THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學
Pao Yue-kong Library
包玉剛圖書館

Copyright Undertaking

This thesis is protected by copyright, with all rights reserved.

By reading and using the thesis, the reader understands and agrees to the following terms:

1. The reader will abide by the rules and legal ordinances governing copyright regarding the use of the thesis.
2. The reader will use the thesis for the purpose of research or private study only and not for distribution or further reproduction or any other purpose.
3. The reader agrees to indemnify and hold the University harmless from and against any loss, damage, cost, liability or expenses arising from copyright infringement or unauthorized usage.

IMPORTANT

If you have reasons to believe that any materials in this thesis are deemed not suitable to be distributed in this form, or a copyright owner having difficulty with the material being included in our database, please contact lbsys@polyu.edu.hk providing details. The Library will look into your claim and consider taking remedial action upon receipt of the written requests.

Pao Yue-kong Library, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

http://www.lib.polyu.edu.hk

This thesis in electronic version is provided to the Library by the author. In the case where its contents is different from the printed version, the printed version shall prevail.

THE HONG KONG POLYTECHNIC UNIVERSITY

INSTITUTE OF TEXTILES AND CLOTHING

A STUDY ON ULTRAVIOLET PROTECTION FACTOR OF COTTON AND COOLMAX BASED ON PLAIN KNITTED STRUCTURE

Yam Lim Yung

A thesis submitted in partial fulfillment of the requirements

for the degree of Master of Philosophy

December 2012

CERTIFICATE OF ORGINALITY

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

____ (Signed)

___YAM Lim Yung_________________________ (Name of student)

ABSTRACT

In order to prevent human from the acute and chronic effects bring out by ultraviolet radiation (UV radiation), plain knitted clothing becomes a feasible alternative to prevent direct contact with UV radiation. One of the main features of knitted fabric is its certain elasticity that different from woven structure, given they are produced from same type of fibre and yarn. Such extension may favour wearer from ease of body movement.

Fifteen types of plain knitted samples were produced from normal cotton, Supima cotton (both conventional and torque-free ring spun yarn of 20Ne and Coolmax yarn of 150dtex. These samples were divided into three groups, single cotton yarn (Group I), two cotton yarns combination (Group II) and Coolmax and cotton yarns combination (Group III).

Ultraviolet protection factor (UPF) of samples in each group were measured in the following conditions, (a) dry and relax, (b) dry and stretch, (c) wet and relax and (d) wet and stretch. Furthermore, there were three different level of stretching, i.e. 10%, 20% and 30% stretching in both machine and cross-machine directions. Samples were wetted separately with five types of solutions including (a) chlorinated pool water, (b) sea water, (c) acidic perspiration, (d) alkaline perspiration and (e) deionized (D.I.) water respectively.

The UPF values at dry and relax state of Group III was the highest while Group II and Group III came second and third. When it was in dry and stretch state, UPF of all Groups dropped and the decrease in rating is most severe in 30% stretching then 20% and 10%. While samples subjected to wetting and measured in relax condition, UPF was further reduced. UPF measured at wet and stretch state were the lowest among four testing conditions.

Statistical regression models were used to predict UPF at the four different conditions by using Tightness Factor, Pore size ratio, Stitch density and Fibre combination. The coefficients of determination (R^2) of all the models were all over 0.81. It could be concluded that these models are a successful tool for predicting UPF of cotton and Coolmax/cotton blends at different possible real-life wearing conditions.

LIST OF PUBLICATIONS

Journal

[1] E.L.Y. Yam, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu and C.W.M. Yuen, "The Relationship between Ultraviolet Protection Factor and Fibre Content", Journal of Textile Engineering (Submitted)

[2] L.Y. Yam, L.L. Lau, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu, C.W.M. Yuen, "The Influence of Fibre Content of Knitted Fabric on the Ultraviolet Radiation Protection Property", Advanced Materials Research, Vol. 550-553, 3241-3244, July (2012).

[3] L.Y. Yam, R.H. Yang, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu, C.W.M. Yuen, "Effect of Ultraviolet Radiation on Textile Fiber – A Review", Journal of Modern Textile Science and Engineering, Vol. 2,No. 1, 42-50 (2011).

Conference

[1] L.Y. Yam, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu and C.W.M. Yuen,"The Relationship Between Ultraviolet Protections Factor and Fibre Content", Proceedings of the TRS 2012, The 41st Textile Research Symposium, University of Minho, Guimarães, Portugal, September 12-14, 2012, pp.391-393.

[2] L.Y. Yam, L.L. Lau, C.W. Kan, J.K.C. Lam, S.P. Ng, H. Hu, C.W.M. Yuen,"The Influence of Fibre Content of Knitted Fabric on the Ultraviolet Radiation Protection Property", Programme Book of The 2012 International Conference on Chemical Engineering and Advanced Materials, Nanyang King's Gate Hotel, Guangzhou, China, July 13-15, 2012, pp.10.

ACKNOWLEDGMENTS

I would like to express my gratitude in sincerity to my chief supervisor, Dr. C. W. KAN, Associate Professor of Institute of Textiles and Clothing at The Hong Kong Polytechnic University, for his comprehensive assistance, patience, valuable opinion and encouragement. Dr. KAN's guidance is invaluable throughout the research study.

I want to express my gratefulness to my co-supervisors, Dr. H. HU, Associate Professor of Institute of Textiles and Clothing at The Hong Kong Polytechnic University and Dr. K. C. LAM, Teaching Fellow of Institute of Textiles and Clothing at The Hong Kong Polytechnic University.

I express my sincere thanks to Ms. M. N. SUN of Fabric Objective Measurements Laboratory and Mr. K. O. CHOI of Physical Testing Laboratory of the Institute of Textiles and Clothing for their kind assistance and valuable advice in experimental work.

Finally, I acknowledge with thankfulness and respect of the late Dr. K. F. CHOI for his supervision in my final year project and would like to say thank you wholeheartedly to my parents and brother, Julian L. F. LEE, friends and group mates, for their support and encouragement for my study.

TABLE OF CONTENTS

References

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CH	Normal Cotton, Conventional ring spun (yarn/fabric)
CH_F	Normal Cotton, Conventional ring spun &
	Supima Cotton, Conventional ring spun (yarn/fabric)
CH_MCG	Normal Cotton, Conventional ring spun &
	Normal Cotton, Torque-free ring spun (yarn/fabric)
CH_MF	Normal Cotton, Conventional ring spun &
	Supima Cotton, Torque-free ring spun (yarn/fabric)
CIE	International Commission on Illumination
CM	Coolmax
CM_CH	Coolmax &
	Normal Cotton, Conventional ring spun (yarn/fabric)
CM_F	Coolmax &
	Supima Cotton, Conventional ring spun (yarn/fabric)
CM_MCG	Coolmax &
	Normal Cotton, Torque-free ring spun (yarn/fabric)
CM_MF	Coolmax &
	Supima Cotton, Torque-free ring spun (yarn/fabric)
D.I. water	deionized water
F	Supima Cotton, Conventional ring spun (yarn/fabric)
F_MF	Supima Cotton, Conventional ring spun &
	Supima Cotton, Torque-free ring spun (yarn/fabric)
MCG	Normal Cotton, Torque-free ring spun (yarn/fabric)

MCG_F	Normal Cotton, Torque-free ring spun & Supima Cotton, Conventional ring spun (yarn/fabric)
MCG_MF	Normal Cotton, Torque-free ring spun & Supima Cotton, Torque-free ring spun (yarn/fabric)
MED	minimum erythema dose
MF	Supima Cotton, Torque-free ring spun (yarn/fabric)
MLR	multiple linear regression
PET	polyethylene terephthalate
SPF	sun protection factor
SPSS	"Statistical Product and Service Solutions" software
UPF	Ultraviolet Protection Factor
UV	Ultraviolet
UV radiation	Ultraviolet radiation
WVT	water vapour transmission

Chapter 1 INTRODUCTION

1.1 Background of Study

The public has always been reminded to avoid any excessive and unnecessary sun exposure, in order to prevent human from the acute and chronic effects bring out by ultraviolet radiation (UV radiation). From the epidemiological perspective, using sunscreen is commonly accepted as a mean to avoid actinic keratoses and squamous cell etc. However, there are some disadvantages including discomfort, frequent reapplication and potential skin allergy. Furthermore, most sunscreens on the market provide less protection for UV-A (315-400nm) than for UV-B (280-315nm) as UV-B has the highest skin damage potential (Algaba and Riva, 2002). Applying UV-B protective sunscreens may eventually lead to increased UV-A exposure since reduced sunburn allow people to stay even longer under the sun might have an increased risk of catching melanomas and nevi.

Following the line of reasoning, wearing clothing textile would become a feasible alternative to sunscreens, especially for people who must work outdoors during the hours of maximum intensity from 10 am to 2 pm (Hustvedt and Crews, 2005). UV radiation is the main environmental factor for a direct relationship with skin cancer, disregarding genetic factor (Ferrini *et al*., 1998; Tenkate, 1998) and that is the reason of regulating well-designed clothing made from UV radiation blocking textiles.

Because of its light weight, cotton fabric and some kind of synthetic fabric made of filament yarns are ideal material for clothing especially for summer days and have been opted by the public.

Most of the previous researches have been focused on some factors such as fibre type, dyes, finishing processes and fabric porosity to resist UV radiation (Abidi *et al*., 2001; Capjack *et al*., 1994; Crews *et al*., 1999; Pailthorpe, 1994; Reinert *et al*., 1997; Zhou and Crews, 1998). Nevertheless, in the recent years, the thinking of the other side of industrial revolution has made people realize that there is an urgent need to protect the environment. This eco-awareness has led to the revival of reduction chemical processes and treatments.

In addition, chemicals such as titanium oxide (TiO_2) and zinc oxide (ZnO) are used in increasing UV protection property of textiles mainly for synthetic fibres, which can be incorporated with chemicals during manufacturing processes. It was not comfortable to wear garment made of pure conventional synthetic fibre, such as polyester which is hydrophobic in nature. Chemicals cannot be incorporated in the way in natural fibre. Surface coating is an alternative to apply these chemicals onto cotton, however, coatings might trigger damages on textile materials or allergic reactions on human skin can happen in tight and sweaty situation, especially in summer days. Therefore, a proper and innovative method needs to be developed to enhance UV protection property on knitted fabric by choosing suitable fibre content.

There were only a few researches (Algaba *et al*., 2007; Laperre *et al.*, 2001; Osterwalder *et al*., 2000) studied on the relationship between fibre composition, stretch condition and moisture content on knitted structures to against UV radiation transmission. Obviously, the unique characteristics of knitted fabric in both wetted state and stretched state did provide area to explore. This research will focus on textile engineering approach on knitted fabrics against UV transmission.

1.2 Objectives

It is clear that all clothing provide certain degree of UV protection. This project is aimed at studying the knitted fabric at textile engineering level such as fibre combination to investigate protective properties instead of through chemical finishing or wet processing to enhance UV radiation protection. Two points that are especially important for optimized summer apparel are lightweight and maximum UV protection.

This project will have the following objectives guiding to the goal:

- To study the protective ability of cotton and Coolmax combinations against UV radiation.
- To examine the relationships of stretch conditions and textiles' corresponding UV

protective ability.

- To understand the effect of moisture content level of fibre in influencing the UV protection behaviour by means of a series of experiment studies.
- To predict UPF at different conditions by statistical regression models.

1.3 Scope of Study

This research project focus would be on fibre and yarn aspects and study UPF at engineering level instead of chemical treatment approaches.

As fibre is the fundamental basic of constituting yarns and fabrics. In textiles, UPF is strongly dependent on the chemical structure of the fibres. The nature of the fibres influences the UPF as they have different chemical composition.

Besides, presence of moisture on clothing may also affect UPF. Level of influence largely depends on the type and moisture regain of fibres, as well as conditioning time, which result in swelling phenomena.

Human perspires to release heat from the body. However, absorption of perspiration may affect the UPF of clothing. A series of test will be carried out to find out the relationship between fibre types and moisture content level. In order to better understand the relationship of perspiration and UPF, man-made perspiration solutions will be employed for evaluation corresponding ratings. Furthermore, the effect of wetting with chlorinated pool water, sea water, and deionized water will also be studied.

For the sake of better comprehending UPF and stretching of fabrics under exposure in UV radiation with or without wetted with various types of solutions will also be studied.

1.4 Methodology

To achieve the objectives of the project, the following research methodology will be employed:

- To study the relationship between yarn structure and UV radiation transmission by a series of physical testing. The physical aspect including but not limited to yarn tenacity, yarn strength and twist number will be examined.
- To study the relationship between moisture content of fibres and UV radiation transmission at different moisture level.
- To simulated actual wearing condition and corresponding UPFs by stretching fabric at different percentage and immense fabrics in various solutions.

1.5 Project Significance and Value

The best technique for reducing UV exposure is to avoid sun exposure, but this is not a generally acceptable solution to all. Recreational exposure accounts for most of the significant UV radiation exposures of the population, and occupational exposure is also significant. And there is growing interest in reducing the UV radiation exposure of outdoor workers.

As there is rising concern over protecting human from uncontrolled exposure to UV radiation transmission. It is reasonable to study UV radiation transmission of different textile materials. This is the fundamental supporting for this project. This project will benefit the knitwear manufacturer and sportswear producer in the global textile industries and will definitely strengthen the research background and reputation in the textile technology regime.

Chapter 2 LITERATURE REVIEW

2.1 Introduction

This chapter will provides a review on UV radiation, fibre content, factors affecting UV radiation transmission and previous works on using clothing as protection against UV radiation. Measurement methods of Ultraviolet Protection Factor (UPF), both *in vivo* and *in vitro* would also be discussed.

2.2 Understanding Ultraviolet Radiation

The human eye only responds to light with wavelength from about 790nm (red) to 430 nm (violet) while wavelength from 100 to 400nm in the electromagnetic spectrum were the ultraviolet radiation (UV radiation).

The ultraviolet light is produced by sun and mostly absorbed by the ozone layer or reflected back into space, thus only a small amount reaches the earth surface. It is light with wavelength beyond ultraviolet and shorter than human eye identifying capacity.

It is commonly to further subdivided the UV spectrum into three regions, which are UV-A (315-400nm), UV-B (280-315nm), and UV-C (100-280nm) according to the AS/NZS 4399:1996 Standard. International Commission on Illumination (CIE) distinguished UV radiation ranging from 280 to 400 nm and defined UV radiation as radiant energy for which the wavelengths of the monochromatic components are smaller than those for visible radiation and more than about 100 nm (AATCC Test 183). Table 2-1 shows classifications, wavelength elative intensities and average photon energies of UV radiation.

Table 2-1 Wavelengths, relative intensities and average photon energies of radiation.

Classification	**Wavelength (nm)**	**Relative intensity (%)**	**Average photon energy (kJ mol^{-1})**
UV-B radiation	280-320	0.5	400
UV-A1 radiation	320-360	2.4	350
UV-A2 radiation	360-400	3.2	315
Visible radiation	400-800	51.8	200
Infrared radiation	800-3000	42.1	63

(Laga and Wasif, 2010)

UV-C is completely absorbed by the ozone and oxygen of atmosphere, so it could not reach the earth. UV-B, approximately 50 % presents at surface of earth (Gies *et al.*, 1992), is most responsible for the development of skin cancers (Yadav and Karolia, 2011). About 95 % UV-A reached the earth's surface that cause little visible reaction on the skin but has been shown to decrease the immunological response of skin cells. Overexposure to UV-A radiation produces similar chronic and collateral effects to those produced by UV-B radiation, although the required doses are higher (Algaba and Riva, 2002). The energies of UV-A and UV-B photons that reaches the earth surface exceed the carbon-carbon single bond energy of 335 kJ mol^{-1}, which explains the reason for UV radiation could initiate chemical reactions. Compared with the 340 to 400 nm portion of the UV-A spectrum, the 280-300nm portion of the UV-B spectrum is about 1000 times more erythmogenic (Wang *et al*., 2001). A decrease of 1 % in ozone layer would allow more solar UV radiation reach the earth's surface and may eventually lead to a 2.3 % increase in the chance of skin cancer (Viková, 2004). The actual damage to human skin from UV radiation is a function of the wavelength of the incident radiation, with the most damage done by radiation around 308nm (Reinert *et al*., 1997).

2.2.1 Measurement of UV Transmission

Measurement of UV transmission is an essential part of studying the protective ability of clothing against UV radiation. Two categories of measurement, i.e. *in vivo* and *in vitro*, have hitherto been widely recognized among scholars. A thoroughly understanding of the correlation and accuracy of the two methods is thus required.

