miss fabric composed by knit and miss loop, the loops presented on the face side is the “knit loop while the miss loops acted as a float line at the back shown on Figures 4-7 (b) and (d), which is similar to the Cross Miss fabric, but with a even longer float line because it is a two knit and two miss structure, the two miss loops will stretch the knit loop closer to each other which, in return, make the fabric become tighter. Therefore the holes on the fabric are even smaller and less UV radiation can pass through the fabric.

4.4.5 Lacoste

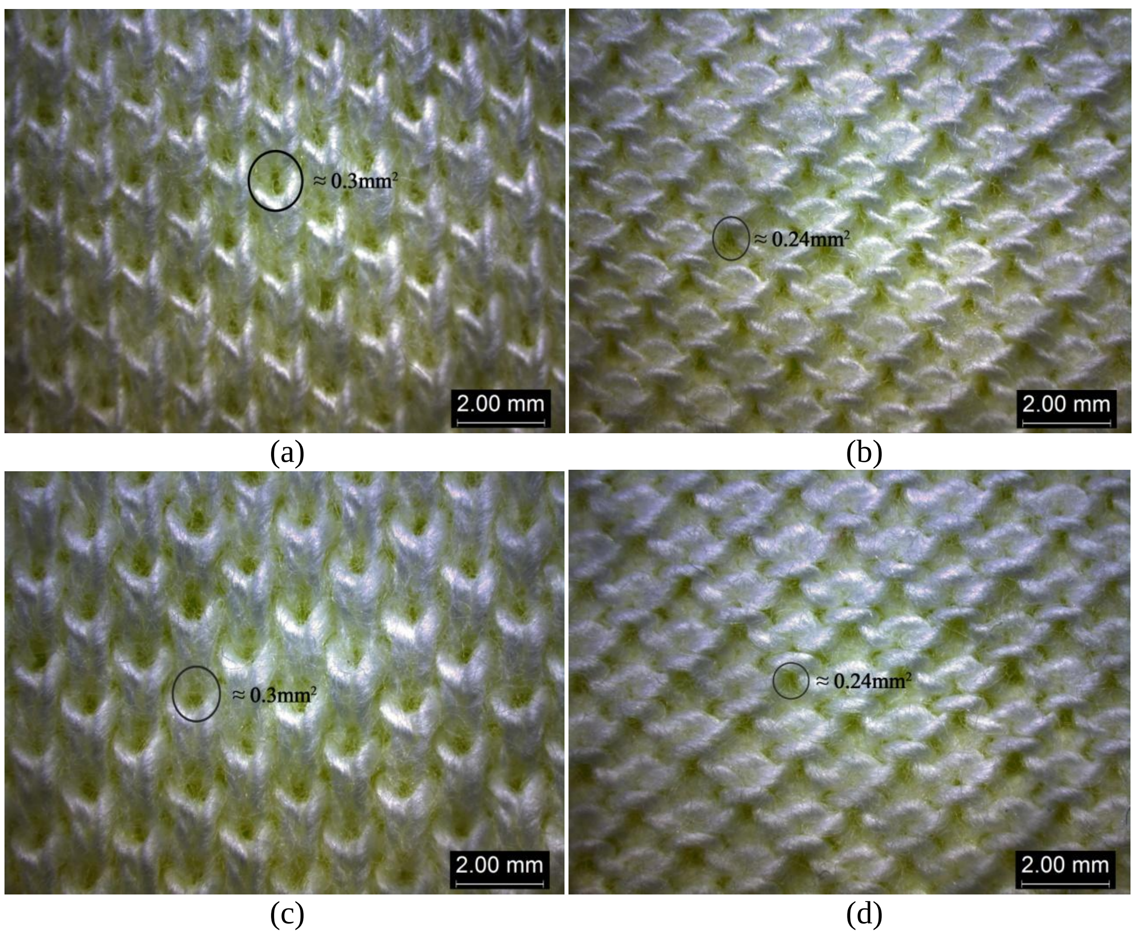
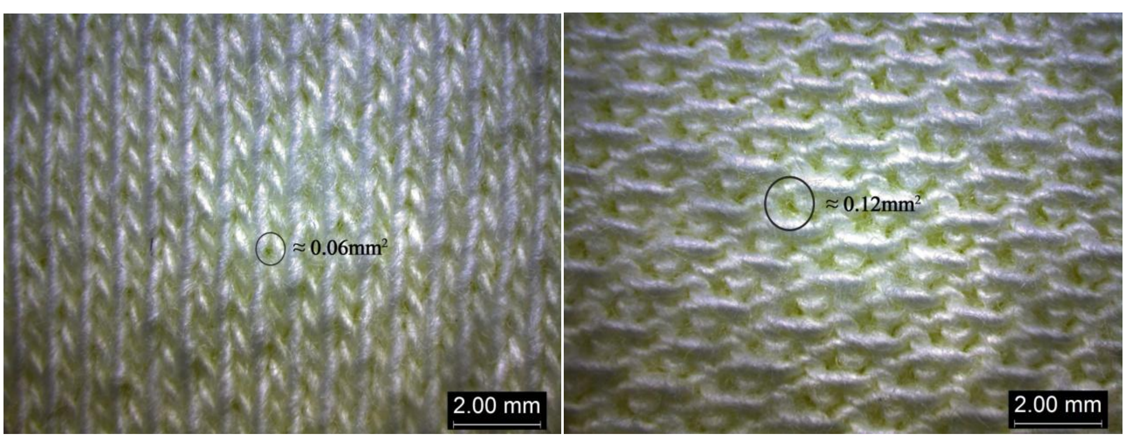


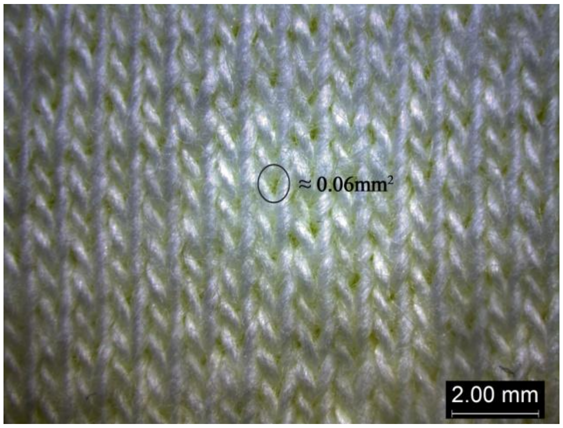
Figure 4-8 (a) Face side of CH Lacoste, (b) Back side of the CH Lacoste, (c) Face side of MCG Plain Lacoste, (d) Back side of the MCG Lacoste

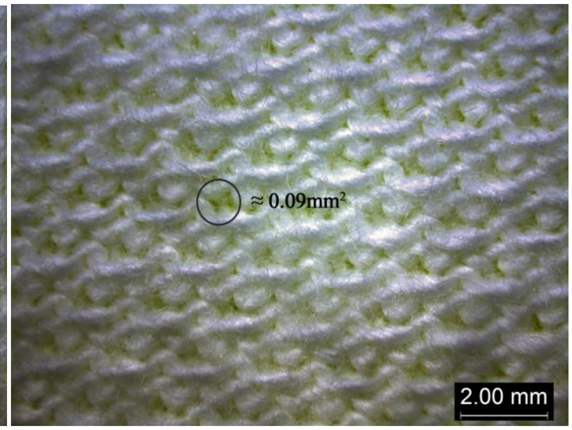
Based on the images of Figures 4-8 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-8 (a) and (c) show the face side of the CH and MCG fabric with pore size 0.3mm^2 respectively while Figure 4-8 (b) and (d) show the back side of the CH and MCG fabric with pore size 0.24mm^2. The pore of the Lacoste fabric can be seen easily and the knit loop on the face side is also formed clearly, but the tuck loops are hardly found because they are cover by the knit loop. Although the pore size is large when compare to the knit and miss fabric, the Lacoste fabric is thicker. It is because the tuck loops hold at the same position as the knit loop during in the knitting process, therefore it will make the fabric become thicker. However, less tuck loops are needed to form the fabric, therefore it is not as thick as the Double Cross Tuck fabric and we can see that the pore size is even smaller than the Double Cross Tuck fabric.

4.4.6 Weft Locknit



(a) (b)



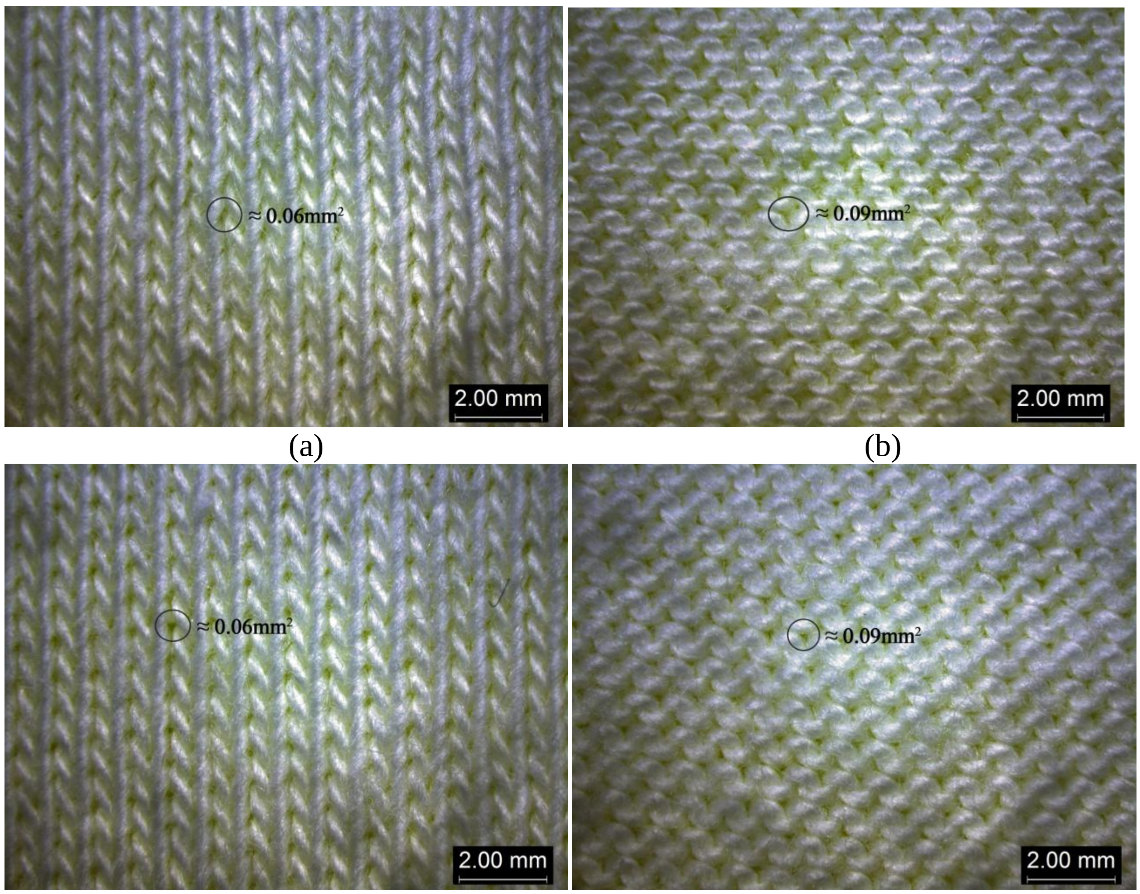


(c) (d)

Figure 4-9 (a) Face side of CH Weft Locknit, (b) Back side of the CH Weft Locknit, (c) Face side of MCG Weft Locknit, (d) Back side of the MCG Weft Locknit

Based on the images of Figures 4-9 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-9 (a) and (c) show the face side of the CH and MCG fabric with pore size 0.06 mm^2 while Figures 4-9 (b) and (d) show the back side of the CH and MCG fabric with pore size 0.12mm^2 and 0.09mm^2 respectively. The structure of Weft Locknit fabric is similar to the Lacoste fabric. For Lacoste fabric, it is composed by knit and tuck while Weft Locknit fabric is composed by knit and miss, and the arrangement of the loops is the same. From the Figures 4-9 (a) and (c), we can see that the loops of the fabric can be seen clearly and arranged regularly. The pore size is smaller than the fabric composed by knit and tuck loop. On the other hand, just like the Cross Miss and Double Cross Miss fabric, there is a float yarn at the back side of the fabric because the miss loops do not really formed a loop on the face side but float at the back. Therefore it will make the fabric tighter by putting the loops closer to each others. Since the miss loops presented on the fabric were less than Cross Miss and Double Cross Miss fabric, therefore the fabric was looser than Cross Miss and Double Cross Miss fabric and it can also be seen that the back side of the knit loop was showed as “U” shape loop at the back.

4.4.7 Plain Knit



(a) (b)

(c) (d)

Figure 4-10 (a) Face side of CH Plain Knit, (b) Back side of the CH Plain Knit, (c) Face side of MCG Plain Knit, (d) Back side of the MCG Plain Knit

Based on the images of Figures 4-10 (a), (b), (c) and (d), the pore size and different type of loop were shown. Figures 4-10 (a) and (c) show the face side of the CH and MCG fabric with pore size $0.06mm^2$ while Figures (b) and (d) show the back side of the CH and

MCG fabric with pore size 0.09mm^2. A plain knit fabric is the most common knitted fabric. It is composed by all knit loops. From the face side, we can see that all loops were packed regularly and some pores are still being seen. At the back, "U" shape loop can be found and it is the back side of the knit loop. Since no tuck loop or miss loop to form the fabric, therefore no float yarn or several loops held on the same position and more UV radiation can pass through the fabric.

4.5 UPF of Different Fabric structure

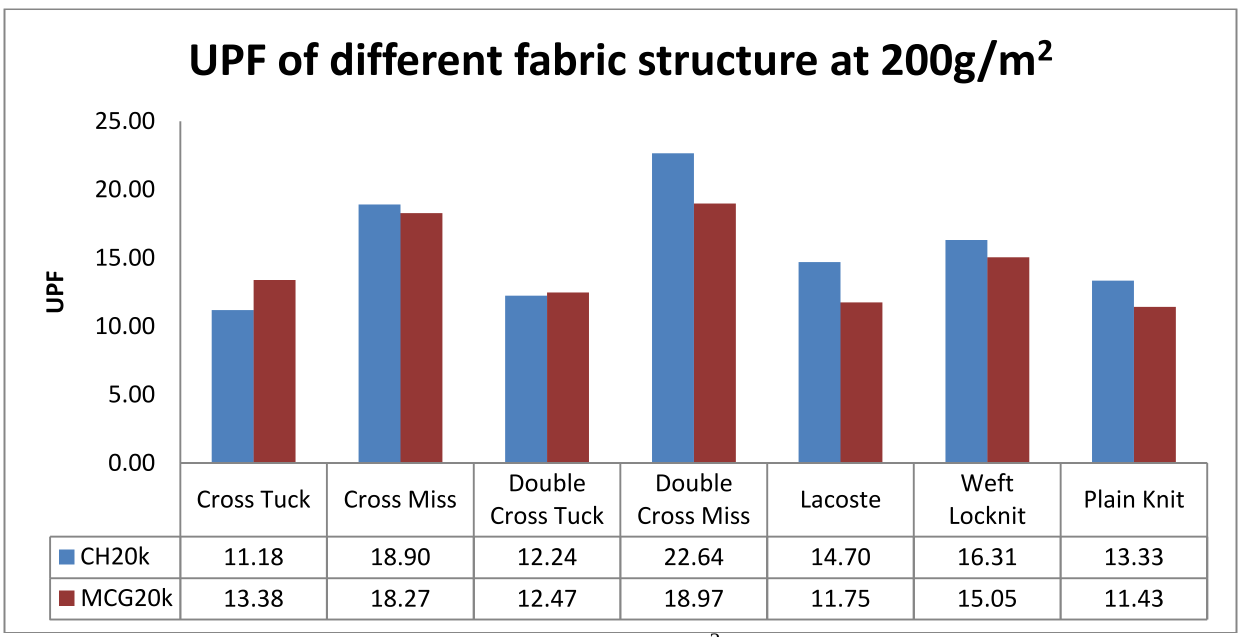


Figure 4-11 UPF of different fabric structure at 200g/m^2

The UPF value shows in figure 4-11 were normalized at the same fabric weight 200g/m^2. Figure 4-11 shows that at the same fabric weight, the UPF of knit and miss structure is always higher than the knit and tuck or all knit structure. The UPF value of knit and miss fabric ranged from 16.31 (Weft Locknit) to 22.64 (Double Cross Miss) of CH series and 15.05 (Weft Locknit) to 18.97 (Double Cross Miss) of MCG series. However, the knit and tuck structure ranged from 11.18 (Cross Tuck) to 14.70 (Lacoste) of CH series and 13.38 (Cross Tuck) to 11.75 (Lacoste) of MCG series. For the variation, it is because the miss loops will pull the knit loops closer to each other and give the fabric a higher stitch density and tighten the fabric, therefore, the pore size of the fabric will become smaller. Also the miss loops will float at the back of the fabric, therefore less UV radiation can pass through the fabric and resulting in higher UPF value. On the other hand, the tuck loops will create a larger hole between the loops, because tuck loop only formed half of a loop and so the yarn will be pulled while another knit loop formed in the same needles position. Since the yarns will be pulled therefore the fabric composed with knit and tuck will have lower UPF value. On the other hand, the UPF of CH series is higher than the MCG series, it might be due to the different in yarn properties, and the yarn properties could affect the manufacturing process from yarn to fabric (Behery, 2005). As the MCG series is a supima cotton, the staple fibre is longer in length and finer in the diameter, also the fibre’s surface is more even with less fibre ends are exposed (General Information about Supima". Supima:World's Finest Cottons. Accessed on 24-10-2012). Although the smoother surface and finer diameter of the yarn can reflect more UV radiation, the fewer number of fibres in the outer layer of the EXTex yarn may partially result in the lower

UPF of the fabrics. It is because the outer layer of the yarn body became loose during the de-twisting process (Xu and Tao, 2008), therefore more UV radiation can penetrate the fabrics through the outer layer of the yarn, and the UPF value of the fabrics will be lower.