2.2.1.1 *In vivo* Measurement

The *in vivo* method is closely similar to the method used to assess the effectiveness of sunscreen lotions in order to determine the sun protection factor (SPF) of an element. "The degree of protection that an element provides against the adverse effects of sunlight is commonly known as the solar protection factor" (Algaba and Riva, 2002). It is defined as the threshold time takes for an erythema (injury to the tissue causing redness to skin) to occur with a protective element applied, divided by the threshold time for the erythema to occur without any protection means. For example, when the skin of a person becomes red after 15 minutes exposure to the sun, by using a protective element such as sunscreen with a protection factor of 20 the reddening will appear after 300 minutes of exposure (Riva, 1999).

The *In vivo* measurement method use human skin as test indicator and measures the minimum erythema dose (MED) of UV radiation. Artificial sources was used and to measure the MED for 24 hours, incremental UV-B doses were used to irradiate the test human unprotected skin on one side of the upper back, and the protected skin where the fabric in place on the other side of the upper back. The UV-B dose for unprotected skin was determined based on the skin photo type. The incremental UV-B dose for the protected skin was determined by multiplying the UV-B dose for the unprotected skin with the fabric *in vitro* UPF value. The ratio of the MED of the protected skin to the MED of the unprotected skin is the *in vivo* UPF (Hoffmann *et al*., 2001a). An *in vivo* test was carried out to confirm the UPF values measured from *in vitro* test (Hoffmann *et al*., 2001a). Impracticality and cost involved were the main limitations of the approach, as it gave a direct response of human skin to UV radiation, and human judgments were required when erythema appear. (Hoffmann *et al*., 2001; Capjack *et al*., 1994)

2.2.1.2 *In vitro* Measurement

Spectrophotometric method is the main approach under *in vitro* measurement. Direct and diffuse UV transmittance through a fabric is a crucial factor in determining the UV protection ability of textiles (Yadav and Karolia, 2011). The transmission of UV radiation through a specimen was measured under a spectrophotometer or spectroradiometer at known wavelength intervals.

The UPF value is computed as the ratio of the erythemally weighted UV radiation irradiance at the detector with no specimen to the erythemally weighted UV radiation irradiance at the detector with a specimen present. The advantage of this method was that it could properly account for any spectral variations in the absorption spectrum of the sample (Capjack *et al.*, 1994) and the reproducibility and repeatability were high. However, one of the shortcomings was calibration had to be done regularly, filters had to be used to block the UV induced fluorescence from the specimen to ensure accuracy of the measurement (Xia, 2004). An *in vitro* method for the calculation of the UPF of textile was described in a European standard, EN 13758 Textiles, Solar UV Protective Properties Part 1. Methods of Test for Apparel Fabrics. The standard described a method for the determination of the erythermally weighted UV radiation transmittance of apparel fabrics to assess solar UV protective properties. (Gambichler *et al.*, 2001b).

2.2.1.3 Accuracy of *in vivo* and *in vitro* Measurements

Menzies *et al*. (1992) examined six fabrics based on *in vitro* spectrophotometric methods and compared with the results of *in vivo* test on human subjects. They found that agreement between the two different test methods was good if the fabrics were positioned a few millimeters off the skin. Agreement was not good when the fabrics were on skin without gap in between. Menzies *et al*. (1992) concluded this was primarily due to the fabric structure provided a clear path, i.e. the openness area for the UV radiation to irradiate the skin in some areas while the yarn and fibre completely blocked the UV radiation in other areas. They called this the 'hole effect' where there was non-uniform irradiance of the subject's skin due to the weaving structure of the fabric. When the fabric is placed further off the skin, the UV radiation is more diffused and the evenly irradiation of the skin, and the correlations between *in vivo* and *in vitro* tests are substantially strengthened.

Lowe *et al*. (1995) measured the UV radiation transmittances of a number of fabrics to determine protection factors. They impinged their human test subjects protected by the various garments with 10, 15 or 31 MED (minimum erythema dose), whichever was appropriate for the garment in question and examined the subjects for erythema 24 hours later. The garments were ranked pass or fail depend on whether any erythema was detected. They found that the summer-weight garments with *in vitro* protection factors of 10 or less failed the 10 and 15 MED exposures. However, the UV radiation protective clothing with *in vitro* protection factors of more than 30 passed the 31 MED exposure tests.

Ravishankar and Diffey (1997) conducted a research, which was testing both *in vivo* and *in vitro* methods on a life size mannequin with three different cotton T-shirts and exposed to the diffuse radiation from 48 fluorescent lamps. Ravishankar and Diffey (1997) found that the *in vivo* UPF of the garment was higher than *in vitro* UPF measured using collimated radiation. The incident angle of UV radiation was varied when compared from collimated beam. It was because higher scattering from increased path length through the specimen. At 45 degrees from normal, the UPF values were about 3 times higher than when irradiated from collimated radiation (Xia, 2004).

Gies *et al* (2000) found out several selected garments tested using either an *in vivo* SPF test or an *in vitro* UPF test would have achieved high degree of similarity protection factor rating in 14 out of the 15 cases tested in the study. Correlation between measured UPFs and SPFs were high within the acceptable measurement error and there was no significant statistical variation between SPFs and UPFs when analyzed as a group. Authors (Gies *et al*., 2000) pointed out that the UPF determinations did not overrate protection against solar UV radiation in comparison to

SPF testing.

In the same year, Hoffmann and his research coworkers (Hoffmann *et al*., 2000) carried out experiments by comparing results based on *in vivo* and *in vitro* methods and found out that depending on the type of fabrics, the determination of the UPF by the *in vitro* method was not in agreement with the *in vivo* method. *In vivo* measurements tend to make with lightweight specially treated UV protective textile showed in contrast to the untreated viscose fabrics that these garments offer very good protection against UV radiation. These results underscoring the importance of developing and refining the UV protective clothing.

Another research carried out by Laperre *et al.* (2001) involved eight laboratories, nine different measuring devices that located in five countries to test against the accuracy of the *in vitro* method. The result shown a difference of measurements among laboratories increased along with the UPF level, while the variance was little in the UPF range from 1 to 70 of each laboratory.

Gies *et al.* (1997) and Gambichler *et al.* (2001a,b) pointed out that an increasing variability for higher UPF levels was associated with *in vitro* spectrophotometric method. The finding may attributed to the large instrumental errors at very low UV transmittance levels (Xia, 2004).The other previous study (Menzies *et al*., 1992) shown that while the *in vivo* test conducted under “off skin” (2-4 mm away from skin) and "on skin" (fabric worn directly on skin) could yield quite different UPF values. Gambichler *et al*. (2001a) tested about 30 summer clothing mainly compose of woven fabrics found that *in vivo* "on skin" measurements were remarkably lower than the UPFs measured from *in vivo* "off skin". Such results confirmed with Menzies *et al*'s (1992) finding and had been attributed to an optical-geometrical effect, i.e. as there was a 2 to 4 mm away from skin, when the UV radiation penetrated through the "opening" of the specimen, there was a greater extends of diffuse because of scattering when there was space away from skin. Following the line of reasoning, when there was no gap between the fabric and skin, only a limited portion of scattering of the UV radiation and thus skin next to fabric will receive almost all the portion of the UV radiation (Gies *et al*., 1992; Kimlin *et al*., 1999).

In conclusion, employing *in vivo* measurement method was time consuming and relatively expensive. While, on the other hand, spectrophotometric method was more applicable in practice as long as the *in vitro* UPF values had a strong correlation with the *in vivo* UPF.

2.2.2 A Review on Testing Method for Protection against UV Radiation

There were several standards dealing with the procedure for the *in vitro* measurement of the UPF of textiles. In the calculations indicated in this section reference will be made to the first standard that appeared, the AS/NZS 4399:1996, developed jointly by

Australia and New Zealand, which forms the basis of other standards. Moreover, this standard will be used throughout the research for the UPFs measurement.

AS/NZS 4399:1996 Sun Protective Clothing: Evaluation and Classification (Table 2-2). The standard depicted measurement of UPF ratings on non-hydrated and unstretched specimen by employing a spectrophotometer to record UV transmission in the range of 290-400 nm wavelengths in spectrum. Requiring at least two samples in the warp and two in the weft directions and measuring each color separately. The area with the lowest cover factor forms of a textured fabric the sample should be tested. The UPF rating applies to the fabric rather than the garment design.

Table 2-2 AS/NZS 4339 UPF Classification System

UPF Range	UVR Protection Category	Effective UVR Transmission (%)	UPF Ratings
15 - 24	Good Protection	6.7 - 4.2	15, 20
25 – 39	Very Good Protection	4.1 – 2.6	25, 30, 35
40 – 50, 50+	Excellent Protection	<2.5	40, 45, 50, 50+

(AS/NZS 4399:1996)

A UPF rating indicates how much UV-R is blocked by a material. For example, a textile with a UPF rating of 20 would only allow 1/20th of the hazardous UV-R falling on its surface to pass through it, and therefore UV-R exposure will be reduced by a factor of 20. The UPF ratings of less than 15, between 15 and 50, and more than 50 (50+) are generally classified as bad, good, and excellent UV-blocking properties for textiles, respectively. A low UPF (less than 15) of cotton is inadequate protection for outdoor activities. Clothing with a greater UPF should be developed to provide high levels of UV protection in a variety of conditions (Wang *et al*., 2011).

Regarding the measurement parameter and the content of the standard, BS 7914:1998 Method of Test for Penetration of Erythemally Weighted Solar UV Radiation Through Clothing Fabrics was found very similar to the AS/NZS 4399 standard and the standard did not contain requirements for clothing product labeling.

BS 7949:1999 Children's Clothing: Requirements for Protection against Erythemally Weighted Solar Ultraviolet Radiation. This standard targeted for clothing for children aged between 6 months and applicable to both garment as well as fabric design. Based on the level of minimum coverage acceptable, three garment designs were defined accordingly and a maximum penetration of 2.5% was allowed for fabric (trimmings exclusive). Garments that pass the test were permanently labeled with reference to the standard and with the wording helps to prevent sunburn while a detachable label remind costumer apply sunscreen to uncovered areas of skin. Only UPF 40 or UPF 40+ was indicated, no exact rating would be provided (Yadav and Karolia, 2011).

UV Standard 80:1999 General and special conditions employed a harsher procedure than those aforementioned tests, which was issued by the International Testing Association for Applied UV Protection. Measurement of UV protection was determined using the erythermal effectiveness and irradiance spectrum (290-400nm) the same as shown in AS/NZS 4399:1996 standard. Measurements were made on both new fabric and fabric that had been gone through wear and tear condition as well, for example, after abrasion and stretched under tension and stretch under hydrated states. Stretch was obtained through tugging the fabric in both directions and the UPF rating was measured at the same time after elongation (Yadav and Karolia, 2011).

For measurements in the wet state, samples were immersed in solution and the UPF rating was then measure once excess moisture has drawn off and recorded after two minutes. Subsequent readings were made at two-minute intervals if the second reading was lower and continue the measurement until an increase or no further decrease was found (Yadav and Karolia, 2011).

AATCC Test Method 183-2000, Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation Through Fabrics. The standard described the specimens fabrics should be prepared before testing by being given 40 domestic washings and dryings, be exposed to stimulated light for a specified time and (for swimwear) be exposed to chlorine water for a specified time. Textiles tested according to AATCC 183 and intended for use for UV protection, should be labeled according to ASTM D 6603 Standard Guide for Labeling of UV-Protective Textiles that requires the UPF rating. The UPF rating and classification category are similar to those stated in AS/NZS 4399.

In 2000, ASTM D6544-00 appeared. Standard Practice for Preparation of Textiles Prior to UV Transmission Testing, which established standard methods of preparing samples in order to simulate two years seasonal use including washing and exposure to sunlight and chlorinated water before evaluating the UPFs (Algaba and Riva, 2002).

BS EN 13758-1:2002, Textiles - Solar UV Protective Properties - Part 1. Methods of Test for Apparel Fabrics: The standard describes a method for the determination of the erythermally weighted UV radiation transmittance of apparel fabrics to assess solar UV protective properties. The standard also requires specimen subject to wear and tear condition, especially for the stretch and wet state which was similar to the UV Standard 80:1999. Stretch condition including direction and force applied should be recorded.

BS EN 13758-2:2001, Textiles - Solar UV Protective Properties. Part 2: Classification and Marking of Apparel. The guidelines introduced a logo for outdoor items and suggested minimum requirements for the UV permeability and skin coverage of clothes, in order to give reasonable protection for an average person exposed to the sun in Europe. The sun-safety logo incorporating the standard number, EN 13758, and the UV protection factor 30+.

In conclusion, the UPF classification in accordance with AS/NZS 4399 was adopted in this research.

2.3 Properties of Fibres behave under UV Radiation

There are certain possible pathways for UV radiation distribution when it reached textile fabric. UV radiation can be reflected, absorbed and/or transmitted by fabric. Part of the radiation is absorbed by the fibres, i.e. it is converted to a different energy form (Alvarez and Lipp-Symonowicz, 2003), for example, synthetic fibre such as polyester. Another part of the radiation passes directly through the fabric via gaps between the fibres and yarns and this part is referred to as the 'transmission' (Gambichler *et al*., 2001a). Some radiation is reflected or scattered by the fibres, which may contribute to transmitted radiation if it is not absorbed by other fibres.

It seems that physico-chemical type of fibre is one of the key parameters influencing the UV protection ability. Several studies (Hoffmann, 2001; Pailthorpe, 1998 and Stanford, 1997) have reported the effect of fibre chemistry on UV protection properties of textiles. It has been found that fibres containing conjugated aromatic system of polymer chains, such as polyester, are more effective in UV absorption (Gambichler *et al*., 2001b; Crews *et al*., 1999; Davis *et al*., 1997).

Cellulose fibres (cotton, flax, viscose) have no double bonds in their chemical structure, thus have a low intrinsic UV absorption capacity providing relatively low

UV protection properties of textile fabrics made thereof (Gambichler *et al*., 2001b; Crews *et al*., 1999; Davis *et al*., 1997). However, natural pigments, pectin and waxes in natural cellulose fibers act as UV absorbers having a favorable effect on UPF of gray-state fabrics. Hustvedt and Crews (2005) first reported a comparatively higher UPF of naturally pigmented cotton fabrics and normal cotton.

2.3.1 General Mechanism of Photodegradation of Fibre

Energy associated with near-UV radiation was about 3.0–4.3 eV which correspond to 72–97 kcal/mol. Common covalent bonds encountered in polymers have bond dissociation energies which for the most part are in between or lower than this energy range. It is reasonable to assume the ultraviolet radiation, which is high energy and short wavelength to be more effective than visible light in promoting a wider range of photochemical reactions, as the photon energy is a function of the wavelength of radiation. For example, solar UV-B range (extending from about 280 nm to 320 nm) is well known to be the most deleterious wavelengths to polymers exposed to sunlight. Absorption of electromagnetic radiation is the prerequisite for photodegradation. (Andrady, 2007)

Provided the UV radiation is absorbed by the polymer and suitable pathways are available for the photo-excited singlet (S) and triplet (T) species to transfer the absorbed energy to trigger photochemical reactions, light-induced damage to the polymer can occur.

Combination of photodegradative and photo-initiated thermo-oxidative mechanisms leading to breakdown of polymers when fibre was irradiated in UV radiation with presence of oxygen (Andrady, 2007). In practical application, UV-visible irradiation would be carried out in air and oxygen played an important role in the photodegradation process. The photodegradation process could be generally separated into three stages, i.e. initiation, propagation and termination.

The initiation process starts by the generation of free radicals on absorption of radiation by polymers which contains a suitable chromophore (either as a part of macro-molecular structure or as an additive or impurity). Typically, the propagation reactions take place between the polymer radical species and either a polymer chain or oxygen. The macromolecular oxy radicals formed may undergo β scission or other reactions. At a given instant during photodegradation, the polymer substrate would contain a variety of macroradicals which may terminate by bimolecular interaction or unimolecular processes (Andrady, 2007).

2.3.1.1 Cotton Fibre

Cotton in the form of cloth suffices one of the basic necessities of the human population and it is the primary natural textile fibre produced in the world (Wakelyn *et al*., 2007).

Cotton is the most important natural textile fibre in the world. It is used to produce apparel, home furnishings, and industrial products. Worldwide about 40% of the fibre consumed was cotton according to the Fibre Economic Bureau, Inc., reported. The moisture regain ratio of cotton is about 8.5%, and cotton is a natural, renewable, biodegradable and sustainable fibre. It is good for people with sensitivity to certain chemicals and can be grown organically and recycled. Fabric can be made out of the cotton that is otherwise wasted during the process of making it into cloth.

2.3.1.2 Photodegradation of Cotton

It has been known that the degradative effect of light on cotton was chemical in nature and lead to the formation of carboxyl and carbonyl groups along the cellulose chain (Philips and Arthur, 1964). Two main mechanisms lead to photodegradation effect were direct photolysis and photosensitized degradation process (Egerton, 1949).