4.6 Conclusion

This chapter has confirmed a total of five properties that are significant for determining UPF values. They are fabric weight, fabric thickness, stitch density, tightness factor and washing cycles. The fabric with knit and miss structure would be more preferred in higher UPF values. It was because the fabric structure with knit and miss loop can provide the knitted fabric with a higher tightness factor, thus the pores size of the knitted fabric will become smaller. In addition, the images of the fabric structure also showed that pore size of the fabric structure with knit and miss loop is smaller than the other type of structure, therefore fabric with knit and miss structure fabric can have a higher UPF value.

CHAPTER 5 EFFECT OF WASHING ON UPF

This part will examine the effectiveness of home laundry on the UPF of the tested fabric.

In this part, the fabrics were washed with AATCC Standard Reference Detergent.

Shrinkage was measured by following AATCC Test Method 135-2010: Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics. The distances between benchmarks on the top of each sample were measured at 0, 1, 3, 5 washing cycles. The course and wale shrinkage were calculated by the following equation:

$\%DC = \left(\frac{B-A}{A}\right) x\ 100\%$……Equation 5-1

Where: DC = Dimensional change,

A = Original dimension, and

B = Dimension after laundering

A negative value for dimensional change represents shrinkage.

The value of dimensional changes was measured three times for each of the sample for a given number of washing cycles. The mean of the measured values were used to calculate the areal shrinkage of the fabric. The method of shrinkage calculation was shown in equation 5-1

5.1 Effect of Shrinkage on UPF

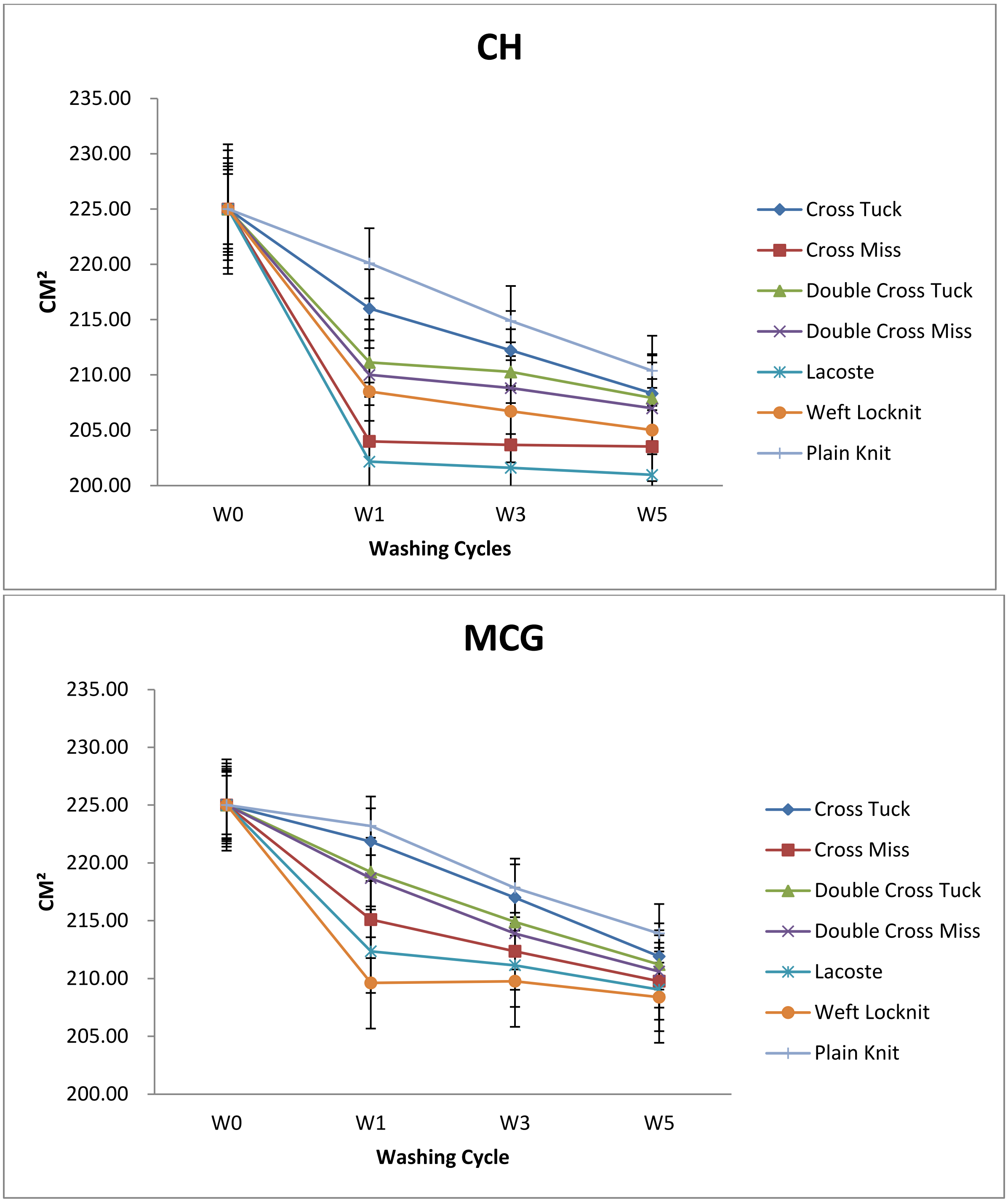


Figure 5-1 Effect of numbers of washing cycles on Fabric shrinkage

From Figure 5-1 and the table of change in area and UPF value in Appendix D, all fabrics shrank after the first washing cycle while the UPF increased. Since the fabric shrank, thus the pore size of the fabrics reduced which restricted UV radiation to pass through the fabrics, therefore the UPF value increased. After five washing cycles, the fabric shrank the most and the UPF value is also the highest among five washing cycles. Therefore it is believed that the home laundry process can enhance the UV blocking ability of the knitted fabrics in certain extend.

To view from another perspective, after the washing process, all fabrics shrank. It is found that the UPF value increased from 18.58% to 48.58% of CH series yarn and from 24.17% to 49.78% of MCG series yarn. The increase of the UPF value is mainly due to the occurrence of shrinkage and the movement of the surface fibre on the pore in between the loops. For the CH series yarn, Lacoste fabric shrank the most but the increase in percentage of UPF was only 21.28%. It is because the tuck loops will create a larger pore than knit or miss loops on the fabric, therefore even the fabric shrank, the UPF will not increase a lot at the same time.

For cross tuck and double cross tuck, the dimensional change in percentage of the fabric was-7.41% and -7.60% respectively. For cross miss and double cross miss the dimensional change in percentage of the fabric was-9.55% and -8.01% respectively. It can be seen that the knit and tuck structure shrank less than the knit and miss. It can be explained that the tuck loop will hold the yarn in the position while the miss loop only float at the back of the fabric and tighten the fabric, therefore the tuck loop may restrict the yarn movement during the washing process.

For MCG yarn series, it is found that Weft Locknit fabric shrank the most and the increase in percentage of UPF was 43.73%. For cross tuck and double cross tuck, the dimensional change in percentage of the fabric was-5.81% and -6.13% respectively. For cross miss and double cross miss the dimensional change in percentage of the fabric was-6.77% and -6.40% respectively. The same phenomenon can also be observed in MCG yarn series which the tuck loop presented on fabric can somewhat resist the lubricant force during washing thus reduce shrinkage problem of the fabric.

Since the shrinkage problem of CH series is severer than the MCG series, it is because the conventional low twist ring yarns have very low strength while torque free ring spun can produce yarn with low twist and relatively high strength simultaneously. Therefore MCG series can resist shrinking during the laundry process and so the fabrics would shrunk less than the fabrics of CH series.

It can be also explained that the MCG series has a higher fibre friction (Xu and Tao, 2008). Therefore the fibre of MCG yarn can hold itself under the washing process and result in a better dimensional stability. However, with less shrank of the MCG series fabrics, the UPF will not increase as much as the CH series fabrics. On the other hand, the Supima Cotton provides stronger and longer staple which made them more durable and it can minimize the effects of shrinkage since less fibre ends are exposed.

5.2 Effect of Numbers of Washing Cycles on UPF

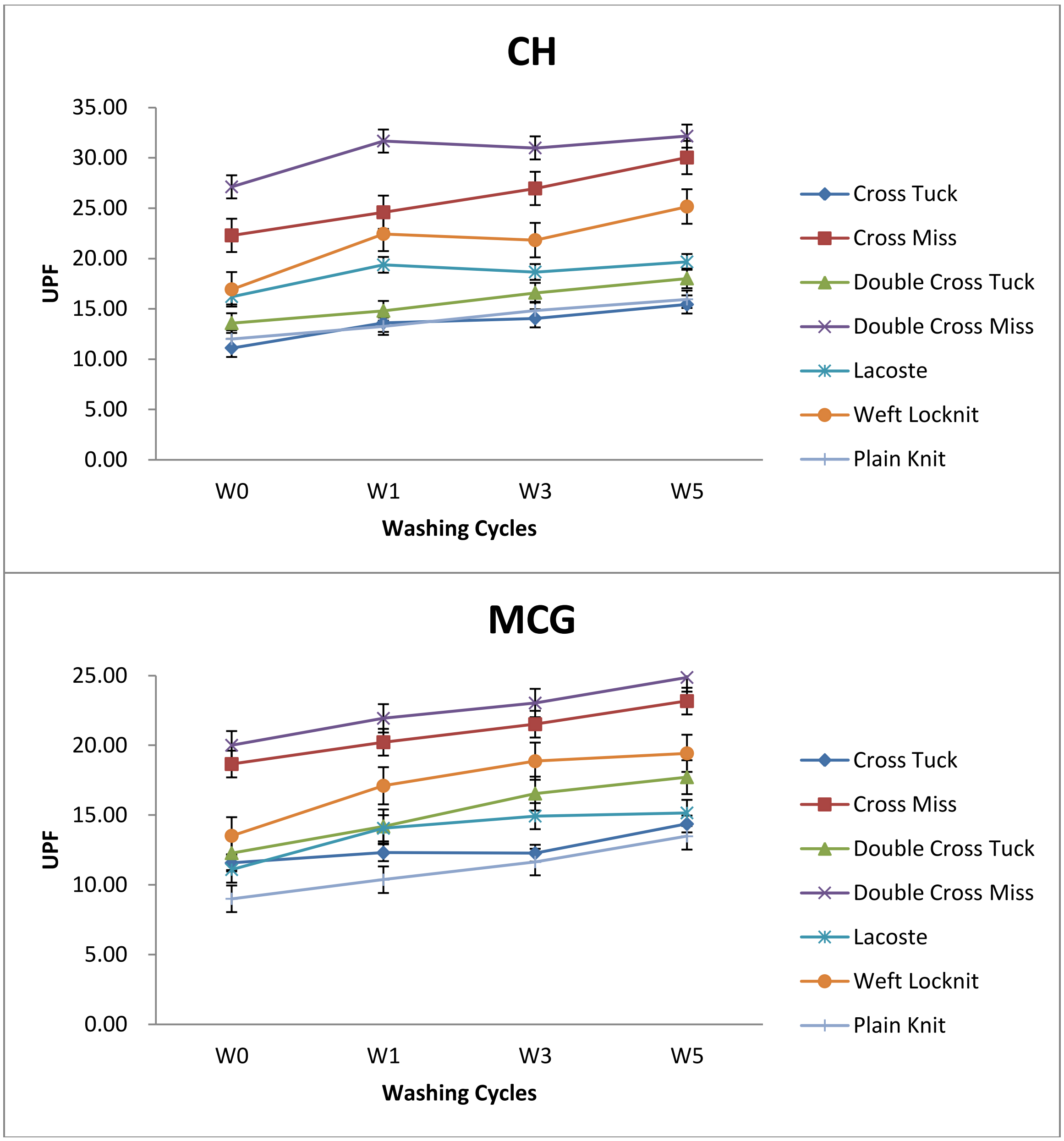
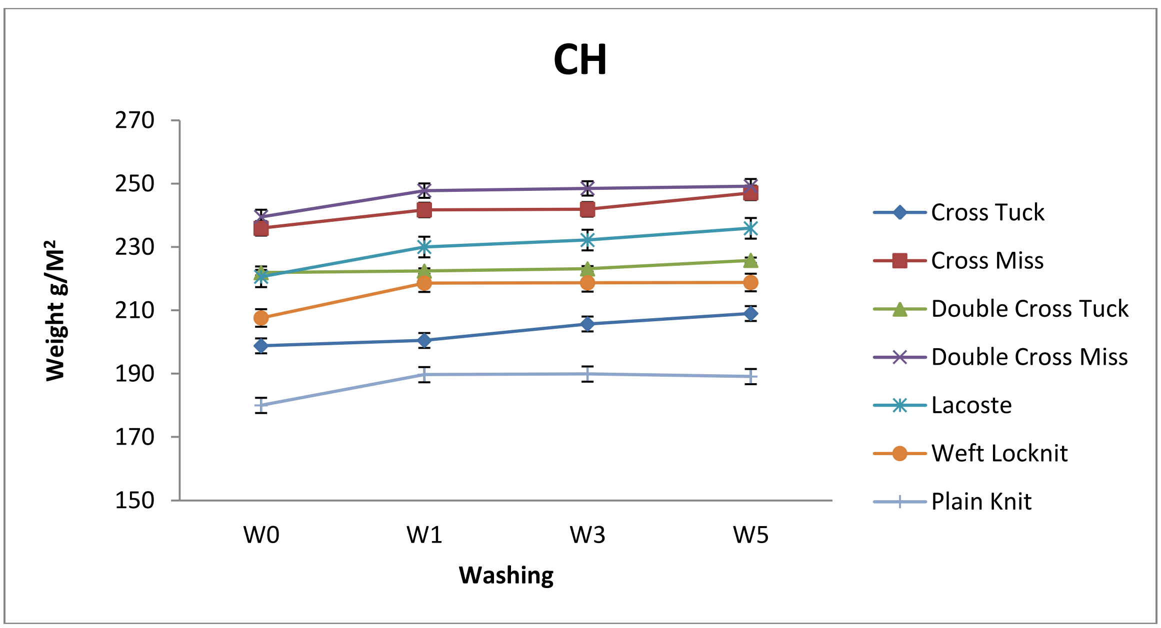


Figure 5-2 Effect of number of washing cycles on UPF

The UPF value of all the fabrics were measured under unwashed status, and then after they were washed with 1 time, 3 times and 5 times. The effects on UPF of different numbers of wash cycles with each treatment for all fabrics are shown in Figure 5-2. Generally speaking, with increasing number of wash cycles, the UPF value of the fabrics being washed will also be increased. Both of the CH and MCG series have the same trend observed. After 3 washing cycles, the UPF value started to have leveled. During the first 3 times wash cycles, the increase of UPF value is mainly due to shrinkage and even pilling. It happens when washing and wearing of fabrics causes loose fibres to begin to push out from the surface of the cloth, and, over time, abrasion causes the fibres to develop into small spherical bundles, anchored to the surface of the fabric by protruding fibres that haven't broken. (Shen et.al, 2011). Since shrinkage and pilling caused the pore size of the fabrics became smaller and tighter, therefore the UPF value increased. However, after certain times of washing, the fabric will reach dimensional stability and at that time, shrinkage will no longer happen and affect the UPF value. On the other hand, the MCG series showed a lower UPF value, it might be explained by presented of the ESTex yarn, although the Supima cotton has a finer and longer staple, the longer staple enhance the softness and luster, thus less fiber ends are exposed (General Information about Supima". Supima: World's Finest Cottons) and more UV radiation will be reflected, the fewer number of fibres in the outer layer of the EXTex yarn may partially result in the lower UPF of the fabrics. While the ESTex yarns a “harder” and “more compact” core and the density decreased toward yarn surface. The outer layer of the yarn body became loose during the de-twisting process (Xu and Tao, 2008), therefore more UV radiation can penetrate the fabrics through the outer layer of the yarn, and therefore the UPF value of the fabric will be lower. Similar to some previous studies (Parisi and Kimlin 1999, Tarbuk et.al, 2006) different yarn structure can also influence the inter yarn pores or the openness of the fabric, thus the UPF of the fabrics will be affected.