Several academic reviews are available (Philips and Arthur, 1985; Phillips, 1980; Baugh and Philips, 1971; McKellar, 1971) suggested photochemistry involves the interaction of visible and ultraviolet light with cotton. To initiate a direct rupture of chemical bonds (Figure 2-1), the radiation of high energy must be absorbed by cellulose. For pure cotton, the cleavage of either carbon-carbon or carbon-oxygen bonds would require energy about 80-90 kcal/mole while for removing hydrogen atom would require about 100 kcal/mole (Launer and Wilson, 1949).

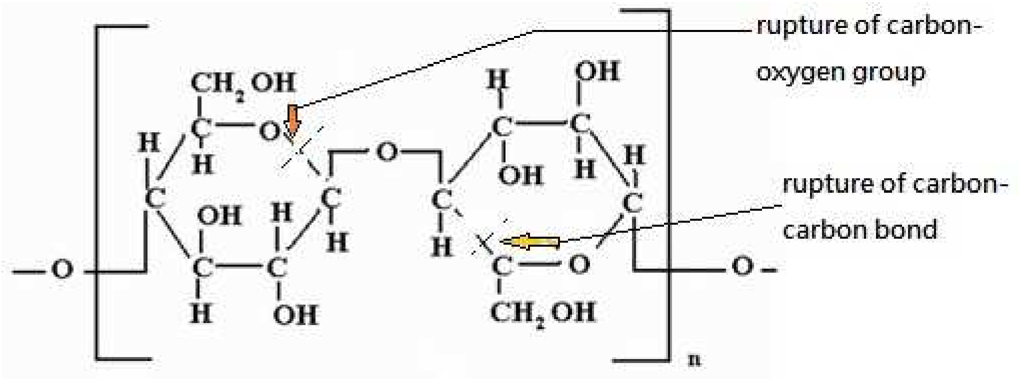


Figure 2-1 Rupture of chemical bonds in photodegradation of cotton

A saturated compound lacks the structural features required to absorb light in the visible spectrum. Light with wavelengths greater than 310 nm is not able to photolyse cotton directly (Philips and Arthur, 1949). Mercury emission at predominantly 254 nm can cause photodegradation and produce free radicals. Irradiated carbohydrates do form a species absorbing at 265 nm (Phillips *et al.*, 1977) that exhibits an autocatalytic influence. The direct photolysis of cellulose with 254 nm radiation results in degradation and is independent of the presence of oxygen (Egerton, 1949; Launer and Wilson, 1949). Changes are increase in the solubility, reducing power, the formation of carboxyl groups and decrease in polymerisation. Although light of wavelengths greater than 310 nm cannot degrade cotton directly, some other compounds such as dyes and some metallic oxides such as TiO_2 and ZnO can absorb near-ultraviolet radiation or visible light and in their excited states can induce the degradation of cotton. These reactions are designated photosensitized degradation but do not have a common mechanism.

2.3.1.3 Polyester Fibre (including Coolmax)

Polyester, an aromatic polyethylene terephthalate (PET), which is also a highly hydrophobic synthetic fibre (Figure 2-2), is known to have a high protective factor against transmittance of UV light because of the chemical applied during manufacturing.

Coolmax is a modified polyester fibre and containing cross-section of proprietary tetra channel. Coolmax fibre was known for their channels that pull moisture from the skin, the process was called wicking. The fabric absorbs and spreads moisture out across fabric to enhance evaporative drying rate because of increased surface area by 20% when compared with the yarn of the same linear density. At the same time air moved in to keep body dry and cool. Cotton on the other hand that absorb and retain fourteen times more moisture than Coolmax. Therefore, the engineered inherence moisture management properties make it suitable for summer light weight clothing (http://www.invista.com/en/brands/coolmax.html, 2012).

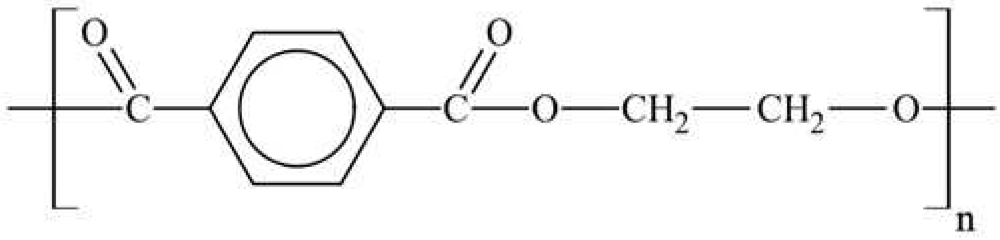


Figure 2-2 Chemical structure of polyester

2.3.1.4 Photodegradation of Polyester (including Coolmax)

Photochemical degradation of polyester in normal daylight spectrum is photolytic in nature, due to the direct absorption by the polymer of radiation at about 310 nm (Andrady, 2007; Lewin, 1998). The terephthaloyl groups absorb strongly in the region, so degradation is localised at the exposed surface and leads to development of surface cracks and formation of embrittlement. Chain scission is accompanied in the absence of oxygen by cross-linking, and in the presence of oxygen by hydroxylation of the aromatic ring to form hydroxyterephthaloyl groups. Carboxyl-carbonyl bond, carbon monoxide, and in the presence of oxygen, also carbon dioxide are the major products. The former two are accounted for the crosslinking and hydroxylation, and the consequent increase in color and fluorescence, is attributed to the formation of radicals on the aromatic ring. Day and Wiles (1972a-c) studied photochemical degradation of polyethylene terephthalate (PET). Mainly based on the analysis of volatile products (CO and CO_2) and on FTIR it was suggested that UV absorption by the aromatic ester group induced Norrish (types I and II) (Figure 2-3) photocleavage (Malanowski *et al.*, 2009).

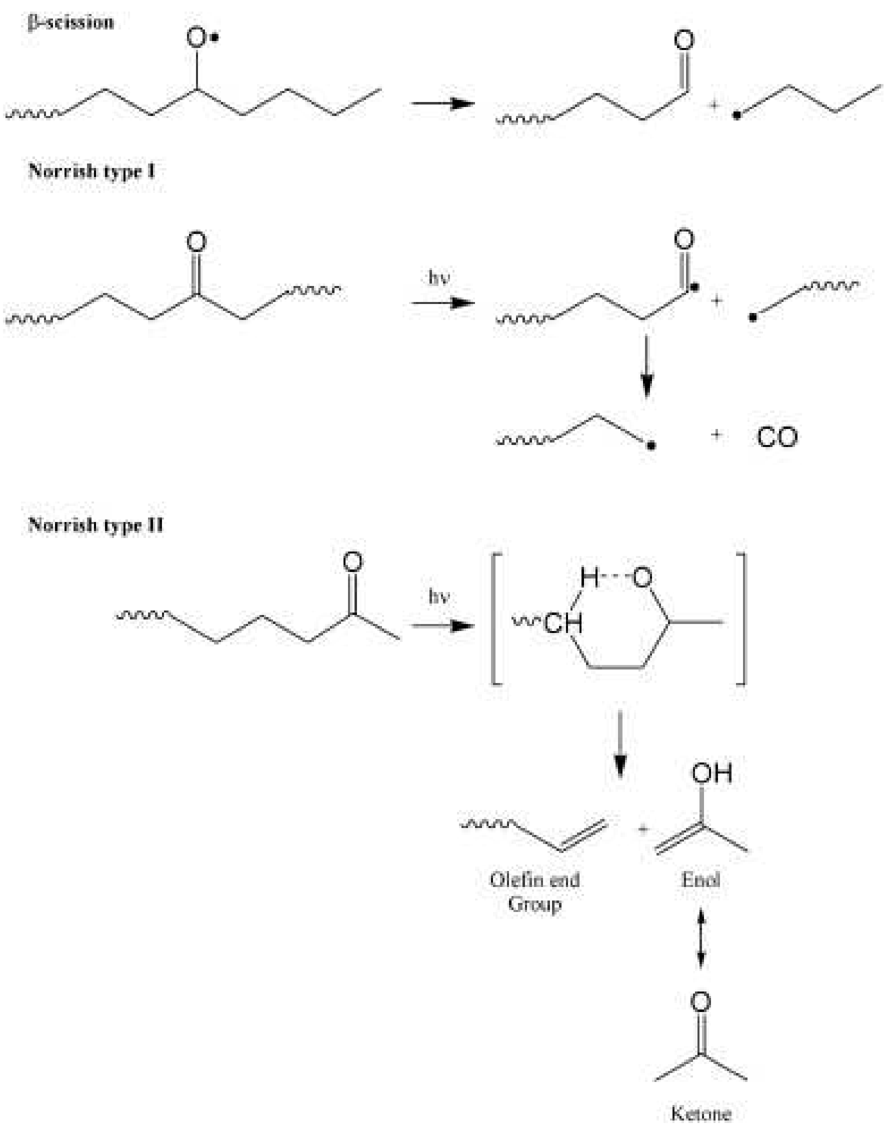


Figure 2-3 Typical photodegradation process (Ito and Nagaib, 2008)

2.4 Factors affecting Ultraviolet Protection Factor (UPF)

2.4.1 Fibre Content

Previous researches have been done to reveal fibre content that would influence clothing's ability against UV radiation (Crews *et al*., 1999; Stanford *et al*., 1995; Capjack *et al*., 1994). However, the other factors such as fabric construction, linear density of yarn, etc have not been controlled, so it was difficult concluded a relationship between fibre types and UPF of textiles.

A study done by Robson and Diffey (1990) indicated that satin or twill made with polyester were of very high UPF, because of the lustrous surface of polyester reflect large portion of incident radiation. Researchers (Robson and Diffey, 1990) further pointed out crepe structure made of polyester decreased UPF significantly because of the structure rather than the fibre type. Reinert *et al.* (1997) showed that undyed polyester had generally better UPF because the polyester fibre had high absorption of UV-B and the TiO_2 delustrant a chemical that strongly absorb UV radiation.

Davis *et al.* (1997) compared eight fabrics of different fibres but with similar structure, fabric count and color. Results showed that polyester samples yield a consistently high level of UPF whereas cotton samples were about 3 to 4 times lower UPF.

Crews *et al.* (1999) found out even polyester samples had the lowest mean cover factor value, they did not show the lowest UPF. The reason was that polyester fibre was very permeability to UV radiation and polyester processed higher absorption ability in the UV-B region inherently and the delustrants acted as a UV absorber thus enhancing the UPF rating (Crew *et al*., 1999).

Polyester is effective in absorbing UV-B because of the benzene rings and conjugated system in its polymer chains and polyester reduced UV transmission in the wavelength region below 312 nm (Laperre *et al.*, 2001; Davis *et al.*, 1997).

Some of the previous researches studied on fibre type and UPF were not comprehensive enough; they were either comparing knit structure and woven structure together (Welsh and Diffey, 1981) or simply reported that no relationship between fibre type and UPF (Gies *et al.*, 1994). The other research (Robson and Diffey, 1990) neglecting factors other than fibre nature itself and recommended avoid a particular fibre type, for example, to avoid wool fibre without specifying all the specimen details.

In conclusion, it is arbitrary to assert that a particular fibre type must have a better UPF than the others, without controlling the knitting/weaving tension, the fabric construction and finishing process involved, etc.

2.4.2 Yarn Properties

Yarn structure could affect the inter-yarn pores and the openness of fabric, however, there were only few studies studying the relationship between the yarn structure and the fabric UV protection effectiveness (Tarbuk *et al*., 2006; Parisi *et al.*, 1999; Sinclair and Diffey, 1997). The subject of those investigations was the yarn linear density and UV protection ability of fabric, but there is not many published research concerned with the UV transmission properties of fabrics related to yarn twist and surface properties.

The study (Stankovic *et al*., 2009) concluded that yarn twist was proved to be an important parameter in determining UV protection properties by the effectiveness of fibre packing in the yarn as well as surface properties. In order to promote optimal UV protection properties and other wearing comfort the appropriate twist level of yarn should be chosen.

2.4.3 Presence of Moisture

Jevtic (1990) found out that the T-shirt had a relative UPF of 15, and the surf shirt a UPF of 36 decreased by a factor of 1/3 in both cases when the material was wetted. The Skin Cancer Foundation of the US mentioned about most fabrics lose about one third of their sun protective ability when wet in 1999 during the "*Get Smart! Go*

Under Cover” campaign. The general statements stand for pale-shaded cotton fabrics. UV absorbing agents (including UV absorbing dyestuffs) on the fibre can minimize or even turn around the effect. When fabrics get wet, scattering is definitely reduced, leading to an increase of UV radiation penetration. To a first approximation, absorbance can be expected to be independent of the environment, hence its contribution to UV protection is retained.

Osterwalder *et al.* (2000) found out the average transmittance was about 30% for bleached cotton, while raised to 50% when wetted. Fabric treated with UV-B absorber, the UV-B absorption below 300 nm remains unchanged when wet. As there is almost no absorption in the UV-A region, the treated fabric behaved like the untreated. Overall result in only a moderate improvement over the untreated cotton. When the cotton fabric treated with both UV-A and UV-B absorber, which absorbed over the full spectrum, here UV protection is provided almost exclusively by absorbance, and providing an increased UPF ratings. Therefore the protection was completely retained even the fabric was wetted.

Besides, UPF also depends on the swelling capacity of the fibres (Gorensek and Sluga, 2004). Several researches supported that wetted fabric usually exhibited lower UPF values and variation of UV transmission because of the reduced optical scattering effect (Gambichler *et al.*, 2001b; Pairsi *et al.*, 2000; Moon and Pailthorpe, 1995;

Pailthorpe, 1994; Jevtic, 1990).

Such hydration effect was based on the fabric type thus affecting the amount of liquid absorbed (Zhang *et al.*, 1997). About 50% decrease in UPF value of hydrated cotton specimen was reported (Moon and Pailthorpe, 1995). Jevtic (1990) reported a 33% decrease in UPF rating of both cotton/polyester and shirt for surfing purpose when the specimens were in wetted state. Standford *et al.* (1997) found that 15 out of 22 cotton/polyester blends specimens in dry state had a 30 UPF rating, while those 15 specimens only yield UPF rating of 10 when wetted. Gies *et al.* (1994) assumed that the amount of water absorbed did affect the magnitude of variation in UPF rating of some of the specimens increased while some of the others decreased. Gies *et al.* (1994) further pointed out the UV transmission rate of cotton and polyester was different with respect of the wetting status. From this finding, conjunction of UV transmission and fibre combination proportion could be linked up.

2.4.4 Stretch

Knitwear is very popular in summer clothing. UV protection by a regular single jersey white garment can be good, provided it was measured in the relaxed state. Osterwalder *et al.* (2000) carried out a research in quantifying the change in UPF under stretch. It was showed that the change of UV radiation transmittance spectrum

$T_{\lambda,X}$ can be modeled with a Lambert–Beer type (Equation 1) approach (Hilfiker *et al.*, 1996).

$$T_{\lambda,X} = P_X + (1 - P_X)\, 10^{-A_\lambda d_X} \text{ ………………Equation (1)}$$

The optical porosity P_X was first measured at various degrees of stretch. The absorption of the fabric is the product of the absorption coefficient A_λ and the optically effective layer thickness d_X. The thickness is reduced by stretch according to the principle of volume retention of the fabric. $_X$ is the amount of areal stretch.

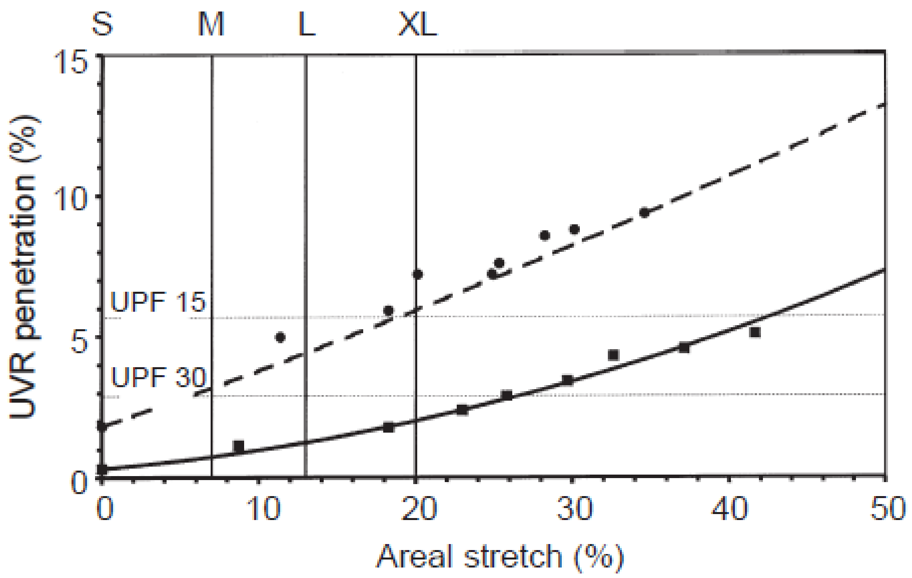
The increase of the UV radiation penetration is almost linear with stretch. UV radiation penetration increase (UPF reduction) can be predicted from the knowledge of the transmittance spectrum in the relaxed state. The relevance of stretch in real life situations is indicated in Table 2-3.

Table 2-3 Stretch percentages relative to “S” size around the chest

	S	M	L	XL
Chest size (cm)	92 ± 3	98 ± 3	104 ± 3	110 ± 3
Stretch (relative to size S)	0%	7%	13%	20%

(Osterwalder *et al.*, 2000)

With reference to Figure 2-4, it may be concluded that a safety factor of "2" away from the relaxed state (double the UV radiation penetration or half the UPF) should be sufficient to account for possible unintentional stretch. Experimental data indicated by symbols. Lines calculated according to Equation (1) (Osterwalder *et al.*, 2000).



– – – Cotton T-shirt (single jersey): 146 g/m^{-2}

—— Cotton polo shirt (single jersey): 205 g/m^{-2}

Figure 2-4 Reduction of UV protection by stretch (Osterwalder *et al.*, 2000)

Several studies suggested that fabric under stretch condition would generally decrease in UPF (Osterwalder *et al*., 2000; Clark *et al.*, 2000; Moon and Pailthorpe, 1995; Gies *et al.*, 1994, 1992), the rationale behind was the hole and porous structures were widened under stretch condition. Clark *et al.* (2000) found out a cotton/lycra knitted specimen, the UPF rating decreased from 23 to 10 with a course-wise stretch of 15% and dropped from 23 to 14 under same stretch condition in wale-wise direction. Kimlin *et al.* (1999) found out a stockings originally with UPF 50, after a 30% stretch in both lengthwise and cross-machine directions did show a decrease of rating in 9 times.

Moon and Pailthorpe (1995) suggested that the UPF rating label on garment was evaluated under relaxed condition but not subjected to average stretch of 15% under normal real wear condition, therefore the rating became less meaningful to real wear situations. Since the UPF rating would decrease significantly while stretching of the fabric.

Kullavanijaya and Lim (2005) carried out a study and conducted UPF evaluation on nylon stocking. Researchers (Kullavanijaya and Lim, 2005) concluded that stretching has a significant reduction on the UPF of stockings. When stretched to 30% of their original size, the UPF of 50 denier stockings decreased by 868%, whereas that of 15 denier stockings decreased by 103%. The larger decrease in the UPF seen in the higher denier stockings is a result of the opening of the tight weave with stretch, hence, allowing more UV radiation to penetrate.

2.5 Conclusions

The review composed several areas with respect methods of UPF measurement, standards guiding the measurement and corresponding rating, the behavior of different fibres irradiated by UV spectrum and factors affecting UPF values were consolidated to facilitate better understanding of the relationship of fibre content and UV radiation.

Chapter 3 METHODOLOGY

3.1 Introduction

Basic yarn information, fabric specifications of samples was tested. Fifteen plain knit samples (variation in fibre composition) were made by the circular knitting machine for the study and two external factors, i.e. stretching and wetting of garment that were believed they could alter the UPF significantly would also be investigated. In order to reveal the extent of alternation, a series of tests were carried out on samples including stretching of samples to three different percentages from the original dimension, wetting samples by chlorinated pool water, sea water, artificial acidic and alkaline perspiration prepared and deionized water (D.I. water) in accordance with British Standard, ASTM and AATCC standards were evaluated.

3.2 Yarn Materials

Five yarn types (cotton and Coolmax yarn) were used in this study and their specifications were shown in Table 3-1. The Central Textiles (H.K.) Ltd. supplied the cotton yarns while Shanghai Ming Mao Industrial Co., Ltd. supplied Coolmax yarns.

Table 3-1 Yarn information

Name of Yarn	Yarn Count	Ring-Spinning Method	Fibre Type	Code
Combed Normal Cotton	Ne 20	Conventional	Cotton	CH
Combed ESTex	Ne 20	Torque - free	Cotton	MCG
Combed Supima Cotton	Ne 20	Conventional	Supima Cotton	F
Combed Supima Cotton ESTex	Ne 20	Torque - free	Supima Cotton	MF
Coolmax	150dtex	Filament yarn	Coolmax	CM

Different yarn combinations are divided into three Groups; Group I (single cotton), Group II (cotton/cotton combinations) and finally Group III (coolmax/cotton combinations) as shown in Table 3-2.

Table 3-2aYarn specifications of yarn in Group I

Fibre	Code	Specific Fibre Type	Spinning Method
Cotton	CH	Combed Normal Cotton	Conventional Ring Spun
Cotton	MCG	Combed Normal Cotton	Torque - free Ring Spun
Cotton	F	Combed Supima Cotton	Conventional Ring Spun
Cotton	MF	Combed Supima Cotton	Torque - free Ring Spun

Table 3-2b Yarn specifications of yarn in Group II

Fibre	Code	Specific Fibre Type	Spinning Method
Cotton + Cotton	CH + MF	Combed Cotton + Combed Supima	Ring Spun + Ring Spun
Cotton + Cotton	CH + F	Combed Cotton + Combed Supima	Ring Spun + torque - free
Cotton + Cotton	CH + MF	Combed Cotton + Supima Cotton	Ring Spun + Ring Spun
Cotton + Cotton	MCG + F	Combed Cotton + Supima Cotton	Torque - free + Ring Spun
Cotton + Cotton	MCG + MF	Combed Cotton + Supima Cotton	Torque - free + Torque - free
Cotton + Cotton	F + MF	Supima Cotton + Supima Cotton	Ring Spun + Torque - free

Table 3-2c Yarn specifications of yarn in Group III

Fibre	Code	Specific Fibre Type	Spinning Method
Coolmax	CM	Coolmax	Filament
Coolmax + Cotton	CM + CH	Coolmax + Combed Cotton	Filament + Ring Spun
Coolmax + Cotton	CM + MCG	Coolmax + Combed Cotton	Filament + Torque - free
Coolmax + Cotton	CM + F	Coolmax + Supima Cotton	Filament + Ring Spun
Coolmax + Cotton	CM + MF	Coolmax + Supima Cotton	Filament + Torque - free

3.3 Basic Yarn Information

Basic yarn information including surface evenness, yarn hairiness, yarn strength, yarn tenacity, yarn twist were tested.

3.3.1 Yarn Surface evenness

There were three ways of revealing surface evenness normally, namely visual measurement (e.g. Zweigle Optical Evenness test), cut and weight method and Uster evenness tester. In order to acquire accurate and highly reproducibility results in short period of time, Uster tester was selected.

The tester measured the thickness variation of a yarn by capacitance measurement. Yarn passed through two parallel plates of capacitor and the values were continuously recorded. Yarn between two plates alters the capacitance, which was governed by the mass of the yarn between the plates and its relative permittivity. The measurements were directly to the mass of the material (yarn or filament) between the plates if the relative permittivity remains the same.

The U%, expressed in terms of mass per centimeter was selected to represent the yarn evenness which is nomo-grams on the mean linear irregularities. Five tests per sample and the total test length was 5,000 meters. The U% was the tester generated figure and devised from Equation (2) as below.

$$U = \frac{a}{x} T$$ ……………….…… Equation (2)

where,

a : area between instant values and mean

x : mean value of mass

T : time

U : evenness

3.3.2 Yarn Hairiness

Yarn hairiness is an undesirable property in fabric production. Some of the methods of testing including Shirley yarn hairiness tester, Zweigle G565 and Uster tester 3 hairiness meter attachment. Again, the Uster tester was selected to take the advantages of accurate and highly reproducibility results within short period of time.

The testing mechanism of yarn was illuminated by a parallel beam of infra-red light as it was running through the measuring head, only light that scattered by the protruding fibres can reach the detector. Direct light was blocked from reaching the detector by an opaque stop. The amount of scattered light is thus converted to electrical signal.

The hairiness "H" value, corresponding to the total length of protruding fibres divided by the length of the sensor by 1 cm was selected to represent the hairiness of different yarns.

The specimen was feed through the specimen feeder to the measuring unit of the Signal Processor. TEST PROCEDURE button was pressed to choose the required program block, and the TEST PARAMETERS button was pressed to change the corresponding variables with the video screen buttons. The REPORT PARAMETERS button was pressed to select up to 20 parameters to be printed on report. The VIDEO RESULTS button was pressed afterwards to select the single-/sum value protocol and the required graphical representation. PRINTER RESULTS was pressed to select graphical results to be printed out and finally started the test by pressing the START/STOP button.

3.3.3 Yarn Strength and Tenacity

All the yarn cones were conditioned in accordance with ASTM D 1776-2004 Standard Practice for Conditioning and Testing Textiles for 24 hours prior to tests by USTER TENSORAPID 4 to measure the yarn strength and tenacity. The device was capable to measurement of tensile strength and elongation of an extensive range of yarns both staple and filament yarn.

The clamp speed and pre-tension were fixed at 5,000 mm/min and 0.5 cN respectively. Test length was 500 mm and 20 results were obtained from each sample, both the breaking force (Newton) and tenacity (cN/tex) were reported.

3.3.4 Yarn Twist

The yarn twist of cotton and blended yarns was test according to ASTM D 1422-1999 Standard Test Method for Twist in Single Spun Yarns by the Untwist-retwist Method. The test was carried out by determining the direction of twist and then a specimen subjected to untwist and then retwist in the opposite direction until it contracted to its original length. Twist, as turns per unit length, is calculated as half the number of turns registered on the counter divide by the 25 cm specimen length, and expressed as number of turns per 1 cm. In this research, the number of twist was determined by operating a Hand-operated Yarn Twist Tester (KFY-1061) from J.A. King and Co. (USA).

3.4 Plain Knitted Fabric Samples Preparation

Fifteen types of plain knitted fabrics were produced from DXC single jersey machine of Fukuhra, Japan. The machine was in 18 inches diameter, with 54 feeders, 20 gauges with 2 cam tracks selection which was suitable for making medium to light weight single jersey. Samples were divided into three groups for study as mentioned in Section 3.2. The fifteen types specimens were divided into three groups, samples in Group II and Group III were produced from 50% and 50% two fibre types blending, except for sample "CM" in Group III, it was produced from 100% coolmax.

3.5 Scouring and Bleaching of Samples

Although the fibre was combed before spinning into yarn, there were some impurities and oil stain from knitting machine. The combined scouring and bleaching process was carried out as pretreatment and the treatment bath was prepared according to Table 3-3. Samples were padded with the liquor at 20-30℃ to 100% liquor pick-up. Those padded samples were steamed for 30 minutes at 102-105℃, then rinse the samples in hot and cold water and dry them afterwards. The liquor ratio was 20 : 1.

Table 3-3 Recipe for scouring and bleaching

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

Liquor Ratio - 20:1

3.6 Ultraviolet Protection Factor Evaluations

3.6.1 Evaluations under Dry and Relax Condition

Samples were conditioned accordance with ASTM D 1776-2004 Standard Practice for Conditioning and Testing Textiles for 24 hours before measured with Cary-300 with Lapsphere for the UPF. The AS/NZS 4399:1996 Sun protective clothing evaluation and classification standard, and the rating was derived from the Equation (3). Readings of each sample were taken from four positions and four times each position (rotate 90° clockwise after each measurement) and afterwards average the readings.

$$\text{UPF} = \frac{E_{eff}}{E'} = \frac{\sum_{290}^{400} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{290}^{400} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda} \quad \text{............ Equation (3)}$$

Where,

E_λ : relative erythemal spectral effectiveness

S_λ : solar spectral irradiance in $Wm^{-2}nm^{-1}$

T_λ : spectral transmittance of the item

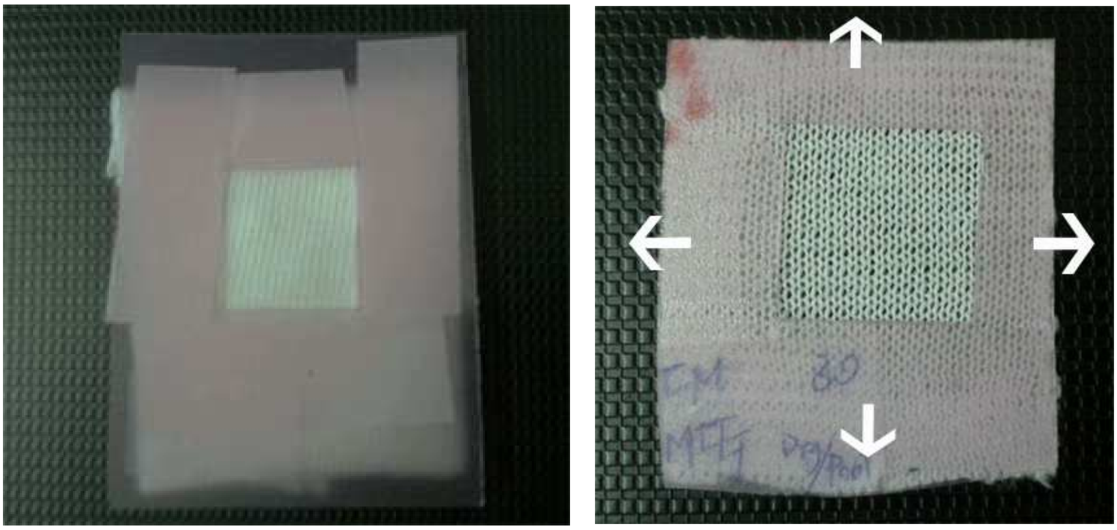
$\Delta\lambda$: wavelength step in nm

λ : wavelength in nm

(*AS/NZS 4399:1996*)

3.6.2 Evaluations under Dry and Stretch Condition

Stretching is another factor that may affect the UPF of which is measured under relaxed state. Samples were stretched in both lengthwise and cross-machine directions in three levels, i.e. 10%, 20% and 30% of the original dimension respectively (Figure 3-1).



(a) (b)

Figure 3-1 (a) Relaxed samples and (b) Stretching of samples at 30% in both lengthwise and cross-machine directions (CM_MCG)

3.6.3 Evaluations under Wet Condition

In order to better understand the variation of UPF on wetted plain knitted fabric, four solutions were used for wetting the fabric samples in the study. The solution used for testing were all freshly prepared.

3.6.3.1 Preparation of Chlorinated Pool Water

Chlorinated pool water was prepared in accordance with testing standard AATCC 162-2011 Colorfastness to Chlorinated Pool Water. The "hardness concentrate" was prepared by adding 800 mL deionized water (D.I. water) to a 1 L volumetric flask and 8.24 g calcium chloride and 5.07 g magnesium chloride were added with stirring until completely dissolved. 51 mL hardness was then diluted to 5100 ml with D.I. water. The solution was finally brought up to 1 L with D.I. water. 0.5 mL household sodium hydrochloride solution was added which was not more than 60 days old afterwards and the actual ppm Cl was adjusted by titration to 5 ppm. 0.01N sodium thiosulfate could be obtained by diluted 10 to 1 volumetrically from 0.1N solution. Finally the pH value of the solution was adjust to pH 7.0 with sodium carbonate or acetic acid as necessary.

3.6.3.2 Preparation of Sea Water Solution

Sea water (sodium chloride) solution was prepared in accordance with testing standard EN ISO 105 Part E02 Colorfastness to Sea Water. 30 g/L aqueous solution was prepared using grade 3 water for sample absorption. Besides 100% pick-up based on the sample weight, additional 75% pick-up and 50% pick-up were applied on sample to test their respective UPF. The different solution picking up testing procedure was apply on both relax and stretched samples.

3.6.3.3 Preparation of Acidic and Alkaline Perspiration

Human sweat during hot weather especially in summer days, clothing being worn were readily absorbing perspiration. Acid and alkaline solutions were prepared in accordance with BS EN ISO 105-E04:2009 Colorfastness to Perspiration. The solution pick-up percentage was 100 percent of the sample weight. The wetted sample was left for five minutes (on the electrical balance to monitor the change in weight during the five minutes) before UPF measurement to ensure thoroughly absorption of the solution in order to better reflect real life wear condition. The wetted samples were measure at three different conditions, including 100%, 75%, 50% pick-up of the original sample weight. Acid and alkaline solutions were prepared as the recipe below in Table 3-4.