5.3 Effect of Number of Washing Cycles on Fabric Weight



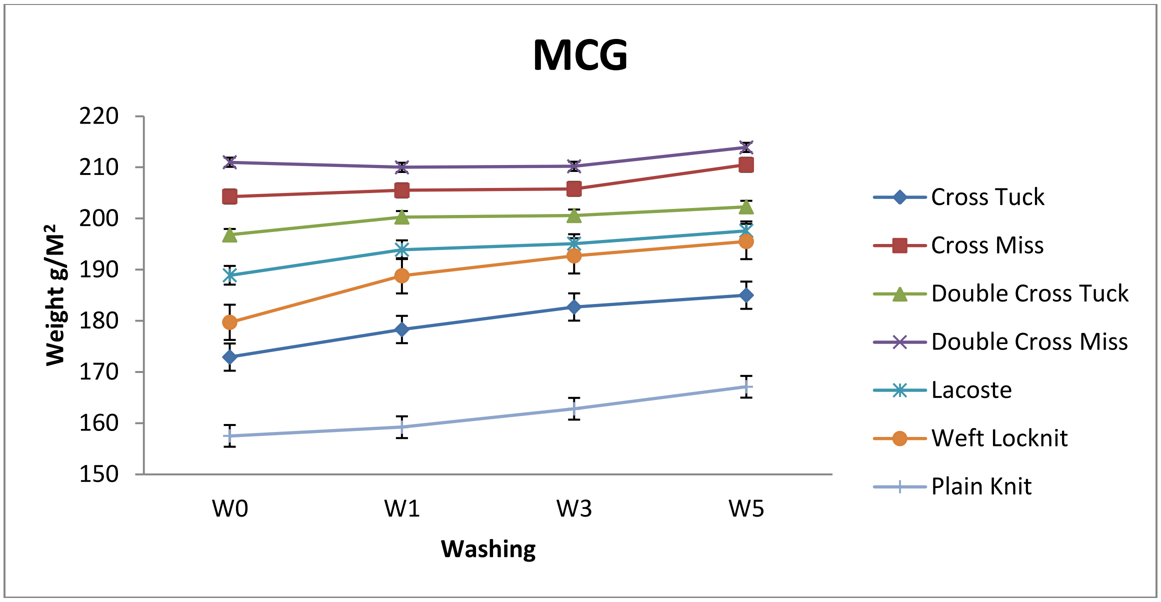
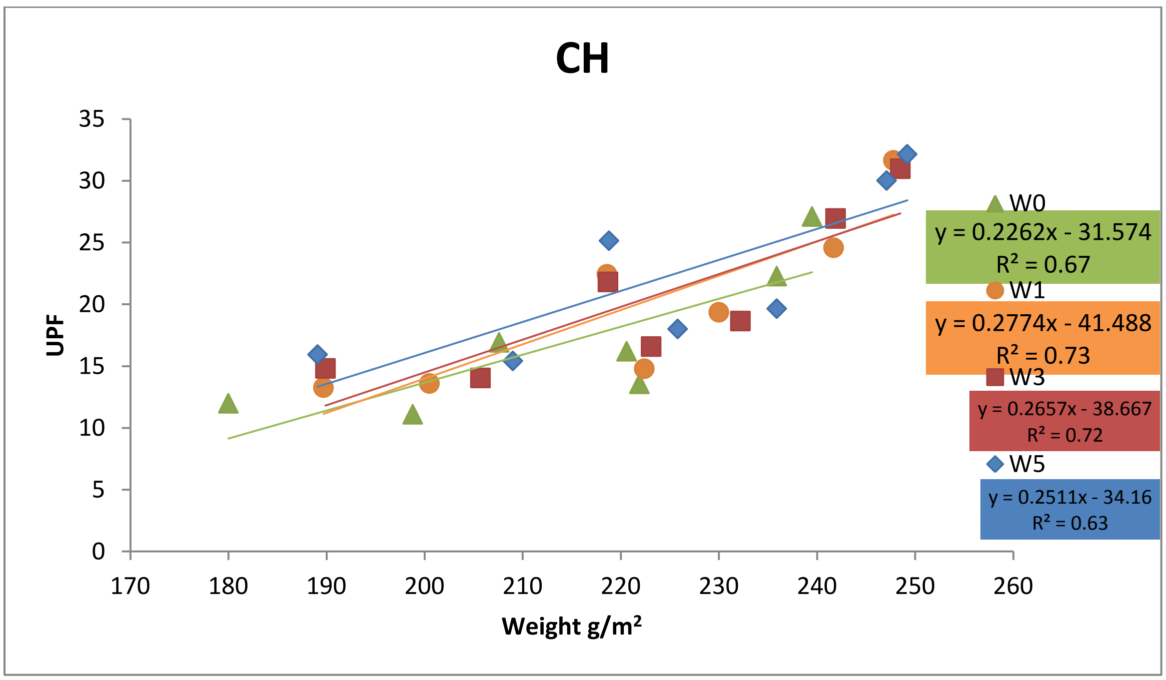


Figure 5-3 Effect of number of wash cycles on fabric weight

From Figure 5-3, the fabric weight increased when the washing cycles increased. It can be explained by the shrinkage that occurred in the fabrics. Both of the CH and MCG series yarn have the same increasing trend. Double cross miss (K+M2:2) is the heaviest while plain knit is the lightest. It is because double cross miss fabric has two miss courses per repeat of the fabric structure, therefore it will pull the loop of the fabric closer together and also after the washing process, the shrinkage problem caused the fabric even tighter, since the more loops were presented per unit area, the fabric weight will be increased. As Davis et al. (1997) observed that fabric mass is an important factor of fabric UPF and high mass is associated with high UPF, therefore shrinkage will cause the fabric weight increase, thus the fabric UPF will also be increased. In addition, the MCG series shows a lower fabric weight than the CH series, it was because the Supima cotton is lighter weight with longer staple fibre while the ESTex yarn is produced with low twist with less torque. Since less torque is a result of the fact that fewer fibres in the outer layer of the yarn (Tao et.al, 2007), therefore the fabric weight of the MCG series is lower than the CH series.

5.4 Effect of Change in Fabric Weight on UPF after Washing



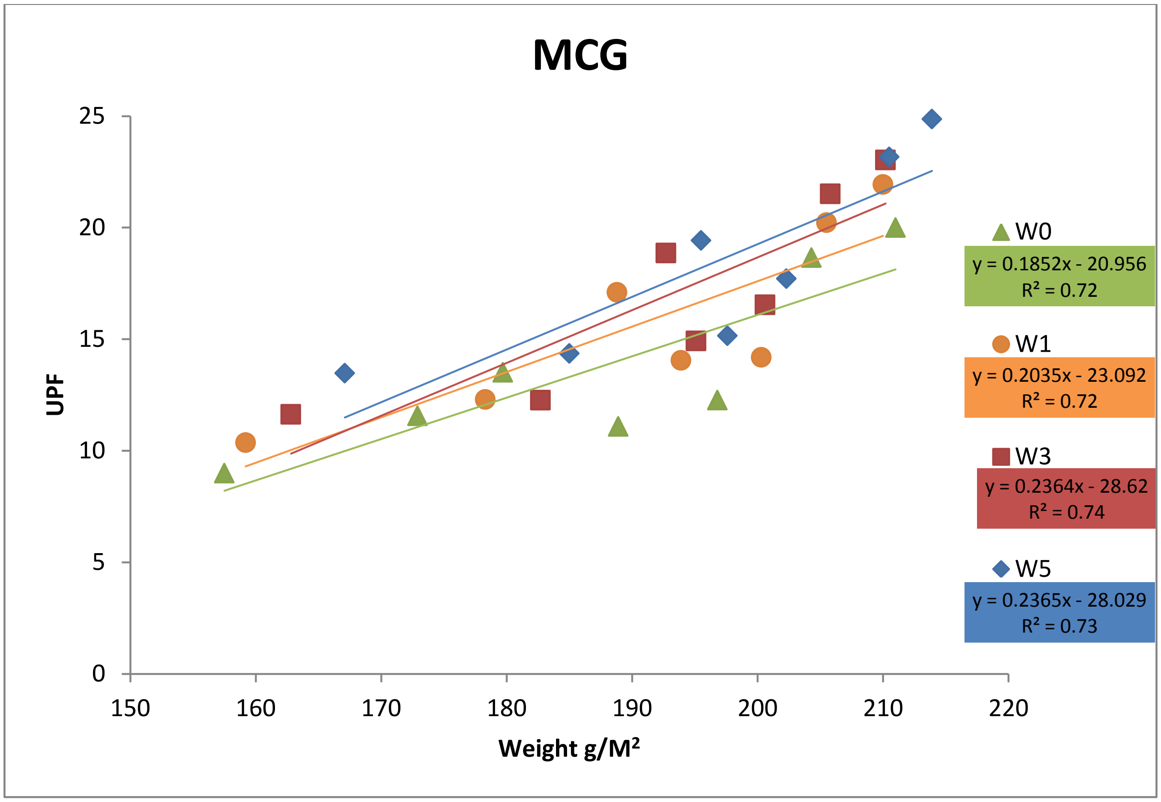


Figure 5-4 Effect of Change in Fabric Weight on UPF after Washing

From Figure 5-4, it shows that the R^2 of CH series of W0, W1, W3 and W5 are 0.67, 0.73, 0.72 and 0.63 respectively. The increase of R^2 can be explained by shrinkage of the fabric (Stanford et.al, 1995). Since the fabric shrank, the hole between the yarns of the fabric will become closer and so the fabric will become heavier. With heavier the fabric, less UV radiation can pass through the fabric and result in higher UPF rating. As stated in the previous discussion, shrinkage will increase the fabric weight and higher UPF can be resulted. For the R^2 of MCG series of W0, W1, W3 and W5 are 0.72, 0.72, 0.74 and 0.73 respectively. The same result can be obtained from MCG series. The relationship between fabric weight and UPF become stronger while the number of washing increased.

UV protection ability of the fabric can be increased through the laundry process. It improves all fabrics that are washed and reduces the amount of UV radiation penetrate the fabrics in the long run.

5.5 Effect of Number of Washing Cycles on Fabric Thickness

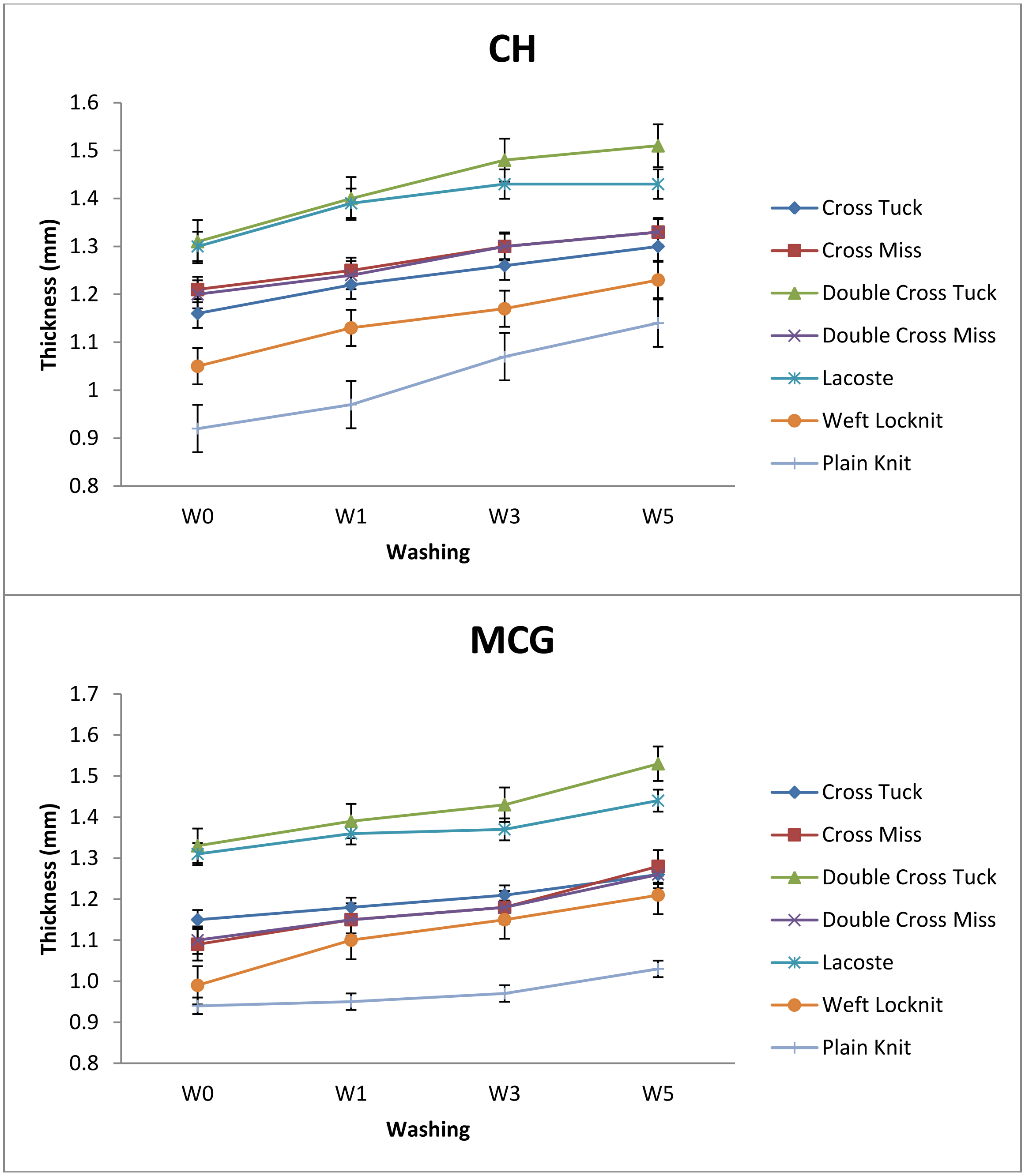
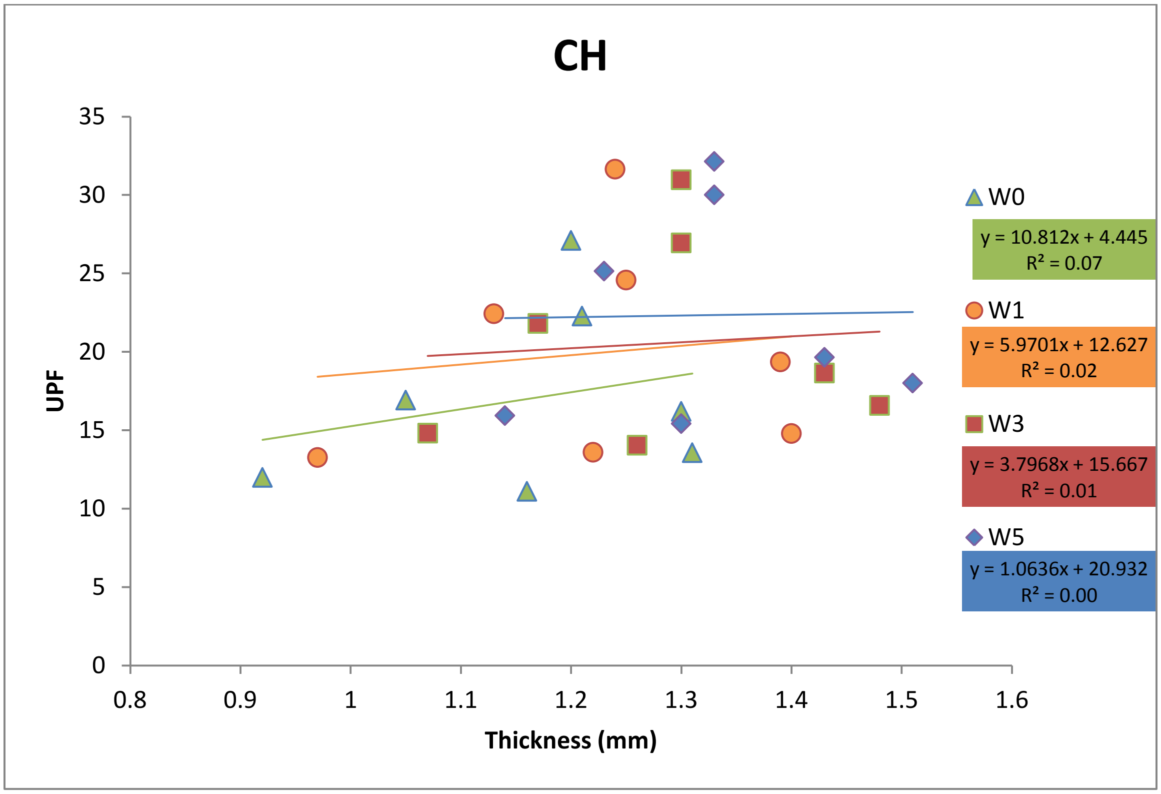


Figure 5-5 Effect of number of wash cycles on fabric thickness

From Figure 5-5, it is observed that when washing cycles increased, the fabric thickness will also be increased. The measured thickness from 0.92mm (Plain knit) to 1.53mm (Double corss tuck). The shrinkage problem caused the fabric become tighter. In addition, the yarns became closer together and so the fabric will be thicker after the washing process. Based on Figure 5-5, it is found that fabric with tuck loop is thicker than the fabric with all knit or knit and miss loop. It is because the tuck loop will not form a complete knit loop during the knitting process, unlike the knit loop, a tuck loop will not form a complete loop of “Omega” shape but rather stay in the previous position and tuck on the previous loop, also it will create a hole when a tuck loop is formed. Therefore, there will be more yarn on the position in which the fabric will become thicker. With more tuck loops presented on the fabric, the thicker the fabric will be. Although thicker the fabric, more UV radiation can be blocking by the yarn, in return, the hole created by the tuck loops will decrease the UV blocking ability of the fabric. Generally speaking, the UPF value of the fabric with tuck loop is lower than the fabric with miss loops, since larger hole can be found on the fabric with tuck loops.