Table 3-4 Recipe for Preparing Acid and Alkaline Solution of BS EN ISO 105-E04

Acid Solution

0.5g	L-histidine monohydrochloride monohydrate ($C_6H_9O_2N_3{\cdot}HCI{\cdot}H_2O$)
5g	Sodium chloride (NaCI)
2.2g	Sodium dihydrogen orthophosphate dihydrate ($NaH_2PO_4{\cdot}2H_2O$)

The solution was brought to pH 5.5 (±0.2) with 0.1 mol/l sodium hydroxide solution

Alkaline Solution

0.5g	L-histidine monohydrochloride monohydrate ($C_6H_9O_2N_3{\cdot}HCI{\cdot}H_2O$)
5g	Sodium chloride (NaCI)
2.5g	Sodium dihydrogen orthophosphate dihydrate ($NaH_2PO_4{\cdot}2H_2O$)

The solution was brought to pH 8 (±0.2) with 0.1 mol/l sodium hydroxide solution

3.6.3.4 Moisture Content Evaluation

Presence of moisture content would exert its influence on the UPF. Three different moisture content levels, i.e. 100%, 75%, 50% of the fabric were tested to evaluate respective UPF. Samples were thoroughly wetted in separate solutions and weight at electrical balance at 100% pick-up of the sample weight first. Then the same wetted sample were left behind at conditional chamber until the amount of solution reaches 75% of the original sample weight and repeat the procedure until the sample contains 50% of the original sample weight to attain the 50% pick-up.

3.6.4 Evaluations under Wet and Stretch Condition

Another possible situation was that the fabric subjected to wetting and stretching at the same time. Samples were stretched at 30% in two directions of the original dimension and were immersed separately in (a) chlorinated pool water, (b) sea water, (c) acidic and (d) alkaline artificial perspiration and (e) D.I. water for ten minutes with very gentle agitation to ensure thorough absorption of liquor. The wetted samples were then laid flat and measured the weight until they were 100% pick-up of the original sample weight. UPF values were measured.

3.7 Fabric Properties

3.7.1 Fabric Thickness

Fabric thickness was relative to UPF of fabric. The test was performed with a thickness measurement device of Model: BC1110-1-04, SDL, USA. Results were measured on five positions of the fabric.

3.7.2 Fabric Weight

The fabric weight was determined by cutting sample after conditioning according to ASTM D 1776-2004 Standard Practice for Conditioning and Testing Textiles for 24 hours and was cut by a standardized die cutter avoid any selvedges or creased area and weight the 100cm^2 samples by electrical balance of an accuracy to 0.001g to get the areal mass, i.e. g/m^2.

3.7.3 Course and Wales Count (Stitch density)

Samples were laid flat and conditioned in accordance with ASTM D 1776-2004 Standard Practice for Conditioning and Testing Textiles for 24 hours before visual count in accordance to ASTM D 3887 Test Methods for Specification of Knitted Fabrics. Fabric count method over 5 different parts all over the samples and avoid counting within 0.5 m from the selvages by using a pick glass. Number of loops count from courses and wales in 1cm^2 were multiplied to obtain stitch density.

3.7.4 Loop Length

Yarns were removed from a strip of known number of loop, straightened by a tension which is varied according to the nature and linear density of the yarn and measured in the straightened state. 3 sets of specimen were prepared for removing a predetermined number of loops, i.e. 50 loops then cut on both end of the markings for measurement. The tension recommended for testing were described in Table 3-5.

Table 3-5 Tension recommended for straightening loops

Yarn	Linear Density	Tension Recommended
Cotton	7 tex or finer	0.75g per unit of tex
	Coarser than 7 tex	0.2g per unit of tex ± 4
All man-made continuous filament	All	0.5g per unit of tex

3.7.5 Tightness Factor

The determination of loop length is a key element of acquiring the tightness factor. Equation (5) shows the calculation of tightness factor in which the smaller the values would be tighter the fabric.

$$TF = \frac{\sqrt{Tr}}{lr} \qquad \text{.................... Equation (5)}$$

where,

Tr : the linear density of ribbon-type yarn, tex

lr : the stitch length of the knitted fabric, mm

3.7.6 Microscopy

Leica M125 stereomicroscope was used for viewing the pores and holes of dry and wet fabric samples under different stretch conditions at 5x magnification. Single yarn at both dry and wet states were viewed at 12.5x magnification.

3.7.7 Determination of the Size of Pores on Samples under Stretching

Image processing software, Photoshop CS5 was used to determine the ration of pores to the whole sample. In this evaluation, samples under different stretching conditions were photographed as a picture; every dot on the picture was interpreted as a pixel. This test simply selected the pixel emerged under stretching and computed its ratio to the whole picture and finally expressed in terms of percentage.

3.8 Statistical Analysis Tools

Software "Statistical Product and Service Solutions" (SPSS) was used for computing a model by means of multiple linear regressions (MLR) for predicting UPF under different testing conditions.

During computing process, several tests were carried out in order to test the validity of procedures and some important values. The explanation and interpretation are denote as follow.

The coefficient of determination (R^2) value in the Model Summary table indicates how well it can explain the overall models' variations, often expressed in terms of percentage. Generally speaking, when it is over 90% ($R^2 > 90\%$), it is a good model for explaining variations.

F-test was used to evaluation the overall linear significance of the model, i.e. if there is a linear relationship between Y (dependant variable) and all the X (independent variables) considered together. "Sig" in the ANOVA table of F-test should be interpreted as probability value (p-value), as "Sig" is meaningless in statistical study. P-value in the ANOVA table should always be smaller than α, which is the significance level and its typical value was 0.05 throughout the research. Smaller than 0.05 imply there is only 5 % chances of a particular outcome (probability) that will happen.

The reason for the "0.05" value is critical simply because it govern if the null hypothesis is to be rejected or not. If the p-value is smaller than 0.05, the null hypothesis will be rejected. As the null hypothesis always state the variances of two variables are equal, when this concept is applied in the MLR, the null hypothesis will state there is NO relationship between Y and X, i.e. a change in either one of the Xs will NOT trigger a corresponding change in Y at 95% level of confidence. On the other hand, there is 5% probability that at least one X and Y has statistical relationship. Once it is observed, the null hypothesis is rejected.

Follow the line of reasoning, if the p-value in F-test is smaller then 0.05, there is a significant relationship between Y and X, it can proceed to next step.

For one way analysis of variance (ANOVA), there are several statistical tests to be performed.

Levene's test is used to test for homogeneity (equality) of variances. It can test the null hypothesis that states the variances from population are statistically similar (Gowda *et al.*, 2012; Levene, 1960).

3.9 Conclusion

This section summarized the preparation of knitted fabric made from circular knitting machine and all the evaluation aspects regarding UPF measurement and tests for fabric properties for the research. Summary of the tests carried out are shown in Table 3-6.

Table 3-6 Summaries of Tests and Testing Conditions

Material	**TEST**	**CONDITIONS**	**Section**
Yarn	Surface Evenness	Uster Tester	3.3.1
	Hairness	Uster Tester 3 Hairiness meter Attachment	3.3.2
	Yarn Strenght & Tenacity	Uster TENSORAPID 4	3.3.3
	Twist Number	Hand-Operated Yarn Twist Tester (KFY-1061)	3.3.4
Fabric (UPF)	UPF (dry)	Normal : Dry & Relaxed	3.6.1
	UPF (stretch)	30%,20%,10% lengthwise & cross-machine direction	3.6.2
	UPF (wet)	Chlorinated Pool Water : 100%,75%,50% pick-up	3.6.3.1
	UPF (wet)	Artificial Sea Water : 100%,75%,50% pick-up	3.6.3.2
	UPF (wet)	Acidic/Alkaline Perspiration : 100%,75%,50% pick-up	3.6.3.3
	UPF (wet)	Moisture Content : D.I. water (100%,75%,50%)	3.6.3.4
	UPF (wet + stretch)	Stretch 30% + Chlorinated Pool Water/Sea Water/Acidic /Alkaline Perspiration/D.I. water	3.6.4
Fabric (Properties)	Thickness	Thickness Meter (BC1110-1-04, SDL, USA)	3.7.1
	Weight	Electronic Balance (accuracy to 0.001g)	3.7.2
	Course & Wales count	ASTM D 3887 : Fabric Count (Visual)	3.7.3
	Loop Length	Visual Count	3.7.4
	Tightness Factor	Manual Calculations	3.7.5
	Microscopy	Leica M125 Stereomicroscope	3.7.6
	Pores Size	Photoshop CS 5 software	3.7.7

Statistical Analysis Tools	Multiple linear regression	SPSS software	3.8

Chapter 4 RESULTS and DISCUSSIONS on UPF of DRY, RELAX and STRETCH SAMPLES

In this section, the UPF of the 20Ne cotton yarns, Coolmax yarn and their combinations in dry (section 4.1) and stretched state (section 4.2) will be discussed. According to the fibre composition, three groups were summarized including Group I (single cotton yarn), Group II (cotton/cotton combination) and Group III (coolmax/cotton combination) for discussion. In addition, structural parameters affecting corresponding UPF values would be analysis and tried to compute and formulate multiple linear regression in order to predict UPF.

4.1 UPF at Dry and Relax State

4.1.1 Group I (single cotton)

The average UPF value is 11.24 for Group I (CH, MCG, F, MF) the four cotton yarns sample. In addition, variations in UPF values of each sample were smaller when compared with the other two Groups (Figure 4-1).

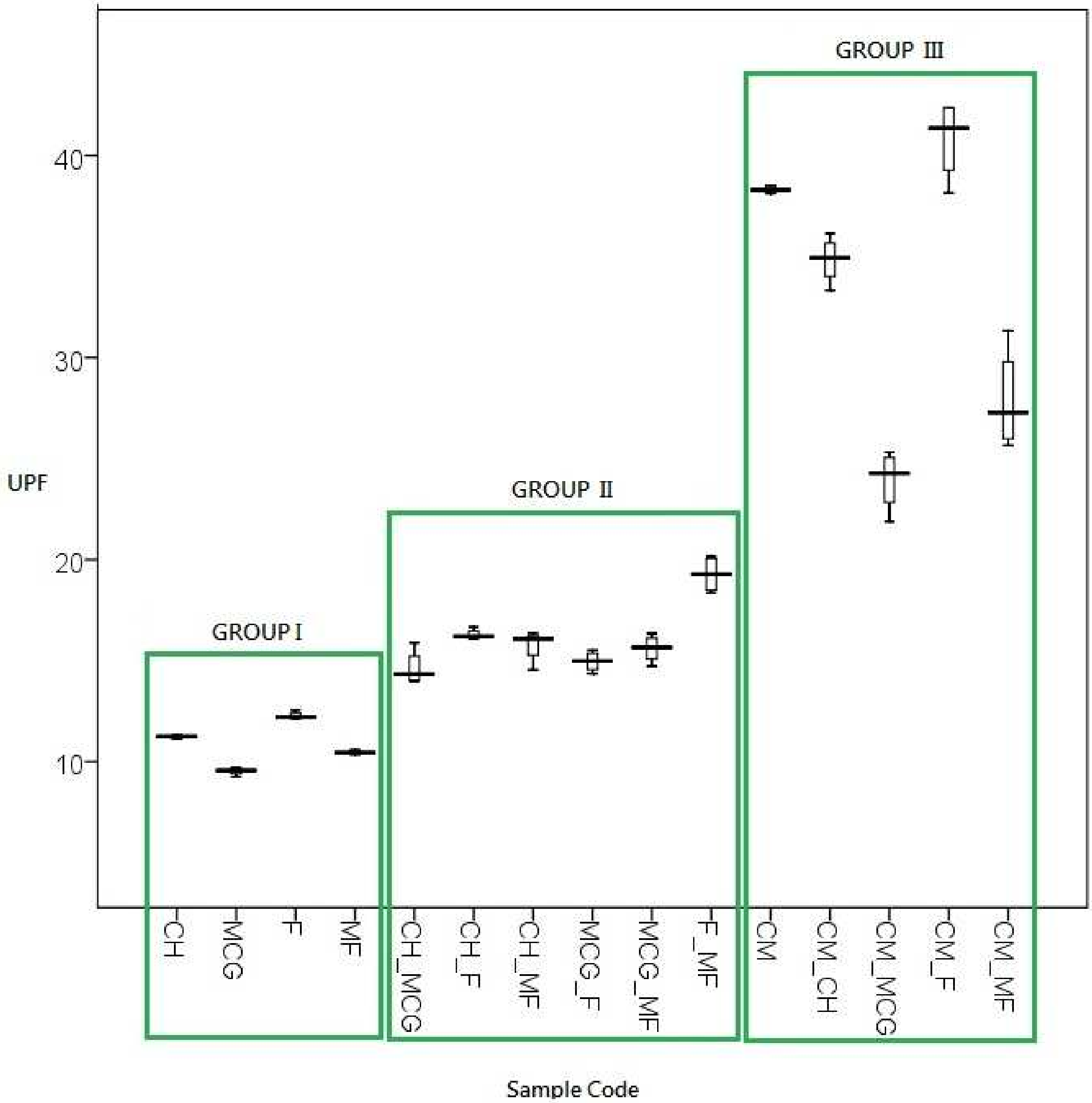


Figure 4-1 Overall UPF results of samples in three Groups

4.1.1.1 Comparison on Spinning Method

Conventional ring spun yarn sample CH provides a better UPF rating than torque-free ring spun yarn sample MCG, provided that the fibre type to be the same, so that spinning method of yarns could affect UPF.

The fibre types of these two samples (CH and MCG) are the same which only differ in spinning method; the same observation also found on the comparison of sample F and MF. Both of the samples F and MF are produced by the same cotton fibre (Supima cotton) and only the spinning methods are different. Sample F is produce from conventional ring spun yarn while sample MF is produced from torque-free ring spun yarn. Torque-free ring spun yarns are commercially known as ESTex.

Normal Cotton conventional ring spun yarn can provide 17.94 % better than torque-free ring spun yarn (UPF : CH (11.24) > MCG (9.53), 17.94 % difference).

Supima cotton conventional ring spun yarn can provide 17.30 % better than torque-free ring spun yarn (UPF : F (12.27) > MF (10.46), 17.30% difference).

Torque-free ring spinning is a technique producing yarn with a torque reduction device in the conventional ring spinning system and the yarn structure is modified (Kan and Wong, 2011; Murrells *et al.*, 2003 and Tao *et al.*, 1997a,b). Yarn twist number can be reduced to a great extend (Kan and Wong, 2011; Murrells *et al.*, 2003 and Tao *et al.*, 1997a,b). Less amount of the yarn twist number on torque-free spun yarn (Table 4-1.) comply with previous findings (Kan and Wong, 2011; Murrells *et al.*, 2003 and Tao *et al.*, 1997a,b).

The yarn twist number per one centimeter of CH = 6.92 > MCG = 4.68 and F = 5.38 >

MF = 4.2, i.e. conventional ring spun > torque-free ring spun. Less twist on torque - free spun yarn render the yarn to be softer hand feel and UV-radiation can penetrate the yarn more easily than conventional ring spun yarns which present more twists number. It helps to explain the finding of ESTex yarns (MCG and MF) perform not as good as those conventional yarns (CH and F).

Table 4-1 Yarn Specifications and UPF of samples in Group I

Sample Code	Ring-Spinning Method	Fibre Type	Twist Number / 1 cm	Tightness Factor	Thickness (mm)	Weight (g/m^2)	Mean UPF
CH	Conventional	Normal Cotton	6.92	1.43	0.92	153.48	11.24
MCG	Torque - free	Normal Cotton	4.68	1.44	0.94	158.87	9.53
F	Conventional	Supima Cotton	5.38	1.42	0.81	143.96	12.27
MF	Torque - free	Supima Cotton	4.20	1.43	0.83	158.70	10.46
				Average : 1.43	Average : 0.88	Average : 153.75	Average : 10.88

4.1.1.2 Comparison on Fibre Type

Supima cotton yarn "F" provides a better UPF rating than common cotton yarn "CH" holding the spinning method to be the same, so that fibre types could affect UPF of yarns.

The spinning methods of these two samples are the same which only differ in fibre content; the same observation also observes on the comparison of sample "MF" and "MCG". Both of the samples "F" and "CH" were produced by the same method (conventional ring spinning). Sample "F" is Supima cotton yarn while sample "CH" is common cotton fibre. Supima cotton fibre is commonly known as ELS (extra long staple). According to Cotton Incorporated, the upper half mean (UHM) length of upland fibre which longer than 32 mm are categorized as extra long staple (Cotton Incorporated and Textile World, 2003).

Supima cotton yarn can provide 9.16% better than normal cotton fibre yarn (UPF : F (12.27) > CH (11.24), 9.16% difference).

Supima cotton yarn can provide 9.76% better than normal cotton fibre yarn (UPF : MF (10.46) > MCG (9.53), 9.76% difference).

The yarn surface roughness (or Unevenness %) of Supima cotton yarn are lower than normal cotton fibre yarn as shown in Table 4-2.