By comparing CH and MCG series, both of them have a similar result, which means the yarns properties do not have a great impact overt the fabric thickness of the knitted fabrics. Since the thickness is mainly depended on the structure of the fabrics.

5.6 Effect of Change in Fabric Thickness on UPF after Washing



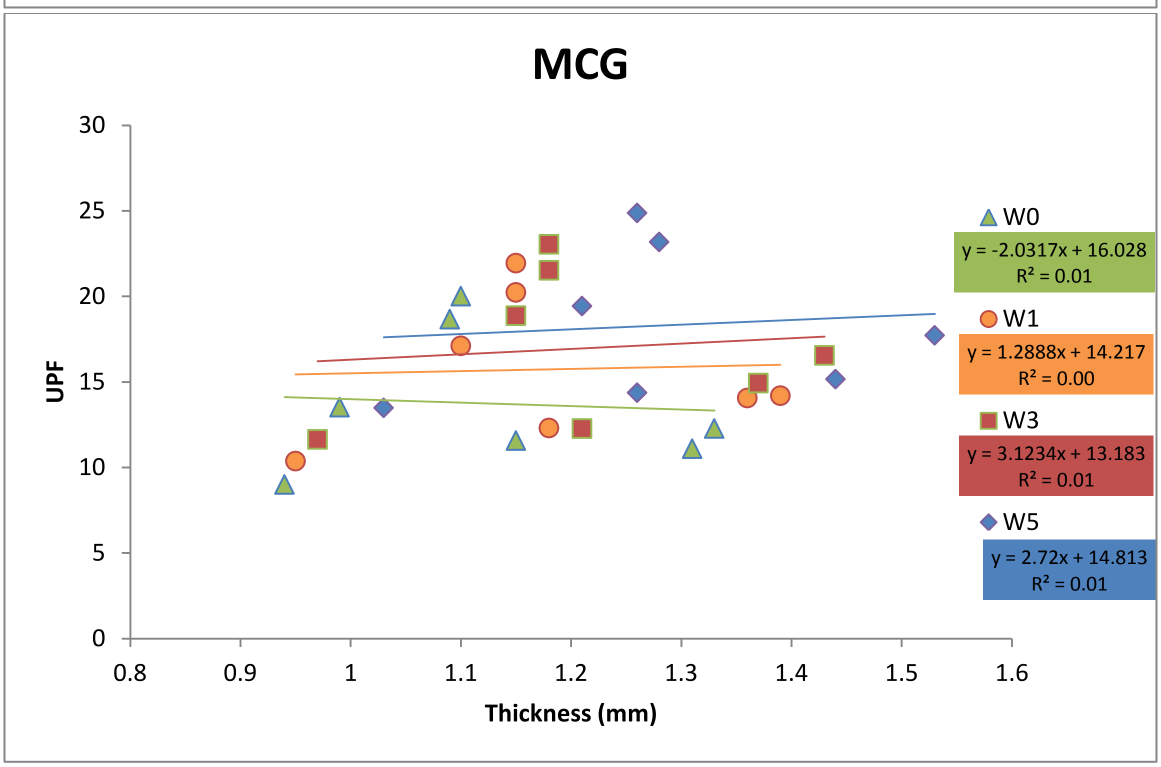


Figure 5-6 Effect of Change in Fabric Thickness on UPF after Washing

From Figure 5-6, it can be observed that the R^2 of CH series of W0, W1, W3 and W5 are 0.07, 0.02, 0.01 and 0.00 respectively. On the other hand, R^2 of MCG series of W0, W1, W3 and W5 are 0.01, 0.00, 0.01 and 0.01 respectively. By comparing CH and MCG series, both of them have a similar result, which means the yarns properties do not have a great impact overt the fabric thickness of the knitted fabrics. Since the thickness is mainly depended on the structure of the fabrics. It is also found that the laundering process does not have a great impact on the UPF. Even though the fabric thickness increased, the UPF does not increase accordingly. It is because other than the fabric thickness, the fabric structure also plays a major role in determining the UPF rating. Different loops have different properties such as tuck loop will make the fabric thicker and have bigger gap among the yarns, other the other hand, miss loop will stretch the yarn close to each other, therefore fabric construction with tuck loop will have lower UPF rating than the fabric construct with miss loop.

5.7 Effect of Number of Washing Cycles on Stitch Density

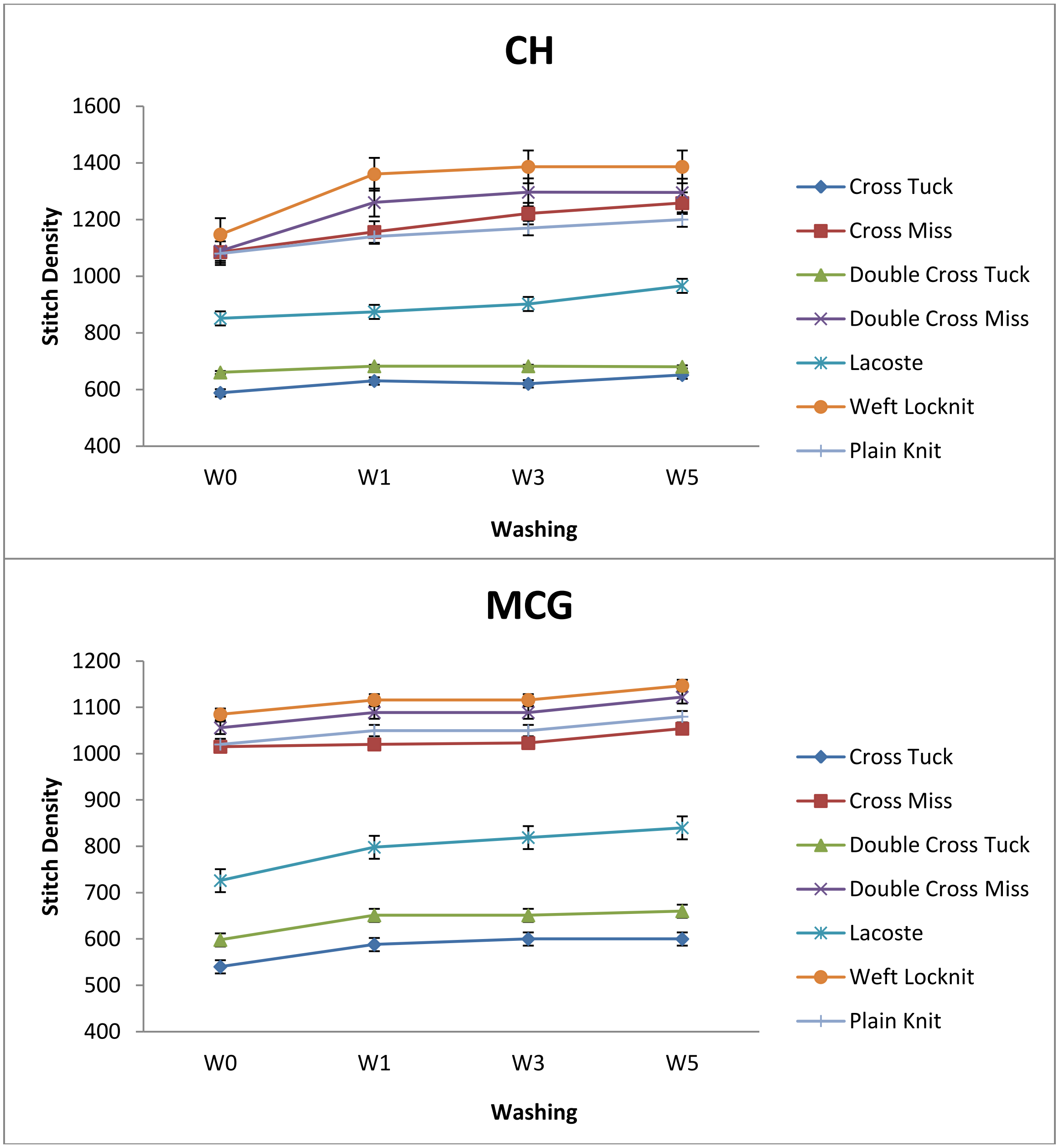


Figure 5-7 Effect of number of wash cycles on Stitch density

From Figure 5-7, all fabrics show an increase of stitch density with the increase of number of wash cycles. When the fabrics were subjected to washing process, shrinkage occurred due to the poor dimensional stability of knitted fabric. Since knitted fabric is formed by interlacing of the yarn, therefore it is more elastic then woven fabric. The reason is that each yarns are not locked among themselves, there will have room for the yarn to move when stretch the knit fabric, therefore it can provide better comfort and high elasticity. Unlike knitted fabric, woven fabric is constructed by weaving, the warp yarn and weft yarn will weave into fabric. Since there will be less space for the yarns to move when they are under tension, therefore woven usually have better dimensional stability than knit fabric. Based on Figure 5-7, it can observe that the first washing cycle has the most significant effect on the stitch density. Most of the fabrics, for example Weft Locknit and Double Cross Miss of CH series, show the stitch density increased by around 18.6 %, for MCG series Double Cross Tuck and Lacoste show the stitch density increased by around 10%. Also the stitch density of MCG series is lower than the CH series, the reason for this phenomenon can be explained by the bulkiness and more compact core of the ESTex yarns do affect the stitch density of the knitted fabric (Tao et.al, 2007)

Overall, washing process does have an effect on the stitch density of the knitted fabric since knitted fabrics have poor dimensional stability. When they are subjected to washing process, shrinkage will occur and cause fabric to shrink. Thus, the pore size of the knitted fabric will be decreased and so more UV radiation can be blocked by the yarn, the UV blocking ability of the fabric will be better.

5.8 Effect of Change in Stitch Density on UPF after Washing

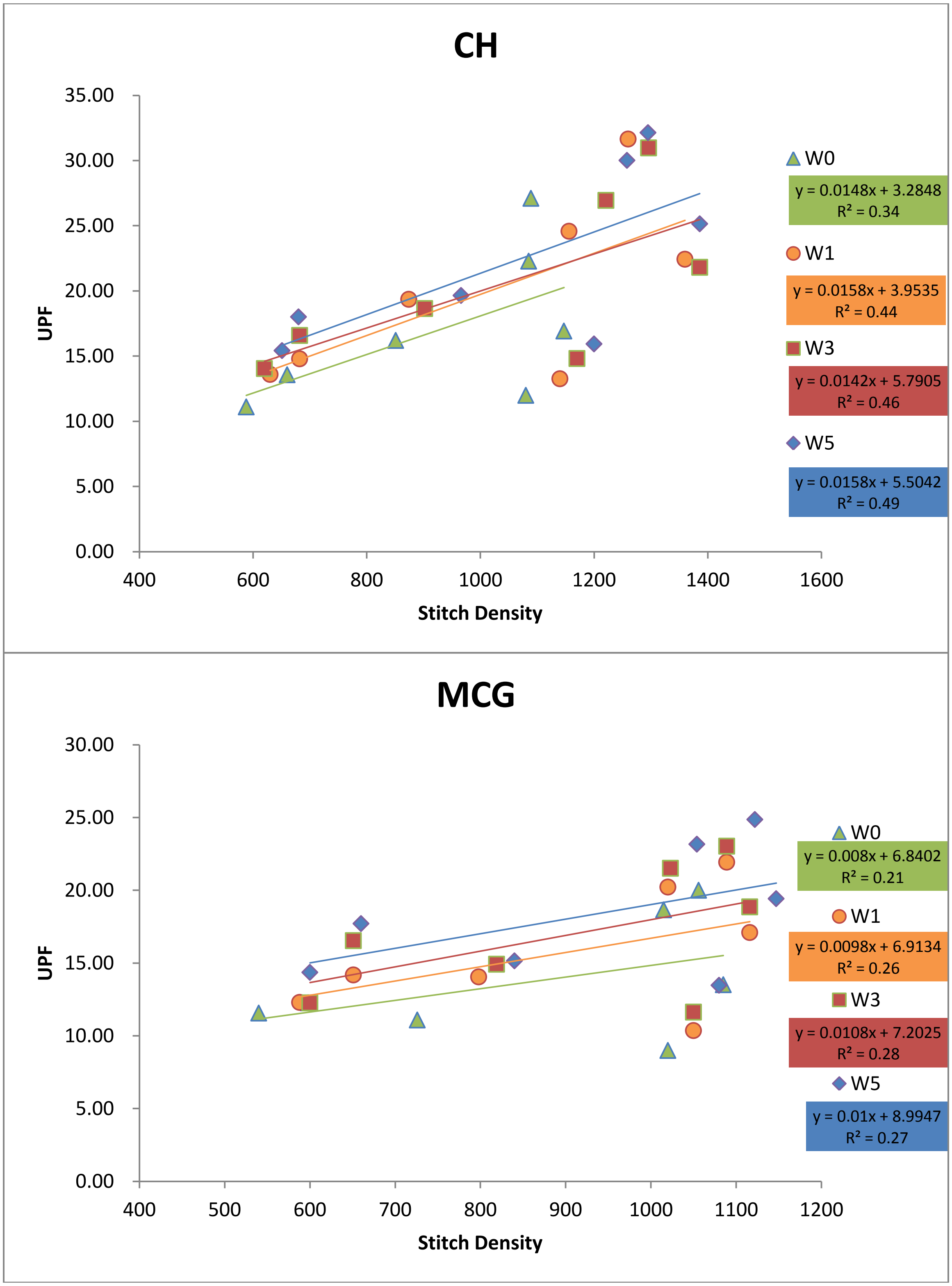


Figure 5-8 Effect of Change in Stitch Density on UPF after Washing

From Figure 5-8, it can be observed that the R^2 of CH series of W0, W1, W3 and W5 are 0.34, 0.44, 0.46 and 0.49 respectively. On the other hand, R^2 of MCG series of W0, W1, W3 and W5 are 0.21, 0.26, 0.28 and 0.27 respectively. By comparing CH with MCG series, both of them have a similar trend, while the washing cycles increase, the R^2 between the stitch density and UPF also increase. The shrinkage effect caused by the laundering process provides a stronger relationship between the stitch density and UPF. As the fabric become tighter, less UV radiation can pass through the fabric. Since knitted fabrics have poor dimensional stability, the stitch density of the knitted fabric will be affected the laundering process. As stated in the previous discussion, shrinkage will tightened the fabrics and so more UV radiation can be blocked by the yarn, the UV blocking ability of the fabric will be better.