Table 4-2 Yarn surface roughness of cotton yarn samples

Sample Code	Yarn Surface Roughness	Fibre Type
CH	8.43	Normal cotton
MCG	8.23	Normal cotton
F	6.98	Supima cotton
MF	7.13	Supima cotton

Smoother Supima cotton yarn can produce higher uniformity fabric surface. According to Central Textiles (H.K.) Ltd., torque-free ring spun yarn can improve about 12-17% textiles surface roughness (www.centraltextiles.com), thus give a better reflection of UV radiation than fabric produced from conventional ring spinning process.

4.1.2 Group II (Cotton/Cotton combinations)

The average UPF rating is 16.19 for Group II, which is 48.80% better than Group I as shown in Table 4-1 and 4-3. The tightness factors of samples in Group II are generally higher than samples in Group I. Average tightness factor value of Group II is 1.49 which is 4.2% higher than the value of Group I (1.43), it helps to explain the reason for general higher UPF ratings of samples in Group II.

Table 4-3 Yarn Specifications and UPF of samples in Group II

Sample	Ring-spinning Method		Type of Cotton		Tightness	Thickness	Weight	Mean
Code	Conventional	Torque-free	Normal	Supima	Factor	(mm)	(g/m^2)	UPF
CH_MCG	CH	MCG	CH & MCG	/	1.52	0.98	169.19	14.89
CH_F	CH & F	/	CH	F	1.48	0.88	164.01	16.29
CH_MF	CH	MF	CH	MF	1.47	0.94	163.78	15.76
MCG_F	F	MCG	MCG	F	1.49	0.88	163.84	14.96
MCG_MF	/	MCG & MF	MCG	MF	1.50	0.87	158.53	15.96
F_MF	F	MF	/	F & MF	1.46	0.86	163.66	19.27
					Average : 1.49	Average : 0.91	Average : 163.83	Average : 16.19

Sample "F_MF" (Combed Supima + Combed Supima ESTex) combination shows the best UPF among this group. Two Supima cotton yarns blend together seems bringing out better UV radiation protective power than normal cotton blended with Supima cotton. The worst combination is normal cotton blended with normal cotton, i.e.

sample CH combined with sample MCG. The effect of fibre type seems outweighing the effect of spinning type in this Group.

The other observation is the overall variations of the ratings are increased when compared with Group I. It can be explained by when two different yarns are used for knitting at the same time, variation in UPF would increase accordingly. As the yarn twist number of each cotton yarn was not the same, the fabric surface will become uneven (Stankovic *et al*., 2009). It explains the reason of greater variation of UPF in Group II (cotton/cotton combination).

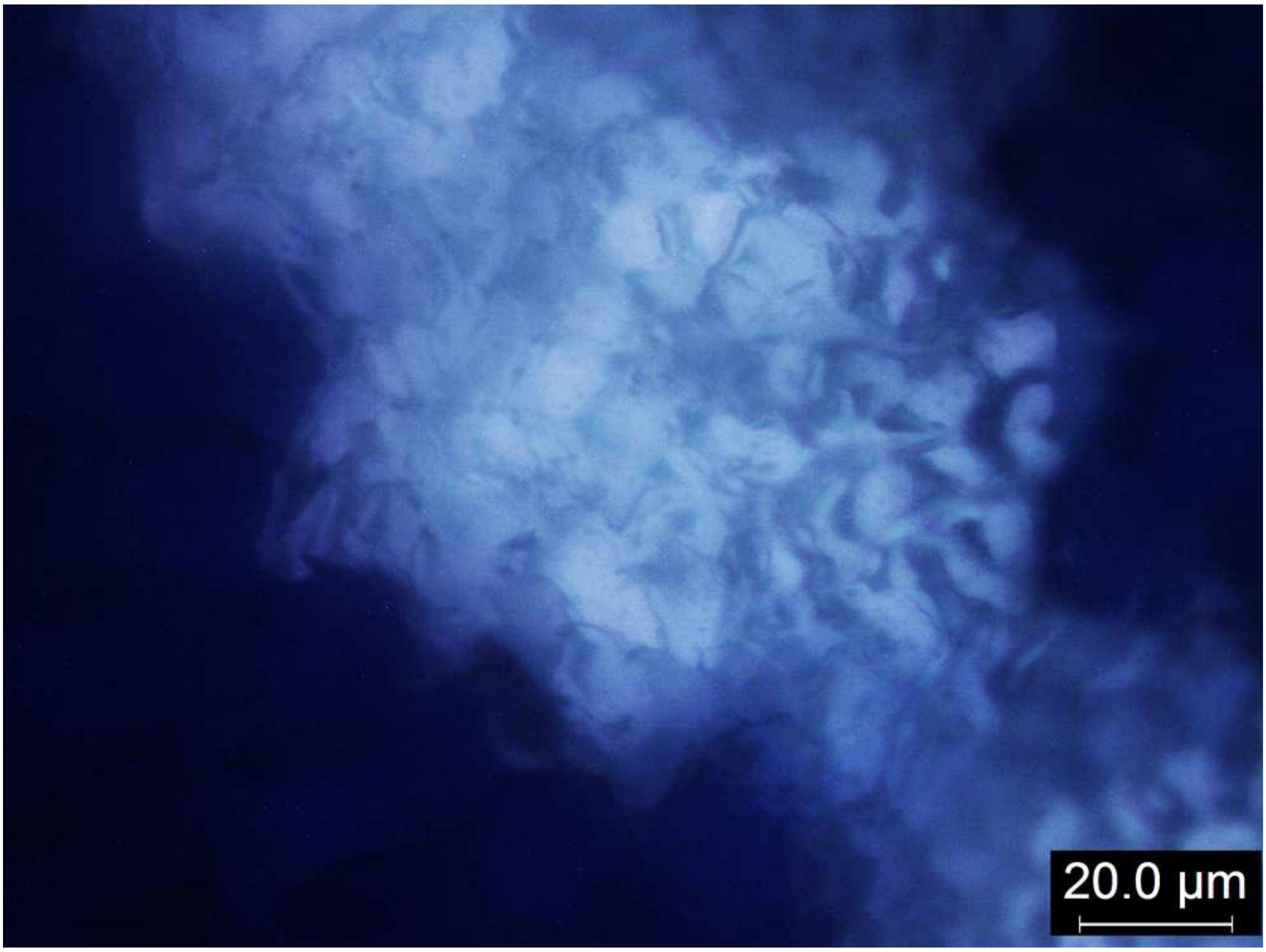
4.1.3 Group III (Coolmax/Cotton combinations)

The average UPF value of Group III is 33.16 (Table 4-4) which is 104.82 % higher than Group II (UPF: 16.19) and 204.78 % higher than Group I (UPF: 10.88). The tightness factor of Group III is 1.48 which is 0.67% lower than Group II (1.49), yet the mean UPF results is 104.82% better than mean UPF result of Group (UPF: 16.19) The results reveal that although tightness factor is an important factor governing UPF property, the natural of fibre can not be neglected.

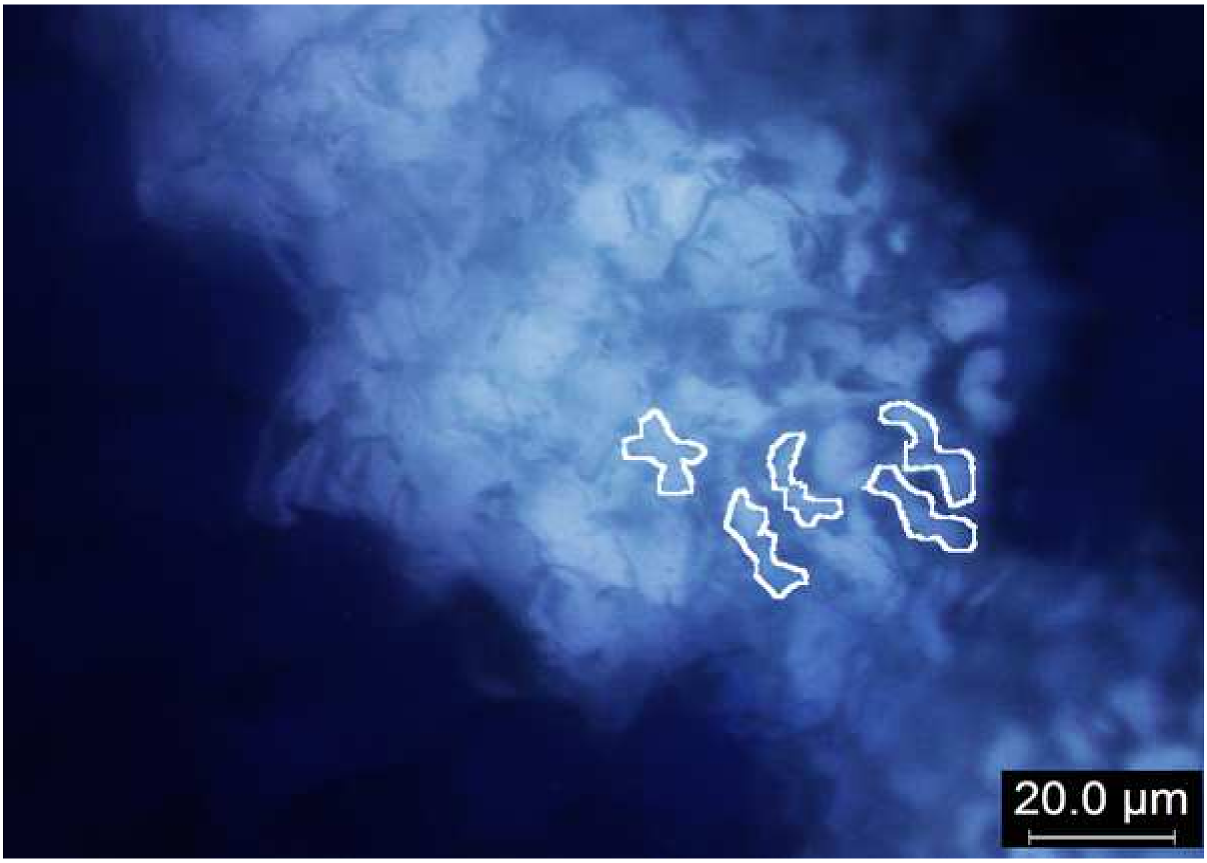
Table 4-4 Yarn Specifications and UPF of samples in Group III

Sample Code	Ring-spinning Method		Type of Cotton		Tightness Factor	Thickness (mm)	Weight (g/m^2)	Mean UPF
	Conventional	Torque-free	Normal	Supima				
CM	/	/	/	/	1.50	0.84	127.16	38.32
CM_CH	CH	/	CH	/	1.48	0.89	153.46	34.84
CM_MCG	/	MCG	CH	/	1.45	0.83	142.49	23.94
CM_F	F	/	/	F	1.52	0.86	147.88	40.82
CM_MF	/	MF	/	MF	1.46	0.82	142.64	27.88
					Average : 1.48	Average : 0.85	Average : 142.73	Average : 33.16

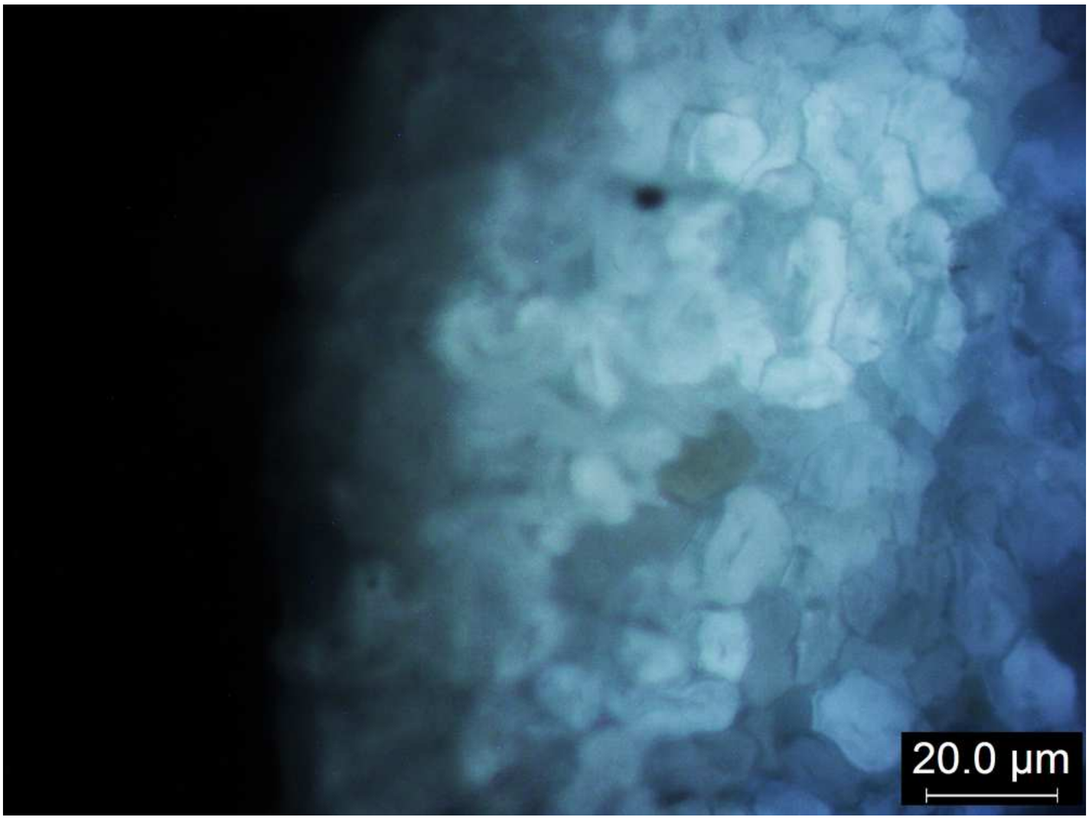
Coolmax (CM) provides average UPF rating 38.32. Coolmax is a kind of polyester, which has different fibre cross-sectional view (Figure 4-2). The delustrant applied during manufacturing acted as a good UV absorber, so it inherently provides better protection against UV radiation than cotton yarns (Crew *et al.*, 1999; Reinert *et al.*, 1997). In addition, the reason for coolmax sample yield a higher UPF than cotton sample was that coolmax contain benzene rings and conjugated aromatic system of polymer chains that were more effective in UV radiation absorption (Gambichler *et al.*, 2001b; Crews *et al.*, 1999 and Davis *et al.*, 1997). On the contrary, cotton (a kind of cellulose) has no double bonds in their chemical structure, thus has a low intrinsic UV absorption capacity and can only provides relatively low UV protection properties than Coolmax samples (Gambichler *et al.*, 2001b; Crews *et al.*, 1999 and Davis *et al.*, 1997). The results observes in Group III seems to resemble the results of Group I (single cotton) but the values are three to four times higher which is complied to the results found Davies *et al*. in 1997. The large extend of variations can be explained by the yarn twist number of coolmax yarn is extremely low to bind the filament together and the yarn twist number is only reported 1.03 per centimeter (Table 4-1).