5.9 Effect of Number of Washing Cycles on Fabric Tightness Factor

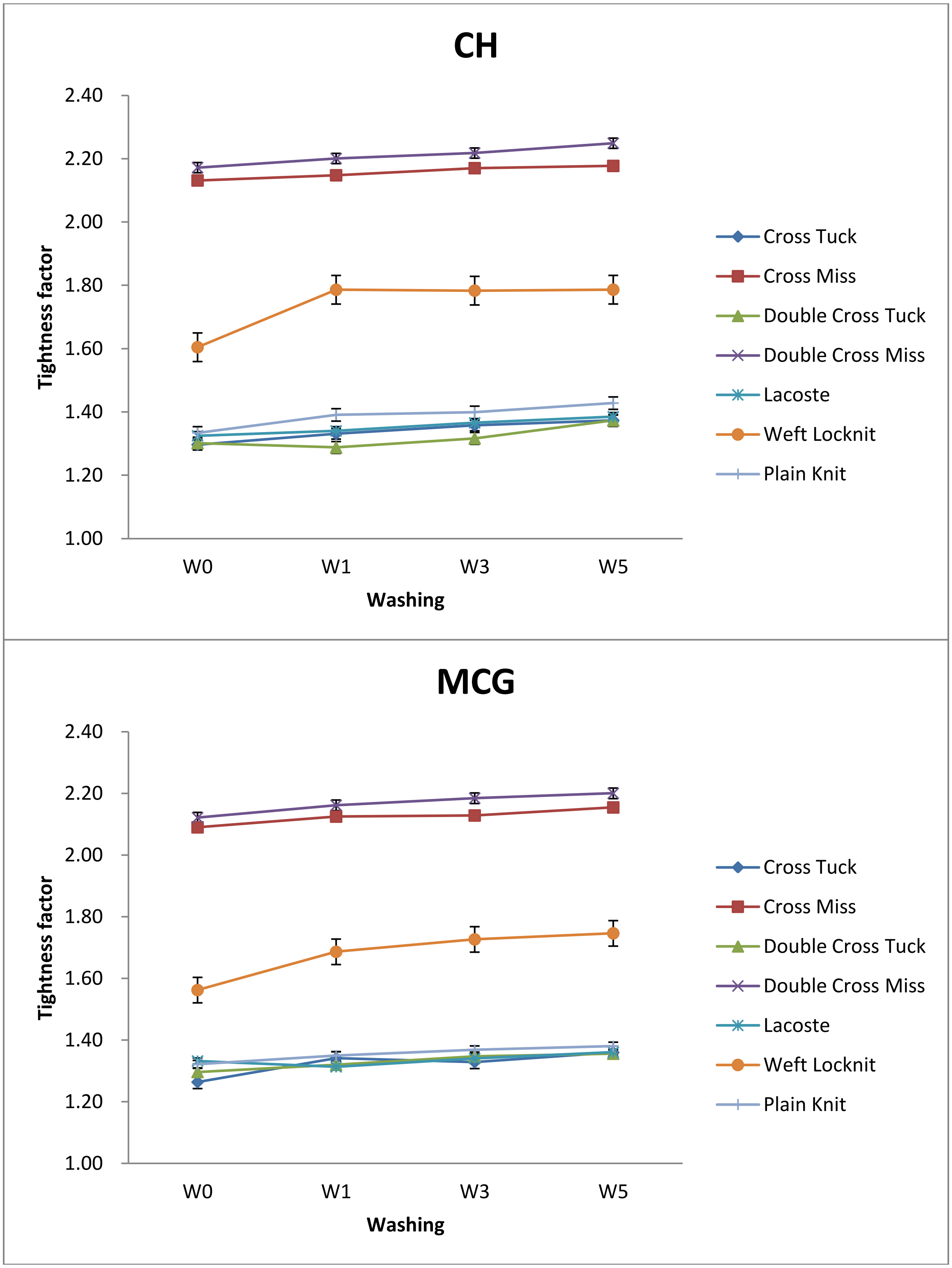


Figure 5-9 Effect of number of washing cycles on fabric tightness factor

From Figure 5-9, the tightness factor of all fabrics is slightly increased after washing process except Weft Locknit. After the first washing cycle the tightness factor of Weft Locknit of CH and MCG showed the largest increase of tightness factor, which was increased by around 11.8%. It may be due to the release of tension during the manufacturing process. Other than that, all fabrics show only slightly increased in the tightness factor, it may be due to the reason that the tightness factor is mainly depended on the fabric structure and the setting of the knitting machine. Since different types of loop have different property and loops are the basic element of the knitted fabric, thus different combination of loops will affect tightness factor of the fabric and it is one of the most important determinant of the tightness factor of the knitted fabric. Other than the different types of loop, tightness factor can also be controlled by setting the knitting machine. With higher the tightness factor, the loop and the pore size of the fabric will be smaller (Sinclair and Diffey 1997), As a result, the fabric will be tighter. So it is believed that the tightness factor is mainly depended on the types of loop and the setting up of the knitting machine. From Figure 5-9, the number of washing cycle does not have a significant effect on the tightness factor, although shrinkage does correspond to higher tightness factor, all fabrics only exhibit slightly increased in tightness factor. It is because the washing process will only affect the dimensional stability of the fabric, and the construction of the fabric will not be altered, thus, the tightness factor will not be significantly affected.

5.10 Effect of Change in Fabric Tightness Factor on UPF after Washing

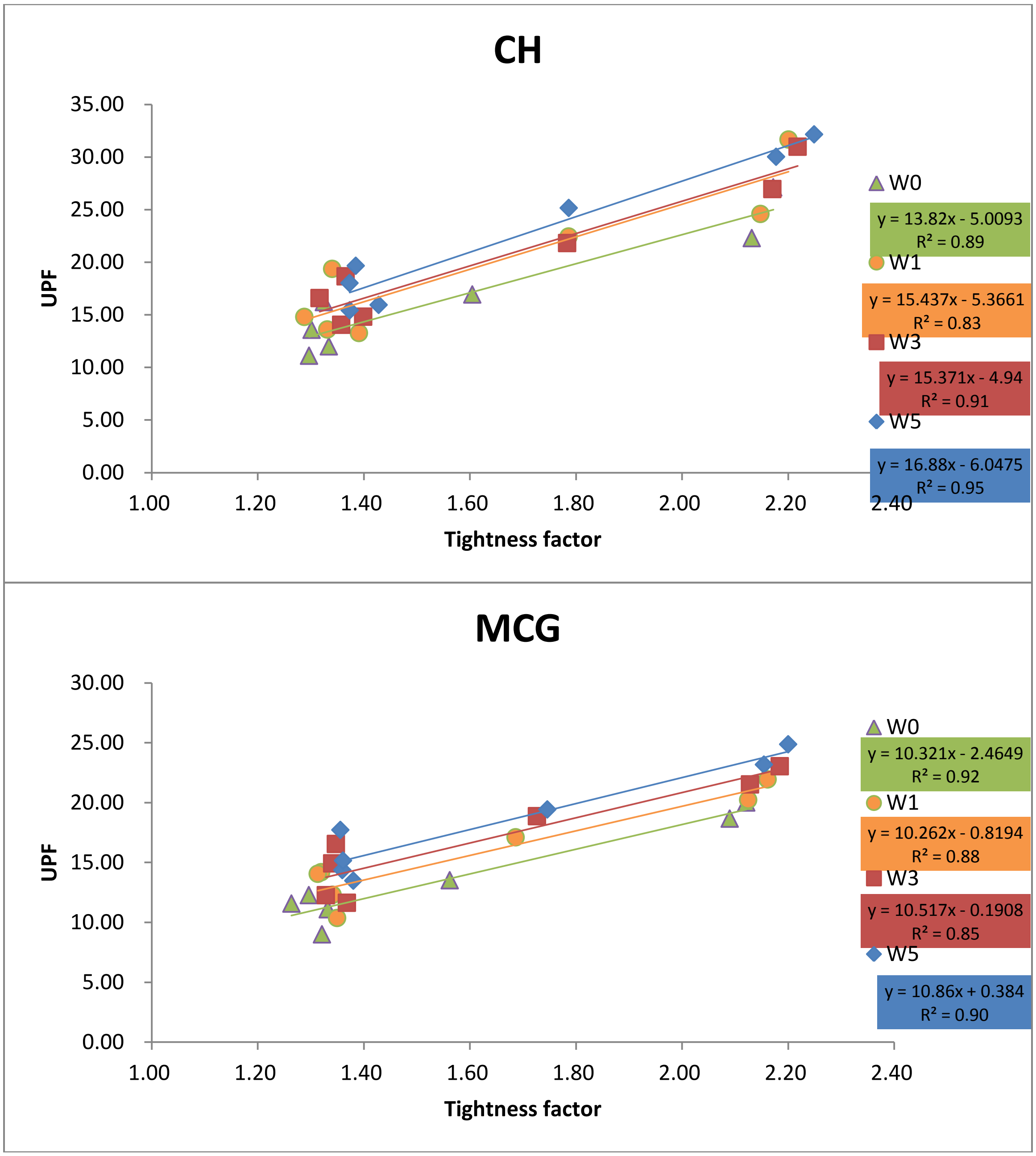


Figure 5-10 Effect of Change in Fabric Tightness Factor on UPF after Washing

From Figure 5-10, it is found that the R^2 of CH series of W0, W1, W3 and W5 are 0.89, 0.83, 0.91 and 0.95 respectively. On the other hand, R^2 of MCG series of W0, W1, W3 and W5 are 0.92, 0.88, 0.85 and 0.90 respectively. There is a significant relationship between the fabric tightness factor and the UPF. Higher the tightness factor, better the UV blocking ability. Since different types of loop will have different tightness factor, the fabric with miss loop will have tighter structure than the fabric with tuck loop. Other than the different types of loop, tightness factor can also be controlled by setting the knitting machine. With higher the tightness factor, the loop and the pore size of the fabric will be smaller (Sinclair and Diffey 1997), as a result, the fabric will be tighter. So it is believed that the tightness factor is mainly depended on the types of loops and the setting up of the knitting machine. From Figure 5-9, although shrinkage does correspond to higher tightness factor, all fabrics only exhibit slightly increased in tightness factor. But the increased in tightness factor made the UPF increased correspondingly. Therefore the tightness factor has a great impact on the UPF, with tighter the fabric, higher the UPF will be.

5.11 Effect of Number of Washing Cycles on Air Permeability

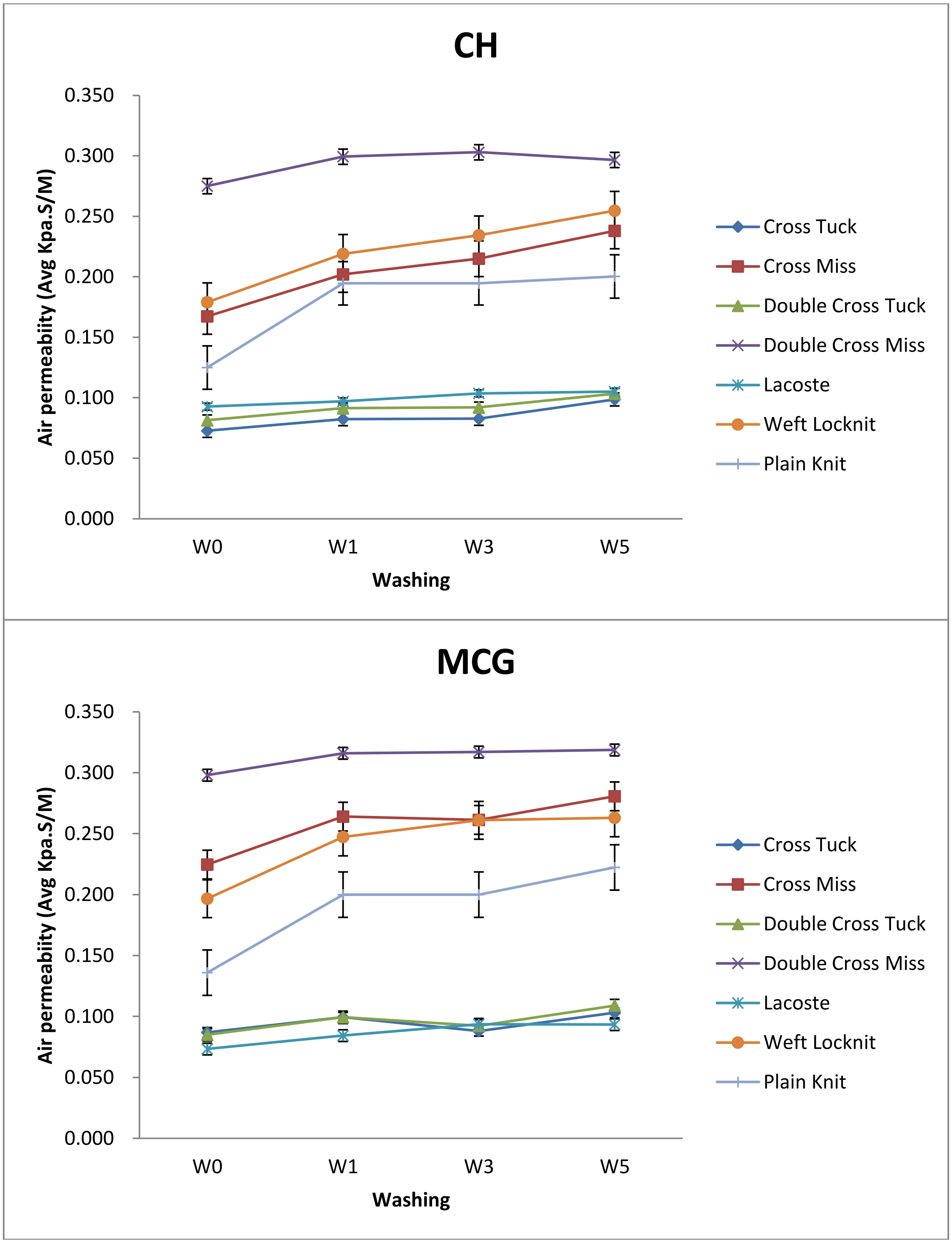


Figure 5-11 Effect of number of washing cycles on air permeability

Figure 5-11 shows that the air permeability will be decreased when the number of washing cycles increased, it is because shrinkage occurred and the fabric shrank. Thus, with a higher value of air permeability means that the fabric is not permeable, this also means that the space between the yarns is smaller and so less UV radiation can pass through the fabric and resulting in higher UPF value. Therefore with the lower air permeability, the higher UPF will be. The air permeability decreases with the increase in the UPF due to the presence of less air space in tightly knitted fabrics. In additions, it reveals that the air permeability of the fabric with knit and miss loop is the worst among all the fabrics. Since the miss loops will pull the loop closer together and a yarn will float at the back of the loop when miss loops presented, therefore it will restricted the air to pass through the fabric and air permeability will be worse. By comparing CH series with MCG series, Figure 5-11 reveals that both of the yarns shared similar results. Although ESTex yarns was stated to have better air permeability than the conventional yarn (Xu and Tao, 2008) in this research fabric produced by ESTex have a slightly worse air permeability than the fabric made by conventional yarns. This might be explained by the higher bulkiness of the ESTex yarns.

5.12 Effect of Change in Air Permeability on UPF after Washing

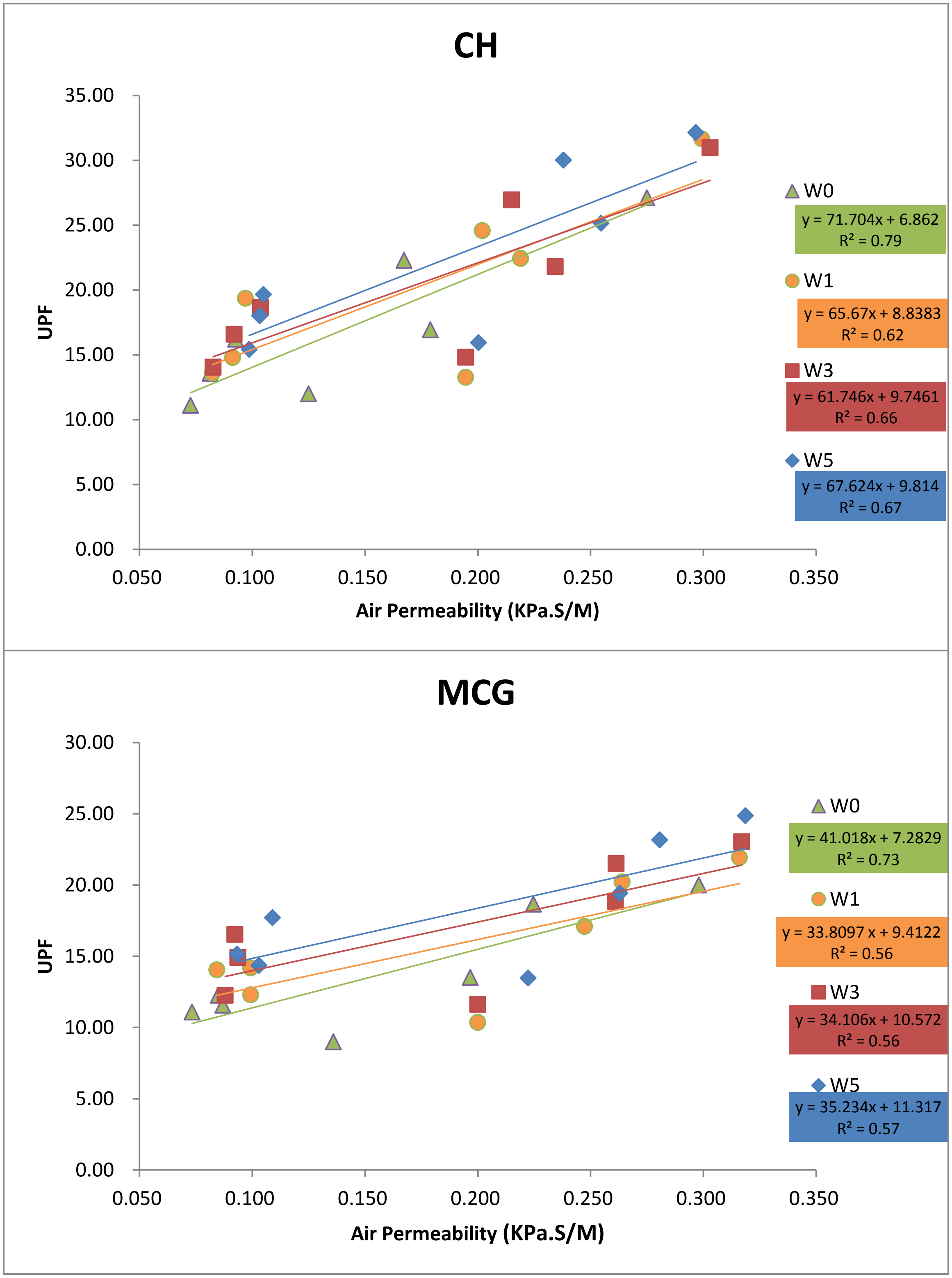


Figure 5-12 Effect of Change in Air Permeability on UPF after Washing

From Figure 5-12, it is found that the R^2 of CH series of W0, W1, W3 and W5 are 0.79, 0.62, 0.66 and 0.67 respectively. On the other hand, R^2 of MCG series of W0, W1, W3 and W5 are 0.73, 0.56, 0.56 and 0.57 respectively. Both of the CH and MCG series showed that the air permeability of the fabrics without any laundering process has the strongest relationship with the UPF. It is also reveals that the relationship between the air permeability of the fabric and the UPF of the CH series is stronger than MCG series. Although ESTex yarns was stated to have better air permeability than the conventional yarn (Xu and Tao, 2008) in this research fabric produced by ESTex have a slightly worse air permeability than the fabric made by conventional yarns. This might be explained by the higher bulkiness of the ESTex yarns.