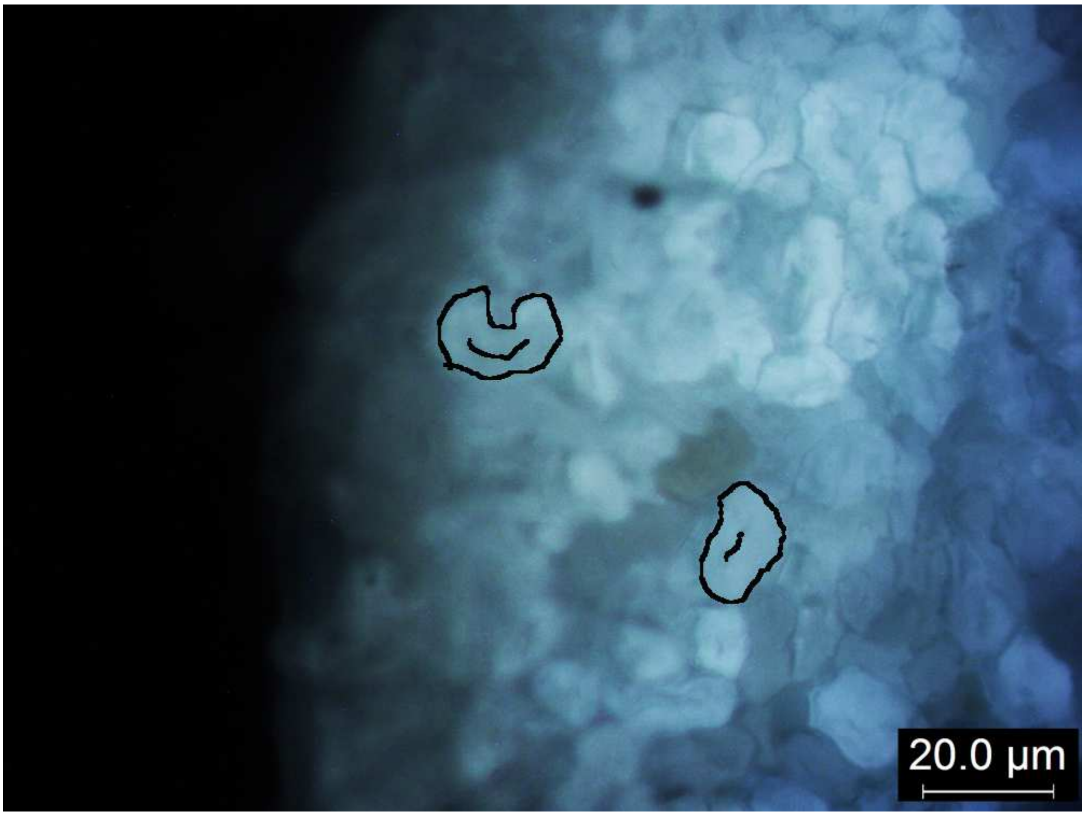
(a) Coolmax - Raw



(b) Coolmax - will illustration



(c) Cotton - Raw



(d) Cotton - with illustration

Figure 4-2 Fibre cross-sectional view of (a) coolmax-raw (b) coolmax-with illustration, (c) cotton-raw and (d) cotton-with illustration

4.1.4 Statistical Prediction of *UPF* ***dry and relax***

Tightness factor, Pore Size Ratio, Number of Stitches and Fibre combination are used to compute and formulate Multiple Linear Regression (MLR) for predicting UPF at dry and relax state ($UPF_{dry\ and\ relax}$). The other factors, namely yarn evenness and hairiness, yarn twist, fabric thickness and weight and loop length had no linear relationships with the dependent variable, i.e. UPF.

4.1.4.1 Multiple Regression Model for UPF *dry and relax*

$$Y = a + b_1(X_1) + b_2(X_2) + b_3(X_3) + b_4(X_4) \quad \text{………………………………………… Equation (6)}$$

Dependant variable,

Y : UPF of dry and relax plain knitted fabric ($UPF_{dry\ and\ relax}$)

Independent variables,

X_1 : Tightness Factor

X_2 : Pore Size Ratio

X_3 : Number of Stitches (total number of stitches in 1 cm^2)

X_4 : Fibre Combination (1: cellulose fibre, 2: cellulose combination, 3: synthetic fibre, 4: cellulose/synthetic combination)

Intercept,

a

Regression coefficient,

b_1, b_2, b_3 and b_4 (slopes)

4.1.4.2 Establish Regression Equation for Predicting *UPF* $_{dry\ and\ relax}$

Table 4-5 is the Coefficients table which shows

Intercept,

$a = -103.14$

Regression coefficients,

$b_1 = 60.04$, $b_2 = -2.07$, $b_3 = 0.41$, $b_4 = 4.99$

Table 4-5 Coefficients table (*UPF* $_{dry\ and\ relax}$)

Model	B	Sig.
(Constant)	-103.14	0.03
Tightness Factor	60.04	0.05
Pore Size Ratio	-2.07	0.14
Number of Stitches	0.41	0.01
Fibre Combination	4.99	0.00

The multiple regression equation of $UPF_{\text{dry and relax}}$:

$$Y = -103.14 + (60.04\ X_1) + (-2.07\ X_2) + (0.41\ X_3) + (4.99\ X_4) \text{ .... Equation (7)}$$

$$UPF_{\text{dry and relax}} = -103.14 + (60.04\ \textit{Tightness Factor}) + (-2.07\ \textit{Pore Size Ratio}) + (0.41\ \textit{Number of Stitches}) + (4.99\ \textit{Fibre Combination})$$

4.1.4.3 Model Summary ($UPF_{\text{dry and relax}}$)

Table 4-6 is the model summary where it shows the coefficient of determination (R^2) is 0.900. This means 90.0% of the variation in the $UPF_{\text{dry and relax}}$ can be explained by the variables of Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.

Table 4-6 Model Summary table ($UPF_{\text{dry and relax}}$)

R Square (R^2)	
0.900	[interpreted as 90.0%]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF dry and relax

4.1.4.4 F-test for overall linear Model Significance ($UPF_{\text{dry and relax}}$)

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

From the ANOVA (analysis of variance) in Table 4-7, the p-value (Sig. in the ANOVA table) of the F-test is 0.00, so the value is smaller than α (which was the significance level and its typical value was 0.05). Therefore, the regression model has a significant linear relationship at a significance level of 0.05

Table 4-7 ANOVA table (*UPF* $_{dry\ and\ relax}$)

Model	Sig.	
Regression	0.00[a]	[*p* - value of F-test]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF dry and relax

4.1.4.5 Verification of the Model Predictive Ability (*UPF* $_{dry\ and\ relax}$)

The *UPF* $_{dry\ and\ relax}$ can be predicted by using Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. In order to test how precise can the regression apply for prediction, verification of the regression is thus needed and results are shown in Table 4-8 as below. The change in percentage was calculated from Predicted value - Actual value / Actual value X 100%.

Table 4-8 Difference (%) between "Actual" and "Predicted" of *UPF* $_{dry\ and\ relax}$

		UPF		Differences (%) between
	Sample code	Predicted	Actual	"Actual" and "Predicted"
Group I	CH	12.17	11.24	+ 8.23%
	MCG	10.34	9.53	+ 8.45%
	F	11.13	12.27	- 9.29%
	MF	10.21	10.46	- 2.36%
Group II	CH _ MCG	13.26	14.89	- 10.91%
	CH_F	15.58	16.29	- 4.33%
	CH_MF	16.48	15.76	- 4.56%
	MCG_F	14.47	14.96	- 3.30%
	MCG_MF	15.71	15.96	- 1.57%
	F_MF	15.99	19.27	- 17.01%

Group III	CM	34.14	38.32	- 10.92%
	CM_CH	35.16	34.84	+ 0.92%
	CM_MCG	24.57	23.94	+ 2.63%
	CM_F	40.25	40.82	- 1.39%
	CM_MF	28.59	27.88	+ 2.54%
			Average :	- 2.55%

Remarks :

+ : Predicted value was Overestimated

- : Predicted value was Underestimated

Generally speaking, the multiple linear regression model ($UPF_{\text{dry and relax}}$) tends to overestimate $UPF_{\text{dry and relax}}$ and the overall differences of all samples are underestimated by 2.55%. There are six out of fifteen samples being overestimated. The worst prediction was -17.01% on sample F_MF, while the best prediction was +0.92% on sample CM_CH. There are twelve samples differences between actual and predicted UPF values within 10% variation. The coefficient of determination (R^2) of the model is 0.900, that means it can explain 90.0% of the total variance by the variables of fibre combination, Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination, the regression model can be concluded as a successful way in predicting $UPF_{\text{dry and relax}}$ state even for blended fibre combinations.

4.2 UPF at Dry and Stretch State

Fabric structure becomes looser under stretched conditions as the poles between loops are opened up under stretching. UPF values decrease along with increasing stretch percentages.

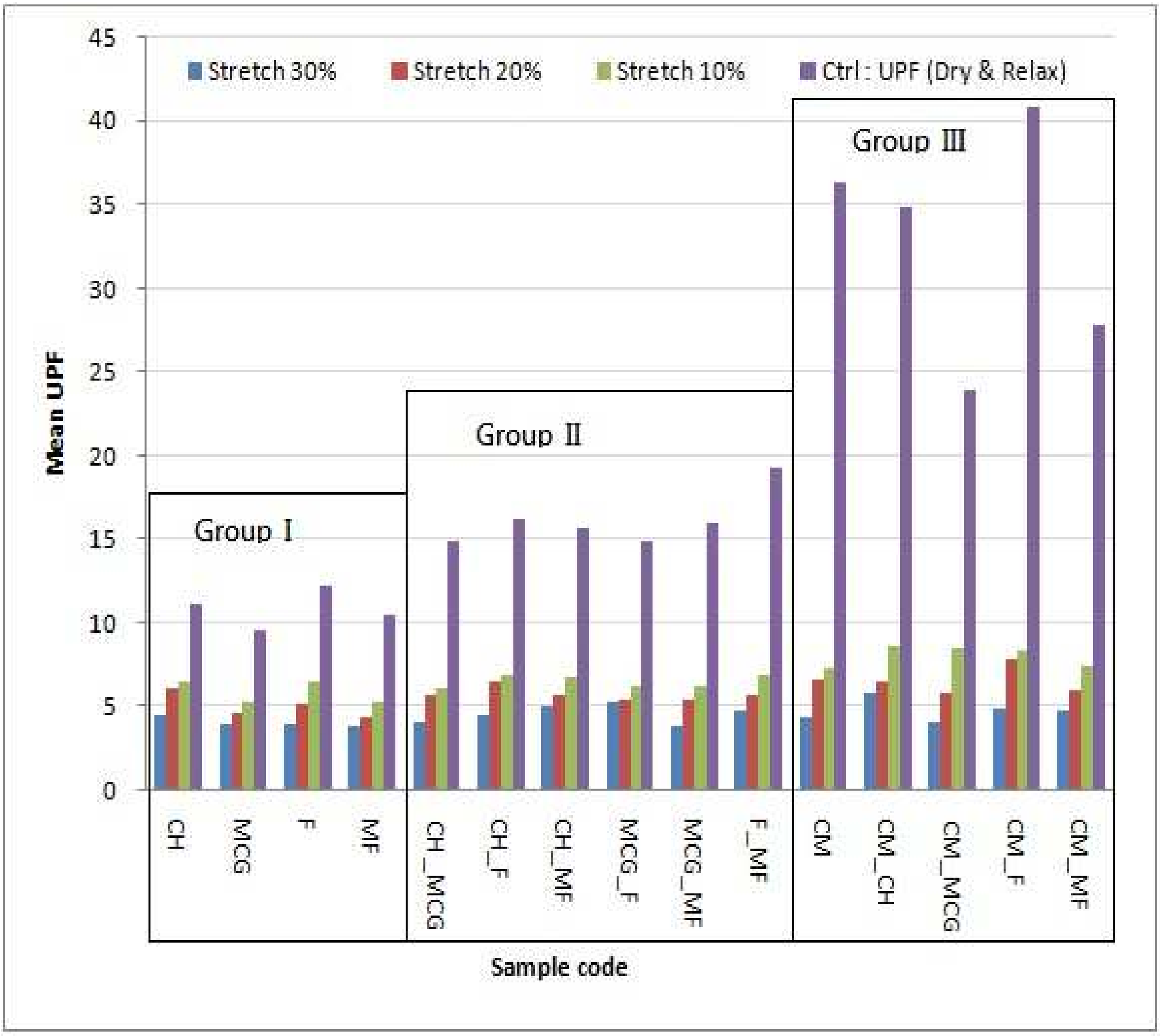
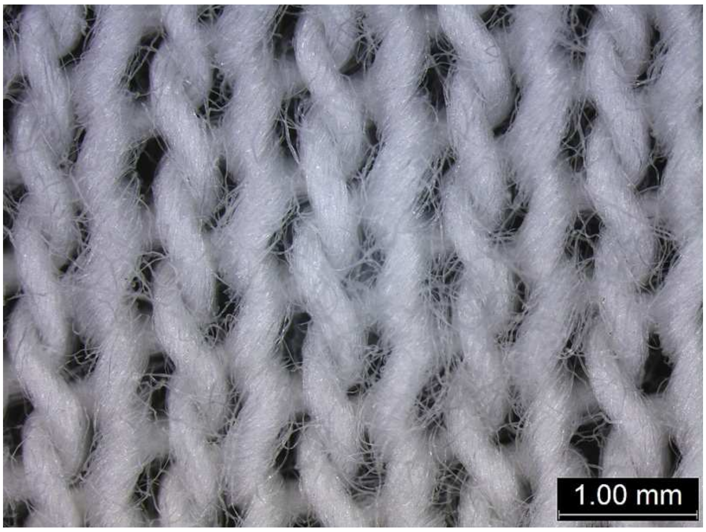
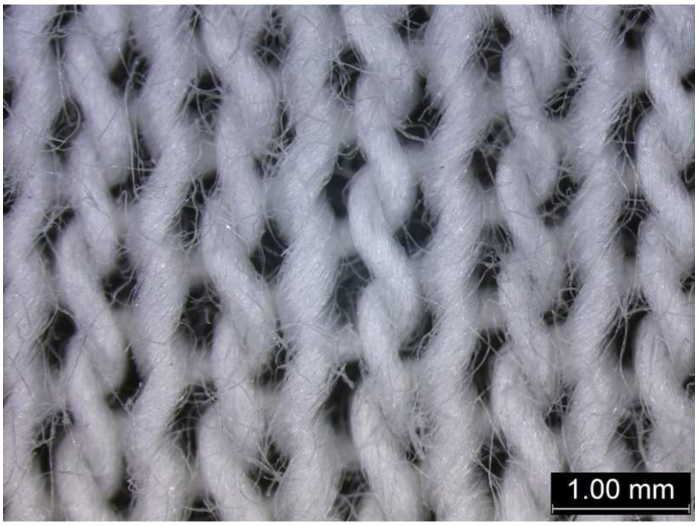


Figure 4-3 Overall performance on UPF under 3 different stretch conditions

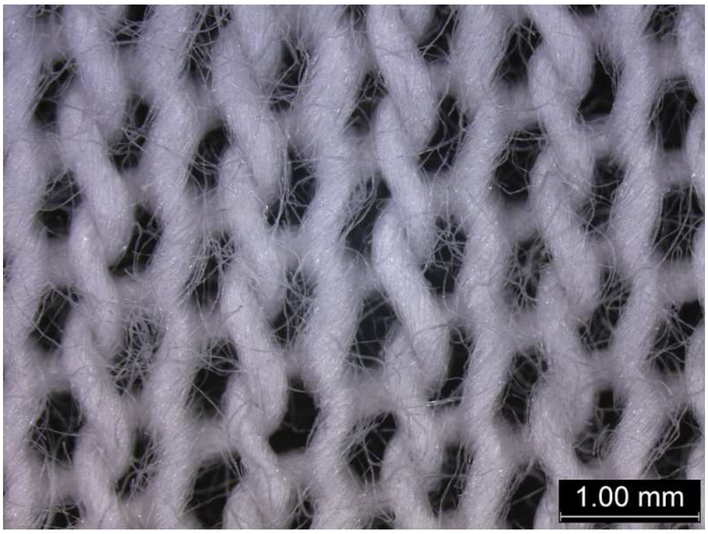
The pores are larger of the same fabric when stretched 30% than 20% and 10% as shown in Figure 4-4. The magnitude decreases in UPF is most profound in Group III, then Group II and Group I that come second and third. As the presence of holes dominating the cause of decreasing UPF, the fibre type and the spinning method becomes insignificant and negligible in this Group.