5.13 Conclusion

In this part, the effect of washing cycles on the fabric weight, fabric thickness, stitch density, tightness factor, air permeability and UPF were studied. The results showed that with a higher number of washing cycles, higher UPF value will be. It is because the shrinkage problem occurred, and it will affect the fabric properties. Since the fabric properties were affected, the fabric structure will be somewhat being changed, thus the UPF value must be altered. It is observed that when the fabric shrank, it became denser and so less space between the loops of the knitted fabrics. Therefore less UV radiation can pass through the fabrics. Therefore the washing process can increase the UPF value of the knitted fabrics. By comparing among the fabric parameters, fabric tightness factor has the strongest relationship with the UPF following by the fabric weight, and fabric thickness showed to have no significant relationship with the UPF. Generally speaking, the relationship between the fabric parameters and the UPF become more significant after laundering process, therefore the laundering process can somehow improves the UV blocking ability, thus reducing the life time exposure to UV radiation of the wearer.

CHAPTER 6 RELATIONSHIP BETWEEN SURFACE PROPERTY AND UPF

In this part, a total of 7 mechanical properties which are considered important in knitted fabric surface and compression properties were evaluated, they are Coefficient of Friction (MIU), Mean Deviation of MIU (MMD), Geometrical Roughness (SMD), Linearity (LC), Compressional Energy (WC), Resilience (RC) and Thickness at 0.5gf/cm^2 (mm) (T_0). As surface and softness properties are highly subjective and the perceptions are different from people (Gong, 1995), therefore the Kawabata Evaluation System for Fabrics (KES-F) was used to measured different mechanical properties of the fabrics. In addition, a statistical tool was also used to evaluate the effect of surface and compression properties of the knitted fabrics on the UPF. Tables 6-1 and 6-2 list out the data of surface and compress properties.

6.1 Effect of Surface and Compression Properties on UPF

TABLE 6-1 LINEAR REGRESSION RESULTS SHOWING RELATIONSHIP BETWEEN SURFACE AND SOFTNESS PROPERTIES AND UPF

Independent variables	Correlation Coefficient
MIU	0.20
MMD	0.46
SMD	0.13
LC	0.22
WC	0.09
RC	0.29
T0	0.19

According to Data of surface and compression properties in Appendix, it is shown that rougher surface does not necessary to have a higher UPF. For example, sample CH4-5 has the highest UPF of 32.15 but the MIU and SMD are only 0.33 and 7.42 respectively. Also, sample MCG5-5 has UPF of 15.16 but the MIU and SMD are 0.37 and 11.69 respectively, which is higher than the values of CH4-5, that means with rougher and stiffer the fabric, the UPF will not be affected since UPF is mainly depended on the fabric parameters and the loop factors. Overall speaking, the value of surface and compression properties of knit and miss structure (sample CH2, CH4, CH6, MCG2, MCG4 and MCG6) were lower than the knit and tuck structure (sample CH1, CH3, CH5 and MCG1, MCG3 and MCG5) and all knit structure (sample CH7 and MCG7) (Au et.al, 2002). For example the value of MIU, MMD, SMD, LC, WC, RC and (T_0) of CH2 are 0.31, 0.018, 3.24, 0.34, 0.60, 37.71 and 1.86 respectively while CH3 are 0.31, 0.021, 5.88, 0.39, 0.69, 40.47 and 1.98, which means they have lower surface friction but with a higher UPF values. On the other hand, the knit and tuck structure offered lower UPF value with higher surface roughness and thickness. Since tuck loops create a subtle cellular effect (Moyer, 1972) on the fabric surface which contributes to the hardness and roughness making the fabric feel crispy, scratchy and thick, thus negatively influencing the surface properties but without increasing the UPF values. That why the correlation between surface properties and UPF is not a significant one. Since surface friction (MIU) and mean deviation of surface friction (MMD) were significantly correlated with the perception of hardness, harshness, roughness and heaviness (Chen et.al, 1992). Moreover, when the samples subjected with more washing cycles, the surface properties of the samples became worse. An explanation would be that during the washing process the fibre on the surface of the yarn become looser and longer, therefore the surface of the samples will be rougher.

Table 6-1 shows only Mean Deviation of MIU (MMD) has a relatively higher correlation with UPF and the others have a relatively low correlation. On the other hand, the results show that with higher the tightness factor, the lower MIU and SMD will be. It might be explained that when the space among the yarns become smaller, the surface roughness and friction will be reduced. The coefficient of friction is the parameter most frequently used in assessing a fabric's degree of smoothness or roughness. As the fabric's structure also contributes to the surface friction, the slackly knitted fabrics generally seem to have higher friction. The comparatively ridgy structure of slackly knitted fabrics compared with tightly knitted fabrics may have offered greater resistance to motion. But in this study, fabrics like Cross miss or Double cross miss tended to have a tight structure with lower surface friction or roughness and at the same time with a higher UPF values, however, fabrics like Weftlock knit or plain knit also have a tight structure with lower surface friction but the UPF value is not as high as Cross miss or Double cross miss. It can be explained that surface friction or roughness of the fabric does not correlated with UPF value, as the MIU and SMD do not show a significant correlation with the UPF. However, the MMD shows a different story, it might imply that with a larger variation of MIU of the fabric, the UPF value will be higher to certain extent. In spite of a relatively higher correlation between MMD and UPF value, it cannot be concluded that the fabric surface properties and softness have a strong correlation with UPF and used to predict the UPF value, since the R^2 is only 0.46. Also the pore sizes of the samples are not fully reflected by the surface and softness properties.

6.1.1 Multiple Regression Model of Surface and Compression Properties

TABLE 6-2 MULTIPLE REGRESSION MODEL OF SURFACE AND COMPRESSION PROPERTIES

Model	r	r^2	Adjusted r^2
1	0.78	0.60	0.55

From Table 6-2, the coefficient of determination r^2 is 60.0 %. This means that 60.0 % of the variation in the UPF can be explained by the variables of Coefficient of Friction (MIU), Mean Deviation of MIU (MMD), Geometrical Roughness(SMD), Linearity (LC), Compressional Energy (WC), Resilience (RC) and Thickness at 0.5gf/cm^2 (mm) (T_0).

6.1.2 ANOVA of Surface and Compression Properties

TABLE 6-3 ANOVA OF SURFACE AND COMPRESSION PROPERTIES

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1099.834	7	157.119	10.417	0.000
	Residual	723.950	48	15.082		
	Total	1823.784	55			

Table 6-3 shows the ANOVA generated from SPSS, the p-value of the F test is 0.000 which less than 0.05, reject the H_0 that all regression coefficients are zeros. Therefore the regression model has a significant linear relationship at a significance level of 0.05. t tests are used to evaluate the significance of each variables, i.e. if the *i*th *X* variable (*X*i) has a significant linear relationship with *Y*, holding the other *X* variables constant. t tests should be used only if F test is significant.

6.1.3 Coefficients of Surface and Compression Properties

TABLE 6-4 COEFFICIENTS OF SURFACE AND COMPRESSION PROPERTIES

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	24.261	11.375		2.133	0.038
	Coefficient of friction	48.328	46.442	0.230	1.041	0.303
	Mean Deviation of MIU	-1059.252	209.334	-0.645	-5.060	0.000
	Geometrical Roughness	-0.272	0.416	-0.094	-0.654	0.516
	Linearity	37.795	35.873	0.187	1.054	0.297

	Compressional Energy	-74.260	20.397	-1.006	-3.641	0.001
	Resilience	-0.374	0.235	-.194	-1.589	0.119
	Thickness at 0.5gf/cm^2	25.109	8.850	0.774	2.837	0.007

$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_{3\ldots+}b_7X_7$

Dependent variable

Y: UPF

Independent variables

X_1: Coefficient of friction

X_2: Mean Deviation of MIU

X_3: Geometrical Roughness

X_4: Linearity

X_5: Compressional Energy

X_6: Resilience

X_7: Thickness at 0.5gf/cm^2 (mm)

Intercept : a

Regression coefficients : b_1, b_2, b_3, b_4, b_5, b_6 and b_7 (slopes)

6.1.4 Interpretation of Regression Coefficients:

From Table 6-4, the p-values of t tests for each regression coefficients are 0.303, 0.000, 0.516, 0.297, 0.001, 0.119 and 0.007, respectively

$P_1 >0.05$ Coefficient of friction does not have a significant linear relationship with UPF at a significant level of 0.05

$P_2 <0.05$ Mean Deviation of MIU has a significant linear relationship with UPF at a significant level of 0.05

$P_3>0.05$ Geometrical Roughness does not have a significant linear relationship with UPF at a significant level of 0.05

$P_4>0.05$ Linearity does not have a significant linear relationship with UPF at a significant level of 0.05

$P_5<0.05$ Compressional Energy has a significant linear relationship with UPF at a significant level of 0.05

$P_6>0.05$ Resilience does not have a significant linear relationship with UPF at a significant level of 0.05

$P_7<0.05$ Thickness at 0.5gf/cm2 (mm) has a significant linear relationship with UPF at a significant level of 0.05

Therefore the only significant variables are Mean Deviation of MIU, Compressional Energy and Thickness at 0.5gf/cm2 (mm), the variables that have no significant linear relationships with UPF are dropped from the model.

6.2 Re-calculate and evaluate Multiple Linear Regression Model of Surface and Compression properties

As the Coefficient of friction, Geometrical Roughness, Linearity and Resilience are dropped from the model, we have to re-run the analysis by just considering the significant independent variables Mean Deviation of MIU, Compressional Energy and Thickness at 0.5gf/cm2 (mm)

6.2.1 Recalculate Model Summary Surface and Compression Properties

TABLE 6-5 RECALCULATE COEFFICIENTS OF SURFACE AND COMPRESSION PROPERTIES

Model	r	r^2	Adjusted r^2
1	0.72	0.52	0.49

From Table 6-5, the coefficient of determination r^2 is 52.0 %. This means that 52.0 % of the variation in the UPF can be explained by the variables of Mean Deviation of MIU(MMD), , Compressional Energy (WC), and Thickness at 0.5gf/cm^2 (mm)(T_0).

F test is used to evaluate the overall linear significance of the model, i.e. if there is a linear relationship between Y and all the X variables considered together

1. The null hypothesis claims that all X variables considered together do not have a linear relationship with Y, i.e. all regression coefficients are 0:

H_0: $b_1 = b_2 = \ldots = b_k = 0$

2. The alternative hypothesis claims that at least one of the

X variables has a linear relationship with Y, i.e. at least one regression coefficient is not 0:

H_1: at least one of $b_1, b_2, \ldots ,b_k \neq 0$

if $p < a$, then reject H_0 and conclude that the regression model contains a significant linear relationship.(a is the significance level and its typical value is 0.05)

6.2.2 Recalculate ANOVA of Surface and Compression Properties

TABLE 6-6 RECALCULATE ANOVA OF SURFACE AND COMPRESSION PROPERTIES

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	943.277	3	314.426	18.569	0.000
	Residual	880.508	52	16.933		
	Total	1823.784	55			

From Table 6-6, the p-value of the F test is 0.000 which less than 0.05, reject the H0 that all regression coefficients are zeros. Therefore the regression model has a significant linear relationship at a significance level of 0.05

t tests are used to evaluate the significance of each variables of X, i.e. if the *i*th *X* variable (*X*i) has a significant linear relationship with *Y*, holding the other *X* variables constant. t tests should be used only if F test is significant.

1. The null hypothesis claims that one of the variables does not have a linear relationship with Y, i.e. the *i*th regression coefficient is 0:

H_0: $b_i = 0$ (i=1,2,3…k)

2. The alternative hypothesis claims that one of the variables has a linear relationship with Y, i.e. the *i*th regression coefficient is not 0:

H_1: $b_i \neq 0$ (i=1,2,3…k)

Use the p-value of t test for evaluation: p-values of t tests if $p < a$, then reject H0 and conclude that one of the variables has a significant linear relationship with Y.

(a is the significance level and its typical value is 0.05)

6.2.3 Recalculate Coefficients of Surface and Compression Properties

TABLE 6-7 RECALCULATE COEFFICIENTS OF SURFACE AND COMPRESSION PROPERTIES

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	26.455	6.621		3.996	0.000
	Mean Deviation of MIU	-1011.216	164.966	-0.616	-6.130	0.000
	Compressional Energy	-62.474	11.636	-0.847	-5.369	0.000
	Thickness at 0.5gf/cm^2	27.234	5.030	0.839	5.415	0.000

$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3$

Dependent variable

Y: UPF

Independent variables

X_1: Mean Deviation of MIU

X_2: Compressional Energy

X_3: Thickness at 0.5gf/cm^2 (mm)

Intercept : a

Regression coefficients : b_1, b^2, and b^3 (slopes)

From the Table 6-6, the multiple regression equation is:

$UPF=26.455+ (-1011.216)\ X_1+ (-62.474)\ X_2+ 27.234X_3$

Interpretation of Regression coefficients:

UPF=26.455+ (-1011.216) Mean Deviation of MIU + (-62.474) Compressional Energy + 27.234 Thickness at 0.5gf/cm^2 (mm)

From Coefficients table of SPSS, the p-values of t tests for each regression coefficients are all 0.000. Therefore the significant variables are Mean Deviation of MIU, Compressional Energy and Thickness at 0.5gf/cm^2 (mm)

6.2.4 Verification of the Recalculate Coefficients of Surface and Compression Properties Model

From the verification of the recalculate coefficients of surface and compression properties model in Appendix E, for CH series, the average difference and the average difference in absolute value are 7.93% and 20.41% respectively while the largest difference is 77.40%. For MCG series, the average difference and the average difference in absolute value are 1.43% and 17.61% respectively while the largest difference is 87.78%. There is a large variance between measured and predicted UPF because some of the surface and compression properties were dropped out at the recalculated model, they are coefficient of friction, geometrical roughness, linearity, and resilience. They were dropped out from the model because they do not have a significant linear relationship with UPF, therefore they are not suitable for predicating the UPF. On the other hand, Table 6-6 shows only 52.0 % of the variation in the UPF can be explained by the variables of Mean Deviation of MIU, Compressional Energy and Thickness at 0.5gf/cm^2 therefore there is a large variance between the measured UPF and predicated UPF since some of the data were dropped at the previous process.

6.2.5 Residuals Statistics of Surface and Compression Properties

Residual: the residual for observation i, denoted by e_i, is the difference between its observed value Y_i and predicted value

$$e_i = Y_i - \hat{Y}_i$$

If the regression assumptions hold, the residuals should look like a random sample from a normal distribution with mean 0 and variance σ^2

6.2.6 Residual Plots and Scatter Plot

The plot of Residuals versus each independent variable, X_1: Mean Deviation of MIU, X_2: Compressional Energy, X_3: Thickness at 0.5gf/cm^2 (mm) is shown in Figure 6-1. Residuals versus the predicted values of UPF and the Normal P-P plot of the residuals is shown in Figure 6-1 and Figure 6-2 respectively

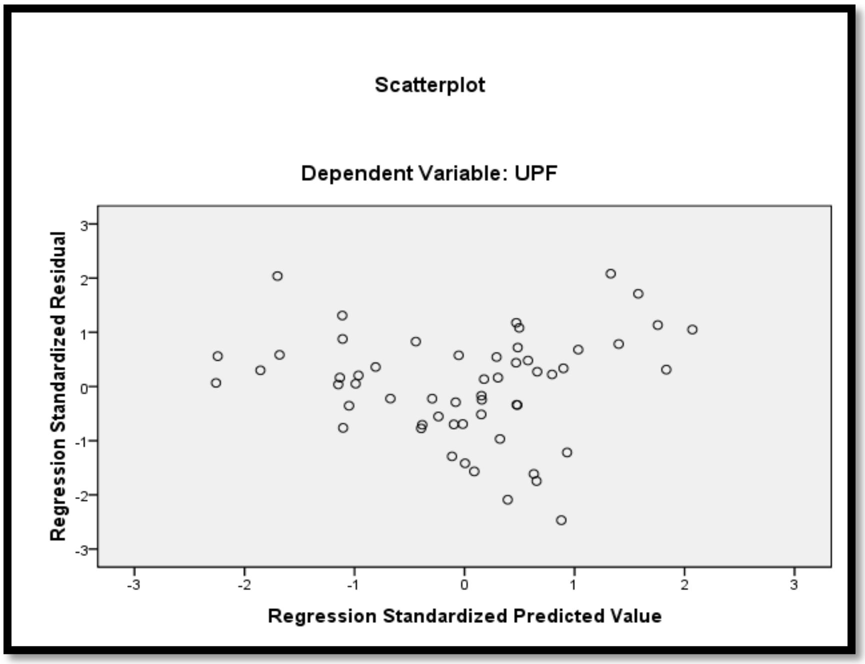


Figure 6-1 Scatter plot of residuals vs. the predicted values

From the Figure 6-1 plot of residuals vs. the predicted values of UPF generated by SPSS, it appears that the residuals are randomly distributed with no pattern and with equal variance as UPF increase, therefore, linearity, constant error variance and independence of error are not violated

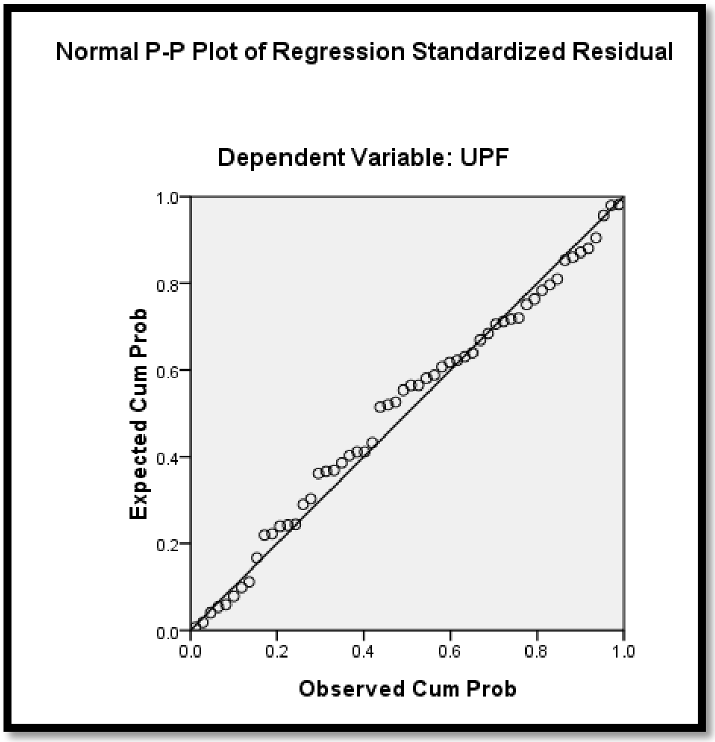


Figure 6-2 Normal P-P Plot of Regression Standardized Residual

From the Normal P-P Plot generated by SPSS, all points are approximately on a straight line, therefore the assumption of Normality of Error is not violated.

6.3 Conclusion

In this chapter, the surface and compression properties of the knitted fabrics were discussed. It was found that the surface properties of the samples became worse after laundering.

Besides, based on the coefficients of surface and compression Properties the only significant variables are Mean Deviation of MIU, Compressional Energy and Thickness at 0.5gf/cm2 (mm), the variables that have no significant linear relationships with UPF are dropped from the model. Since some of the surface and compression properties were dropped out at the recalculated model, therefore only 52.0 % of the variation in the UPF can be explained by the variables of Mean Deviation of MIU, Compressional Energy and Thickness at $0.5 gf/cm^2$.

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusion

As the hazards caused by UVR have become a major concern of the public in recent years, many researches have been done to study the UV blocking ability of clothing. However, there are many factors that can affect the UV blocking ability of clothing, such as, the fabric parameters and the finishing processes applied to the fabric. In addition, there are few studies have focused on the UV blocking ability of knitwear, especially studying the relationship between the knitted fabric parameters and the UPF. In this study, the effect of fabric weight, fabric thickness, fabric count (stitch density), fabric shrinkage, tightness factor, air permeability, number of washing cycles and fabric structure of the cotton fabrics on UPF had been evaluated. Different kinds of international testing standard and different statistical tools are used to evaluate the UPF value of the cotton knitted fabric and various results could be obtained. For international standard, they included ASTM D3776 - 96(2002) Standard Test Methods for Mass Per Unit Area (Weight), ASTM D1777 -96(2007) Standard Test Method for Thickness of Textile Materials, ASTM D3887 Standard Specification for Tolerances for Knitted Fabrics (Fabric count). Measurement, AATCC Test Method 135-2010: Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics, AS/NZS 4399:1996 "Sun protective Clothing- Evaluation and Classification" and KES-F8 air permeability test . For statistical tools, they included Multiple Linear Regression and Factor Analysis.

1. Based on the fabric weight measurement, it was found that fabric weight of single knit is positively associated with the UPF, with higher fabric weight per unit area, the fabric porosity will be lower. Since the space between the yarns are smaller and heavier fabric, allowing less UV radiation to penetrate and therefore, higher UPF will be result.

2. For the fabric thickness measurement, results revealed that thickness were positively associated with the UPF. However, the effect was not significant. This might be due to the effect of different loops presented on different structure of fabric.

3. For the fabric count (stitch density) measurement, it was found that the fabric count (stitch density) had a positive effect on the UPF. For single knitted fabric, the effect was not so significant, this might be explained by the reason of different type of loops had different properties, for example a tuck loop would create a hole between the yarn, in return, more UV radiation could pass through the fabric and resulting in lower UPF. However, the double cross miss and cross miss fabrics had showed a UPF value among all of the selected knitted fabrics. Since the fabrics structure with miss

loop had a much higher stitch density than the others and the UPF value would also be higher because the high density of the fabric could block the UV radiation.

4. Generally speaking, tighter the fabric usually has a higher UPF value. Fabric with open structure and low mass tends to have a lower UPF value. For example, Cross Tuck, Lacoste and plain knit. On the other hand, fabrics with tight structure, such as cross miss and double cross miss will provide higher UPF value, it is because the miss loops will pull the knit loops closer together and so the pore size of the fabric will be smaller. Thus, less UV radiation can pass through the fabric.

5. For the numbers of washing cycles, clothing usually shrank after washing process and the UPF value will be increased. Fabrics with high shrinkage typically show an increase in their UPF value with increased number of washing cycles. It is because the increase of mass with increased wash cycles, in which the pore size of the fabric become smaller. Overall, the improvement of UPF is the most rapid during the first 5 wash cycles.

6. For the air permeability, the single knitted fabrics was also positively assoicated with the UPF. With a higher value of air permeability test, the fabric was not permeable, this also means that the space between the yarns was smaller and so less UV radiation could pass through the fabric and resulting in higher UPF value. Also the fibre

surface might also affect the breathability of the fabric, therefore different kinds of fibre and yarn should also be considered.

7. For the fabric structure, the knitted fabrics with knit and miss loop had the higher UPF value than the knit and tuck or all knit fabrics, it was because the miss loops would pull the knit loops closers to each other and gave the fabric a higher stitch density. Also the miss loop would float at the back of the fabric, therefore less UV radiation could be pass through the fabric and resulting in higher UPF value. On the other hand, the tuck loops would create a larger hole between the loops, because the loops would be pulled, therefore the fabric composed with knit and tuck would have lower UPF value.

7.2 Recommendations

In this study, the relationship between knitted fabric structure and UPF had been studied. However, due to time limitation, there is still a lot of space for further investigation on the relationship between knitted fabric and UPF. Some recommendations are suggested for future development.

1. In this research, only 20 machine gauge circular knitting machine was used, others common machine gauge such as 22 and 25 machine gauge can be used for further study. Since the machine gauge will have great impact on the openness of the fabric structure, therefore it is worth to study the relationship between different number of machine gauge and UPF.

2. In this study, all fabrics sample only subjected to maximum of 5 times washing cycles, more washing cycles can be done to study the effect of dimensional changes of the fabrics on UPF. Normally, knitwear fabric can withstand around 50 times of washing cycles

3. In addition, other than under laboratory setting of measuring the UPF values, the UPF values measured under the real wearing conditions are also needed. In order to provide an accurate evaluation of UV blocking ability of the fabric, it is necessary to test the fabric under real situation. Testing on human being can be done to provide a more realistic results compare to the test done under laboratory condition. Apart from it, the simulation of radiation, diffusion of light and the testing subject being tested under different angles in order to get a comprehensive measurement

4. The garment type and design should also be considered for future study, for example different part of the garment can be composed by different type of fabric structure and

fibre depending on the intensity being exposed to UV radiation. Since the garment type and design are also have a great impact on the UV blocking ability, therefore a good design of the garment to protect human from the hazard of UV radiation is necessary.

5. In this study, the knitted fabrics produced are still relatively heavy and thick which are not comfortable to wear in summer. Future works should pay more effort to produce a light in weight and thinner in thickness knitted fabric with excellent UV protection for summer use.

6. More types of knitted fabric structure should be produced for studying their relationship with UPF. In long term, a database can be created so that the manufacturer or the consumer can estimate the UPF level by simply check with the database before they are planning to produce or buy it.

7. Effect of different detergent during the laundering process can be investigated since the detergent will influence the UPF during the laundry process.

APPENDIX A

Fabric Description

Details of sample no.

Sample No.	**Yarn**	**Washing Cycles**	**Structure**	**Sample No.**	**Yarn**	**Washing Cycles**	**Structure**
CH1-0	CH	0	Cross tuck	MCG1-0	MCG	0	Cross tuck
CH2-0	CH	0	Cross miss	MCG2-0	MCG	0	Cross miss
CH3-0	CH	0	Double cross tuck	MCG3-0	MCG	0	Double cross tuck
CH4-0	CH	0	Double cross miss	MCG4-0	MCG	0	Double cross miss
CH5-0	CH	0	Lacoste	MCG5-0	MCG	0	Lacoste
CH6-0	CH	0	Weft Locknit	MCG6-0	MCG	0	Weft Locknit
CH7-0	CH	0	Plain Knit	MCG7-0	MCG	0	Plain Knit
CH1-1	CH	1	Cross tuck	MCG1-1	MCG	1	Cross tuck
CH2-1	CH	1	Cross miss	MCG2-1	MCG	1	Cross miss
CH3-1	CH	1	Double cross tuck	MCG3-1	MCG	1	Double cross tuck
CH4-1	CH	1	Double cross miss	MCG4-1	MCG	1	Double cross miss
CH5-1	CH	1	Lacoste	MCG5-1	MCG	1	Lacoste
CH6-1	CH	1	Weft Locknit	MCG6-1	MCG	1	Weft Locknit
CH7-1	CH	1	Plain Knit	MCG7-1	MCG	1	Plain Knit
CH1-3	CH	3	Cross tuck	MCG1-3	MCG	3	Cross tuck
CH2-3	CH	3	Cross miss	MCG2-3	MCG	3	Cross miss
CH3-3	CH	3	Double cross tuck	MCG3-3	MCG	3	Double cross tuck
CH4-3	CH	3	Double cross miss	MCG4-3	MCG	3	Double cross miss
CH5-3	CH	3	Lacoste	MCG5-3	MCG	3	Lacoste
CH6-3	CH	3	Weft Locknit	MCG6-3	MCG	3	Weft Locknit
CH7-3	CH	3	Plain Knit	MCG7-3	MCG	3	Plain Knit
CH1-5	CH	5	Cross tuck	MCG1-5	MCG	5	Cross tuck
CH2-5	CH	5	Cross miss	MCG2-5	MCG	5	Cross miss
CH3-5	CH	5	Double cross tuck	MCG3-5	MCG	5	Double cross tuck
CH4-5	CH	5	Double cross miss	MCG4-5	MCG	5	Double cross miss
CH5-5	CH	5	Lacoste	MCG5-5	MCG	5	Lacoste
CH6-5	CH	5	Weft Locknit	MCG6-5	MCG	5	Weft Locknit
CH7-5	CH	5	Plain Knit	MCG7-5	MCG	5	Plain Knit

Appendix B

Surface and compressional properties of Kawabata Evaluation System

All parameters obtained for these hysteresis curves

Fabric thickness at 0.5 gf/cm^2	Fabric thickness at 0.5 gf/cm^2	T_0	mm
Compressional energy	Energy in compressing fabric under 50 gf/cm^2	WC	gf.cm/cm^2
Compressional resilience	Percentage energy recovery from lateral compression deformation	RC	%
compressibility	Percentage reduction in fabric thickness resulting from an increase in lateral pressure from 0.5^2 to 50 gf/cm^2	EMC	%
Coefficient of friction	Coefficient of friction between the fabric surface and a standard contactor	MIU	-
Geometrical	Variation in surface geometry	SMD	micron

Appendix C

Fabric Parameters and SPSS generated data

Data of independent variables and dependent variables of CH and MCG series

Sample No.	Fabric weight (g/m^2)	Fabric thickness (mm)	Stitch denstiy	Air permeability (KPa.S/M)	Tightness factor	Measured UPF
CH1-0	198.8	1.16	588	0.073	1.30	11.11
CH2-0	235.9	1.21	1085	0.167	2.13	22.29
CH3-0	221.9	1.31	660	0.081	1.30	13.58
CH4-0	239.5	1.20	1089	0.275	2.17	27.11
CH5-0	220.6	1.30	851	0.093	1.32	16.21
CH6-0	207.6	1.05	1147	0.179	1.60	16.93
CH7-0	180.0	0.92	1080	0.125	1.33	12.00
CH1-1	200.5	1.22	630	0.082	1.33	13.61
CH2-1	241.7	1.25	1156	0.202	2.15	24.59
CH3-1	222.4	1.40	682	0.091	1.29	14.80
CH4-1	247.8	1.24	1260	0.299	2.20	31.66
CH5-1	230.0	1.39	874	0.097	1.34	19.37
CH6-1	218.6	1.13	1360	0.219	1.79	22.44
CH7-1	189.7	0.97	1140	0.195	1.39	13.27
CH1-3	205.7	1.26	620	0.083	1.36	14.05
CH2-3	241.9	1.30	1221	0.215	2.17	26.96
CH3-3	223.1	1.48	682	0.092	1.32	16.59
CH4-3	248.5	1.30	1296	0.303	2.22	30.98
CH5-3	232.2	1.43	902	0.104	1.37	18.66
CH6-3	218.7	1.17	1386	0.234	1.78	21.82
CH7-3	189.9	1.07	1170	0.195	1.40	14.82
CH1-5	209.0	1.30	651	0.099	1.37	15.43
CH2-5	247.1	1.33	1258	0.238	2.18	30.02
CH3-5	225.8	1.51	680	0.103	1.37	18.02
CH4-5	249.2	1.33	1295	0.297	2.25	32.15
CH5-5	235.9	1.43	966	0.105	1.38	19.66
CH6-5	218.8	1.23	1386	0.255	1.79	25.16
CH7-5	189.1	1.14	1200	0.2	1.43	15.94
MCG1-0	172.9	1.15	540	0.087	1.26	11.57
MCG2-0	204.3	1.09	1015	0.225	2.09	18.66
MCG3-0	196.8	1.33	598	0.085	1.30	12.27

Data of independent variables and dependent variables of CH and MCG series (Cont'd)

MCG4-0	211.0	1.10	1056	0.298	2.12	20.01
MCG5-0	188.9	1.31	726	0.073	1.33	11.09
MCG6-0	179.7	0.99	1085	0.197	1.56	13.52
MCG7-0	157.5	0.94	1020	0.136	1.32	9.00
MCG1-1	178.3	1.18	588	0.099	1.34	12.30
MCG2-1	205.5	1.15	1020	0.264	2.12	20.23
MCG3-1	200.3	1.39	651	0.099	1.32	14.19
MCG4-1	210.0	1.15	1089	0.316	2.16	21.94
MCG5-1	193.9	1.36	798	0.084	1.31	14.06
MCG6-1	188.8	1.10	1116	0.247	1.69	17.10
MCG7-1	159.2	0.95	1050	0.203	1.35	10.37
MCG1-3	182.7	1.21	600	0.088	1.33	12.27
MCG2-3	205.8	1.18	1023	0.261	2.13	21.52
MCG3-3	200.6	1.43	651	0.092	1.35	16.55
MCG4-3	210.2	1.18	1089	0.317	2.18	23.04
MCG5-3	195.1	1.37	819	0.094	1.34	14.93
MCG6-3	192.7	1.15	1116	0.261	1.73	18.87
MCG7-3	162.8	0.97	1050	0.21	1.37	11.63
MCG1-5	185.0	1.26	600	0.103	1.36	14.37
MCG2-5	210.5	1.28	1054	0.281	2.15	23.18
MCG3-5	202.3	1.53	660	0.109	1.36	17.72
MCG4-5	213.9	1.26	1122	0.319	2.20	24.87
MCG5-5	197.6	1.44	840	0.093	1.36	15.16
MCG6-5	195.5	1.21	1147	0.263	1.75	19.43
MCG7-5	167.1	1.03	1080	0.222	1.38	13.48

Measured UPF vs Predicted UPF of yarn type CH

Sample No.	**Measured UPF**	**Predicted UPF**	**Difference (%)**
CH1-0	11.11	11.49	3.38%
CH2-0	22.29	25.22	13.14%
CH3-0	13.58	15.29	12.61%
CH4-0	27.11	25.72	-5.13%
CH5-0	16.21	16.81	3.67%
CH6-0	16.93	17.87	5.54%
CH7-0	12.00	11.86	-1.19%
CH1-1	13.61	12.84	-5.59%
CH2-1	24.59	26.74	8.77%
CH3-1	14.80	16.34	10.37%
CH4-1	31.66	28.32	-10.55%
CH5-1	19.37	18.72	-3.36%
CH6-1	22.44	22.63	0.82%
CH7-1	13.27	14.02	5.67%
CH1-3	14.05	13.76	-2.11%
CH2-3	26.96	27.98	3.80%
CH3-3	16.59	17.45	5.18%
CH4-3	30.98	29.42	-5.04%
CH5-3	18.66	19.71	5.67%
CH6-3	21.82	23.24	6.49%
CH7-3	14.82	15.39	3.82%
CH1-5	15.43	14.78	-4.20%
CH2-5	30.02	29.01	-3.38%
CH3-5	18.02	18.39	2.06%
CH4-5	32.15	30.02	-6.62%
CH5-5	19.66	20.64	4.97%
CH6-5	25.16	23.90	-5.01%
CH7-5	15.94	16.54	3.73%
		Avg	1.70%
		Avg **(absolute value)**	5.42%
		Max	13.14%
		Min	-10.55%

Measured UPF vs Predicted UPF of yarn type MCG

Sample No.	Measured UPF	Predicted UPF	Difference (%)
MCG1-0	11.57	8.92	-22.88%
MCG2-0	18.66	20.86	11.78%
MCG3-0	12.27	13.21	7.58%
MCG4-0	20.01	22.01	10.00%
MCG5-0	11.09	13.75	23.95%
MCG6-0	13.52	14.45	6.92%
MCG7-0	9.00	9.93	10.35%
MCG1-1	12.30	10.62	-13.71%
MCG2-1	20.23	21.89	8.21%
MCG3-1	14.19	14.69	3.51%
MCG4-1	21.94	23.05	5.05%
MCG5-1	14.06	15.05	7.08%
MCG6-1	17.10	17.48	2.19%
MCG7-1	10.37	10.63	2.55%
MCG1-3	12.27	11.23	-8.45%
MCG2-3	21.52	22.28	3.52%
MCG3-3	16.55	15.35	-7.23%
MCG4-3	23.04	23.56	2.26%
MCG5-3	14.93	15.62	4.68%
MCG6-3	18.87	18.60	-1.44%
MCG7-3	11.63	11.24	-3.40%
MCG1-5	14.37	12.16	-15.32%
MCG2-5	23.18	24.11	4.03%
MCG3-5	17.72	16.66	-6.00%
MCG4-5	24.87	25.05	0.70%
MCG5-5	15.16	16.86	11.25%
MCG6-5	19.43	19.82	2.02%
MCG7-5	13.48	12.51	-7.23%
		Avg	1.50%
		Avg **(absolute value)**	7.62%
		Max	23.95%
		Min	-22.88%

Residuals Statistics of independent variables

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	8.5752	30.2780	18.0814	5.62893	56
Residual	-2.22881	4.00081	0.00000	1.21444	56
Std. Predicted Value	-1.689	2.167	0.000	1.000	56
Std. Residual	-1.750	3.141	0.000	0.953	56

Component Matrix and Rotated Component Matrix

(a) (b)

Component Matrix	Component			Rotated Component Matrix	Component		
	1	2	3		1	2	3
Tightness	0.873	-0.244	0.279	Air permeability	0.958	0.092	-0.037
Air permeability	0.849	-0.444	-0.095	Stitch density	0.911	0.148	-0.062
Stitch density	0.821	-0.400	-0.151	Tightness	0.875	-0.024	0.364
Fabric thickness	0.629	0.439	0.599	Fabric thickness	0.055	0.954	0.019
Fabric weight	0.018	0.921	0.300	Fabric weight	-0.149	-0.842	-0.374
Fabric dimension	-0.566	-0.681	0.294	Fabric dimension	0.319	0.106	0.913
Washing cycles	0.404	0.593	-0.630	Washing cycles	-0.449	0.393	0.763

Appendix D

Change in area and change in UPF value of the fabrics after laundering process and Percentage of change in area and change in UPF value

Change in area and change in UPF value

CH20K	W0	W0	W1	W1	W3	W3	W5	W5
Structure	Area(cm2)	Avg UPF	Area(cm²)	Avg UPF	Area(cm²)	Avg UPF	Area(cm²)	Avg UPF
Cross tuck	225.00	11.11	216.00	13.61	212.22	14.05	208.32	15.43
Cross miss	225.00	22.29	204.00	24.59	203.68	26.96	203.52	30.02
Double cross tuck	225.00	13.58	211.14	14.80	210.27	16.59	207.90	18.02
Double cross miss	225.00	27.11	210.00	31.66	208.81	30.98	206.98	32.15
Lacoste	225.00	16.21	202.16	19.37	201.60	18.66	200.96	19.66
Weft Locknit	225.00	16.93	208.50	22.44	206.72	21.82	205.02	25.16
Plain Knit	225.00	12.00	220.10	13.27	214.88	14.82	210.38	15.94

MCG20	W0	W0	W1	W1	W3	W3	W5	W5
Structure	Area(cm2)	Avg UPF	Area(cm²)	Avg UPF	Area(cm²)	Avg UPF	Area(cm²)	Avg UPF
Cross tuck	225.00	11.57	221.85	12.30	217.00	12.27	211.90	14.37
Cross miss	225.00	18.66	215.09	20.23	212.35	21.52	209.76	23.18
Double cross tuck	225.00	12.27	219.20	14.19	214.88	16.55	211.20	17.72
Double cross miss	225.00	20.01	218.68	21.94	213.90	23.04	210.60	24.87
Lacoste	225.00	11.09	212.35	14.06	211.14	14.93	209.04	15.16
Weft Locknit	225.00	13.52	209.61	17.10	209.76	18.87	208.38	19.43
Plain Knit	225.00	9.00	223.20	10.37	217.83	11.63	213.90	13.48

Percentage of change in area and change in UPF value

CH20K	W0		W1		W3		W5	
Structure	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)
Cross tuck	0	0.00	-4.00	22.44	-5.68	26.47	-7.41	38.87
Cross miss	0	0.00	-9.33	10.30	-9.48	20.93	-9.55	34.69
Double cross tuck	0	0.00	-6.16	9.00	-6.55	22.20	-7.60	32.69
Double cross miss	0	0.00	-6.67	16.77	-7.20	14.27	-8.01	18.59
Lacoste	0	0.00	-10.15	19.47	-10.40	15.09	-10.68	21.28
Weft Locknit	0	0.00	-7.33	32.54	-8.12	28.87	-8.88	48.58
Plain Knit	0	0.00	-2.18	10.59	-4.50	23.53	-6.50	32.86

MCG20	W0		W1		W3		W5	
Structure	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)	Area(Δ in %)	UPF(Δ in %)
Cross tuck	0	0.00	-1.40	6.34	-3.56	6.05	-5.82	24.17
Cross miss	0	0.00	-4.40	8.39	-5.62	15.31	-6.77	24.18
Double cross tuck	0	0.00	-2.58	15.61	-4.50	34.79	-6.13	44.34
Double cross miss	0	0.00	-2.81	9.65	-4.93	15.14	-6.40	24.30
Lacoste	0	0.00	-5.62	26.70	-6.16	34.55	-7.09	36.64
Weft Locknit	0	0.00	-6.84	26.53	-6.77	39.56	-7.39	43.73
Plain Knit	0	0.00	-0.80	15.19	-3.19	29.28	-4.93	49.78

Appendix E

Kawabata Evaulation System - Surface property and compressional property, and SPSS generated data

Data of surface and compression properties

Sample No.	UPF	MIU (Coefficient of friction)	MMD (Mean Deviation of MIU)	SMD (Geometrical Roughness)	LC (Linearity)	WC (Compressional Energy)	RC (Resilience)	T_0 (Thickness at 0.5gf/cm^2 (mm))
CH1-0	11.11	0.29	0.018	4.04	0.35	0.62	41.08	1.82
CH2-0	22.29	0.31	0.018	3.24	0.34	0.60	37.71	1.86
CH3-0	13.58	0.31	0.021	5.88	0.39	0.69	40.47	1.98
CH4-0	27.11	0.32	0.016	6.90	0.35	0.56	40.01	1.80
CH5-0	16.21	0.36	0.024	8.36	0.40	0.63	39.84	1.90
CH6-0	16.93	0.29	0.016	3.12	0.36	0.56	40.59	1.68
CH7-0	12.00	0.29	0.018	6.78	0.35	0.50	37.32	1.51
CH1-1	13.61	0.30	0.019	4.09	0.34	0.64	36.12	1.95
CH2-1	24.59	0.31	0.018	3.34	0.37	0.66	35.96	1.95
CH3-1	14.80	0.32	0.021	6.09	0.41	0.67	39.56	1.99
CH4-1	31.66	0.33	0.016	7.15	0.36	0.61	35.88	1.95
CH5-1	19.37	0.37	0.024	8.49	0.38	0.63	37.64	2.05
CH6-1	22.44	0.30	0.016	3.22	0.38	0.63	37.99	1.83
CH7-1	13.27	0.31	0.021	7.77	0.35	0.50	37.56	1.58
CH1-3	14.05	0.30	0.017	4.39	0.37	0.63	34.20	1.87
CH2-3	26.96	0.33	0.015	3.60	0.37	0.59	33.57	1.88
CH3-3	16.59	0.33	0.019	6.89	0.43	0.71	37.03	2.03
CH4-3	30.98	0.33	0.014	6.66	0.37	0.59	35.75	1.89
CH5-3	18.66	0.39	0.024	8.24	0.40	0.57	38.41	1.96
CH6-3	21.82	0.32	0.019	5.92	0.38	0.55	37.11	1.72
CH7-3	14.82	0.32	0.018	8.33	0.37	0.58	31.35	1.66
CH1-5	15.43	0.29	0.018	4.62	0.37	0.64	36.95	1.90
CH2-5	30.02	0.34	0.013	4.43	0.38	0.65	33.53	1.94
CH3-5	18.02	0.35	0.020	7.82	0.39	0.76	37.76	2.19
CH4-5	32.15	0.33	0.016	7.42	0.36	0.62	34.13	1.92
CH5-5	19.66	0.38	0.026	9.92	0.38	0.63	35.26	2.03
CH6-5	25.16	0.33	0.018	6.20	0.35	0.59	34.83	1.85
CH7-5	15.94	0.31	0.018	8.43	0.38	0.57	36.43	1.64
MCG1-0	11.57	0.29	0.016	4.56	0.35	0.60	43.46	1.81
MCG2-0	18.66	0.27	0.013	2.79	0.36	0.69	37.51	1.83
MCG3-0	12.27	0.32	0.020	8.26	0.43	0.74	43.42	1.95

Data of surface and compression properties (Cont'd)

MCG4-0	20.01	0.28	0.014	5.43	0.37	0.65	38.18	1.75
MCG5-0	11.09	0.33	0.024	7.59	0.44	0.69	41.75	1.85
MCG6-0	13.52	0.30	0.022	4.22	0.37	0.61	39.71	1.64
MCG7-0	9.00	0.27	0.025	5.90	0.37	0.52	35.61	1.45
MCG1-1	12.30	0.31	0.016	4.86	0.41	0.71	36.95	1.90
MCG2-1	20.23	0.29	0.013	2.92	0.43	0.72	36.18	1.81
MCG3-1	14.19	0.33	0.020	7.51	0.45	0.82	38.97	2.14
MCG4-1	21.94	0.29	0.014	5.73	0.38	0.67	35.63	1.86
MCG5-1	14.06	0.34	0.024	8.59	0.43	0.65	42.35	1.91
MCG6-1	17.10	0.30	0.022	4.72	0.41	0.55	42.94	1.60
MCG7-1	10.37	0.29	0.020	5.96	0.36	0.55	34.13	1.55
MCG1-3	12.27	0.33	0.017	5.15	0.39	0.74	35.56	2.01
MCG2-3	21.52	0.31	0.013	3.29	0.40	0.74	32.74	1.91
MCG3-3	16.55	0.35	0.018	7.86	0.43	0.82	34.58	2.21
MCG4-3	23.04	0.31	0.015	6.10	0.39	0.67	34.03	1.85
MCG5-3	14.93	0.37	0.022	9.84	0.44	0.73	35.83	2.03
MCG6-3	18.87	0.31	0.021	5.47	0.39	0.61	35.02	1.71
MCG7-3	11.63	0.31	0.019	6.26	0.37	0.68	30.75	1.69
MCG1-5	14.37	0.34	0.017	5.77	0.41	0.78	34.28	2.02
MCG2-5	23.18	0.33	0.012	3.67	0.41	0.69	33.96	1.84
MCG3-5	17.72	0.35	0.017	7.53	0.41	0.87	35.32	2.34
MCG4-5	24.87	0.32	0.013	7.03	0.40	0.68	33.77	1.83
MCG5-5	15.16	0.37	0.021	11.69	0.41	0.70	36.13	2.07
MCG6-5	19.43	0.31	0.022	6.28	0.39	0.64	34.53	1.74
MCG7-5	13.48	0.33	0.015	6.33	0.41	0.67	31.47	1.61

Measured UPF vs Predicted UPF of yarn type CH

Sample No.	Measured UPF	Predicted UPF	Difference (%)
CH1-0	11.11	19.71	77.40%
CH2-0	22.29	21.38	-4.10%
CH3-0	13.58	16.49	21.43%
CH4-0	27.11	23.89	-11.89%
CH5-0	16.21	14.73	-9.10%
CH6-0	16.93	21.94	29.61%
CH7-0	12.00	18.45	53.75%
CH1-1	13.61	20.79	52.78%
CH2-1	24.59	20.14	-18.09%
CH 3-1	14.80	17.68	19.45%
CH4-1	31.66	24.62	-22.23%
CH5-1	19.37	18.82	-2.86%
CH6-1	22.44	20.47	-8.78%
CH7-1	13.27	16.45	23.97%
CH1-3	14.05	20.69	47.26%
CH2-3	26.96	25.68	-4.75%
CH3-3	16.59	18.71	12.79%
CH4-3	30.98	26.66	-13.95%
CH5-3	18.66	20.04	7.41%
CH6-3	21.82	20.02	-8.25%
CH7-3	14.82	17.10	15.38%
CH1-5	15.43	19.41	25.82%
CH2-5	30.02	25.36	-15.54%
CH3-5	18.02	18.72	3.88%
CH4-5	32.15	23.59	-26.64%
CH5-5	19.66	16.25	-17.35%
CH6-5	25.16	22.36	-11.11%
CH7-5	15.94	16.86	5.80%
		Avg	7.93%
		Avg (absolute value)	20.41%
		Max	77.40%
		Min	-26.64%

Measured UPF vs Predicted UPF of yarn type MCG

Sample No.	Measured UPF	Predicted UPF	Difference (%)
MCG1-0	11.57	21.73	87.78%
MCG2-0	18.66	20.07	7.56%
MCG3-0	12.27	13.73	11.93%
MCG4-0	20.01	19.34	-3.35%
MCG5-0	11.09	8.79	-20.73%
MCG6-0	13.52	11.12	-17.77%
MCG7-0	9.00	8.73	-3.03%
MCG1-1	12.30	17.61	43.16%
MCG2-1	20.23	17.86	-11.70%
MCG3-1	14.19	13.98	-1.45%
MCG4-1	21.94	20.82	-5.11%
MCG5-1	14.06	13.39	-4.78%
MCG6-1	17.10	13.49	-21.10%
MCG7-1	10.37	13.51	30.28%
MCG1-3	12.27	18.10	47.52%
MCG2-3	21.52	19.29	-10.37%
MCG3-3	16.55	17.75	7.24%
MCG4-3	23.04	20.08	-12.83%
MCG5-3	14.93	14.09	-5.62%
MCG6-3	18.87	13.48	-28.55%
MCG7-3	11.63	10.40	-10.58%
MCG1-5	14.37	15.29	6.42%
MCG2-5	23.18	21.80	-5.94%
MCG3-5	17.72	18.73	5.71%
MCG4-5	24.87	20.03	-19.46%
MCG5-5	15.16	18.02	18.83%
MCG6-5	19.43	11.04	-43.17%
MCG7-5	13.48	13.33	-1.11%
		Avg	1.42%
		Avg (absolute value)	17.61%
		Max	87.78%
		Min	-43.17%

Residuals Statistics of surface and compression properties

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	8.7268	26.6578	18.0814	4.14131	56
Residual	-1.01551E1	8.56536	.00000	4.00115	56
Std. Predicted Value	-2.259	2.071	.000	1.000	56
Std. Residual	-2.468	2.082	.000	.972	56

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