(a) Stretch 10%



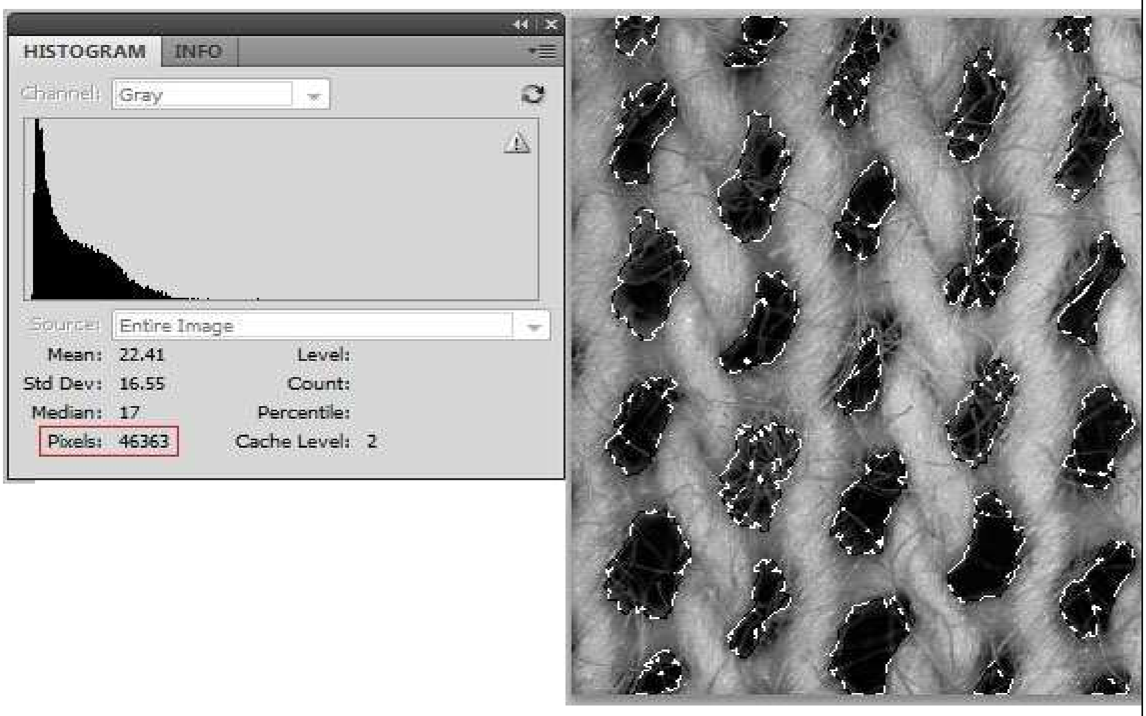
(b) Stretch 20%



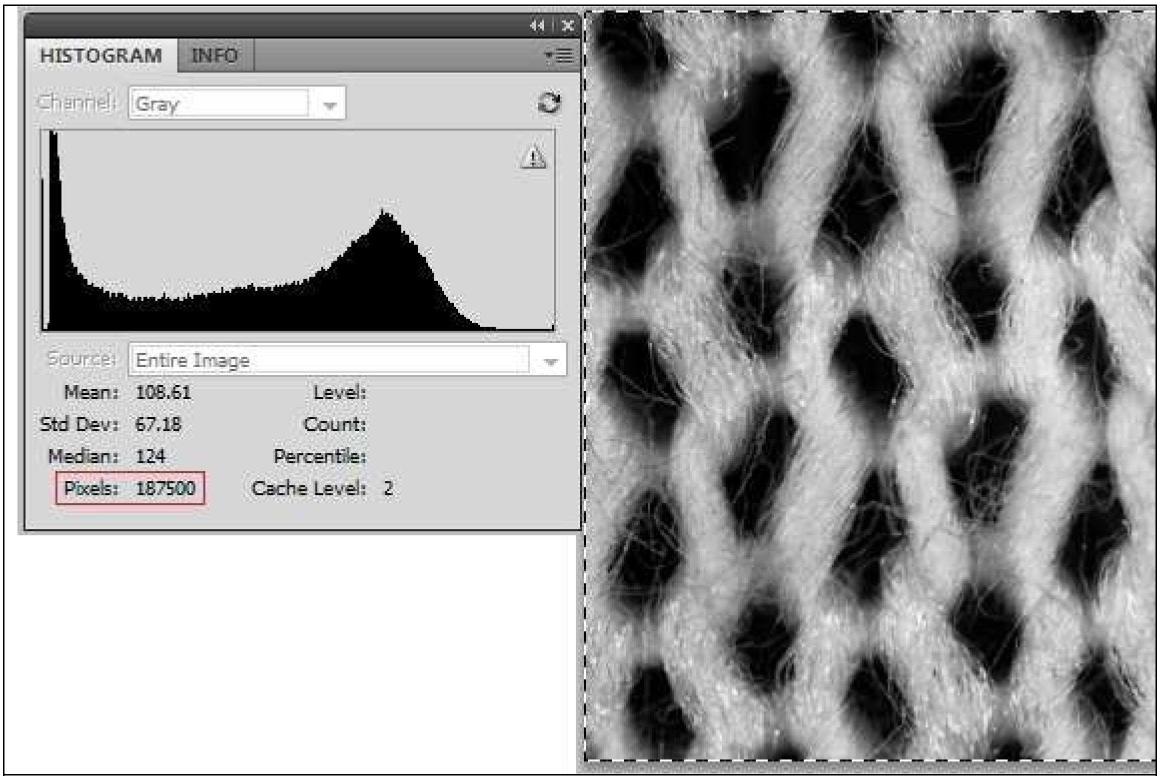
(c) Stretch 30%

Figure 4-4 Sizes of holes on sample "CH_F" subjected to (a) 10%, (b) 20% and (c) 30% stretching in both lengthwise and cross-machine directions

The size of holes is interpreted as the "black pixels" and it is comparing to the whole picture pixels by Photoshop software to determine the open area to sample ratio. The black pixels (which are in fact the pores and holes in-between loops emerge under stretching) are selected and determined by Photoshop as shown in Figure 4-5a. With referring to Figure 4-5a, total number of black areas count is 46363 pixels. On the other hand, the whole picture pixels (including both black and white "areas") count is 187500 pixels (Figure 4-5b). Then the black to whole picture pixels ratio is 46363 over 187500 pixels that equals to 24.73% (CH_F stretch 30%).



(a) Number of black pixel (CH_F stretch 30%)



(b) Number of whole picture pixel (CH_F stretch 30%)

Figure 4-5 Number of pixels of (a) pores and (b) whole picture

Table 4-9 Black pixel to whole picture's pixel ratio

	Sample code	**Black pixel to whole picture's pixel ratio**		
		Stretch 10%	Stretch 20%	Stretch 30%
Group I	CH	8.87%	20.39%	26.11%
	MCG	10.63%	22.16%	23.25%
	F	9.57%	21.47%	24.99%
	MF	10.14%	20.96%	23.19%
Group II	CH_MCG	9.95%	20.41%	23.83%
	CH_F	9.10%	17.57%	24.73%
	CH_MF	7.19%	16.29%	25.04%
	MCG_F	6.71%	17.37%	26.13%
	MCG_MF	10.41%	20.24%	25.91%
	F_MF	8.82%	18.25%	24.36%
Group III	CM	9.26%	17.56%	23.62%
	CM_CH	5.47%	18.50%	21.47%
	CM_MCG	9.94%	18.78%	22.08%
	CM_F	7.64%	20.19%	22.41%
	CM_MF	8.47%	18.65%	23.08%

Summary of decrease in UPF under different stretching percentages are shown in Figure 4-6 and it shows that the magnitude of decrease in UPF were most profound on 30% stretching, followed by 20% and10% regardless of types of samples (Table 4-9).

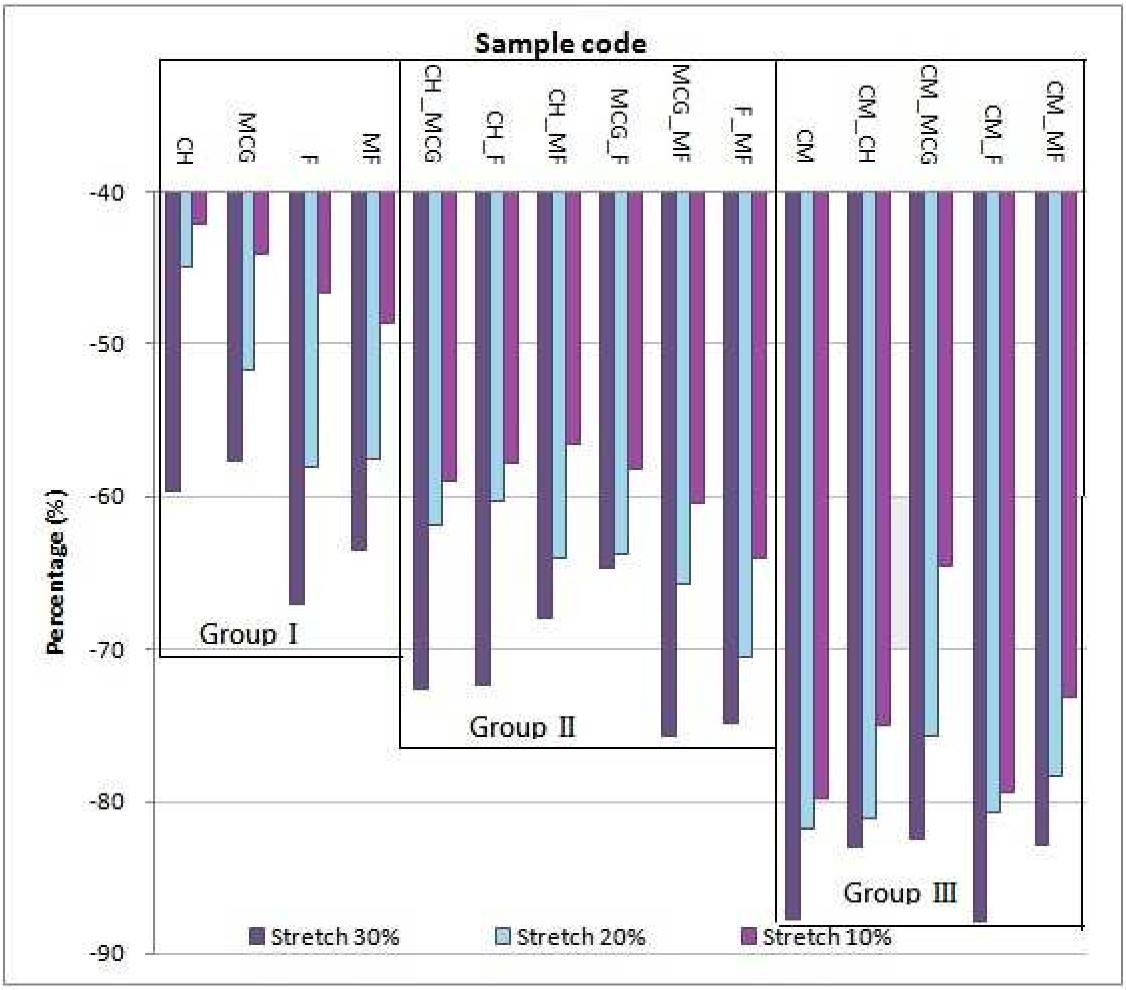


Figure 4-6 Decrease in UPF (%) after stretching of fifteen samples in dry state

4.2.1 Establish Regression Equation for Predicting $UPF_{dry\ and\ stretch}$

UPF of samples stretched 30%, 20% and 10% are averaged to derive an average value. It is difficult to determine the stretching percentage on a particular part of the clothing during wearing, so the three stretching percentages are averaged to get the general value to become the dependant variable for prediction.

Table 4-10 is the Coefficients table which shows the

Intercept,

a = 11.43

Regression coefficients,

b_1 = 2.58, b_2 = -0.64, b_3 = 0.01, b_4 = -0.34

Table 4-10 Coefficients table ($UPF_{\text{dry and stretch}}$)

Model	B	Sig.
(Constant)	11.43	0.00
Tightness Factor	2.58	0.03
Pore Size Ratio	-0.64	0.00
Number of Stitches	0.01	0.02
Fibre Combination	-0.34	0.01

The multiple regression equation of $UPF_{\text{dry and stretch}}$:

$$Y = 11.43 + (2.58\ X_1) + (-0.64\ X_2) + (0.01\ X_3) + (-0.34\ X_4) \text{ .... Equation (8)}$$

$$UPF_{\text{dry and stretch}} = 11.43 + (2.58\ \textit{Tightness Factor}) + (-0.64\ \textit{Pore Size Ratio}) + (0.01\ \textit{Number of Stitches}) + (-0.34\ \textit{Fibre Combination})$$

4.2.1.1 Model Summary ($UPF_{\text{dry and stretch}}$)

Table 4-11 is the model summary where it shows the coefficient of determination is 0.856. This means 85.6% of the variation in the $UPF_{\text{dry and stretch}}$ can be explained by the variables of Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.

Table 4-11 Model Summary table (*UPF* $_{dry\ and\ stretch}$)

R Square (R^2)	
0.856	[interpreted as 85.6%]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF dry and stretch

4.2.1.2 F-test for overall linear Model Significance (*UPF* $_{dry\ and\ stretch}$)

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.

From the ANOVA (analysis of variance) table, the *p*-value ("Sig." in the ANOVA table) of the F-test is 0.00 (Table 4-12), so the value is smaller than α (which was the significance level and its typical value was 0.05). Therefore, the regression model has a significant linear relationship at a significance level of 0.05

Table 4-12 ANOVA table (*UPF* $_{dry\ and\ stretch}$)

Model	Sig.	
Regression	0.00[a]	[*p* - value of F-test]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.

b. Dependent Variable: UPF dry and stretch

4.2.1.3 Verification of the Model Predictive Ability (UPF $_{dry\ and\ stretch}$)

The *UPF* $_{dry\ and\ stretch}$ can be predicted by using Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. In order to test how precise could the regression apply for prediction, verification of the regression is thus needed and results are shown in Table 4-13 as follow. The change in percentages were calculated from (Predicted value - Actual value) / Actual value X 100%.

Table 4-13 Difference (%) between "Actual" and "Predicted" of *UPF* $_{dry\ and\ stretch}$

	Sample code	UPF		Differences (%) between
		Predicted	Actual	"Actual" and "Predicted"
Group I	CH	5.17	5.75	- 9.98%
	MCG	4.95	4.66	+ 6.23%
	F	4.99	5.24	- 4.85%
	MF	4.55	4.54	+ 0.11%
Group II	CH _ MCG	5.20	5.28	- 1.48%
	CH_F	5.46	5.94	+ 2.71%
	CH_MF	5.27	5.84	- 9.90%
	MCG_F	5.18	5.65	- 2.71%
	MCG_MF	4.70	5.22	- 10.00%
	F_MF	5.31	5.81	- 8.62%
Group III	CM	5.41	5.60	+ 2.34%
	CM_CH	6.45	7.06	- 8.63%
	CM_MCG	5.62	6.15	+ 1.83%
	CM_F	6.36	7.06	- 9.92%
	CM_MF	5.40	6.09	- 6.00%
				Average : - 3.92 %

Remarks :

+ : predicted value was Overestimated

-: predicted value was Underestimated

Generally speaking, the multiple linear regression model tends to underestimate *UPF* $_{dry\ and\ stretch}$ and the overall differences of all samples are -3.92%. There are ten out of fifteen samples being underestimated. The worst prediction is -10.00% on sample MCG_MF, while the best prediction is +0.11% on sample MF. All of the fifteen samples between actual and predicted UPF values within 10% variation, and the coefficient of determination (R^2) of the model is 0.856, that means the model can explain 85.6% of total variances by variable of Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. The regression model can be concluded as a successful way in predicting $UPF_{\text{dry and stretch}}$ state even for different fibre combinations.

4.3 Conclusions of UPF at Dry, Relax and Stretch State

For Group I (single cotton), the UPF ratings in this group were compared on two aspects, i.e. on spinning method and on fibre type. Cotton yarns produced from conventional ring spinning method can well protect against UV radiation than torque-free ring spun yarn, and it is believe that the yarn twist number plays an important role in affecting corresponding UPF. As the yarn twist number directly influenced by spinning methods, it can be concluded that spinning method can affect UPF.

When comparison was on the fibre type, Supima cotton yarn can provide better UPF than normal cotton yarn, holding spinning method was the same. It can be explained by the better reflectance of Supima cotton fabric. In short, both fibre type and spinning method would affect UPF of fabrics.

For Group II (cotton/cotton combinations), results suggested that combination of two Supima cotton yarns knitting together could provide better UPF than either two normal cotton yarns combination or one normal cotton knitting with a Supima cotton yarn. The spinning method became less important in affecting UPF in this group.

For Group III (coolmax/cotton combinations), the UPF values were the highest among the three Groups. The results of each blending samples were similar to the samples in Group I but in a higher level, as the presence of Coolmax would increase the protective ability against UV radiation.

When samples were measure under stretched condition in dry state, it exhibited a remarkable reduce in protective power, as pores were opened up and UV radiation is easily penetrate through the poles as shown in Figure 4-4.

In addition, greater stretch percentages came along with greater reduction in UPF, it can be explained by the fact that the amount and the size of pores increased when samples were subjected to greater tension. Summarized downfall of UPF expressing in terms of percentage after stretching in three different extend are shown in Table 4-8.

A general summary of change in UPF of samples under relax and different stretch conditions are show in Table 4-14

Table 4-14 Summary of decrease in UPF (in dry state) at three different percentages

	Samples	UPF in Dry & Relax State	Decrease in UPF under **stretching** in :		
			30% of both directions	20% of both directions	10% of both directions
Group I	CH	11.24	-59.66%	-44.94%	-42.10%
	MCG	9.53	-57.65%	-51.64%	-44.19%
	F	12.27	-67.02%	-58.11%	-46.69%
	MF	10.46	-63.55%	-57.56%	-48.67%
Group II	CH/MCG	14.89	-72.72%	-61.92%	-59.03%
	CH/F	16.29	-72.42%	-60.28%	-57.83%
	CH/MF	15.76	-68.06%	-64.02%	-56.66%
	MCG/F	14.96	-64.76%	-63.70%	-58.16%
	MCG/MF	15.96	-75.72%	-65.73%	-60.46%
	F/MF	19.27	-74.97%	-70.47%	-64.09%
Group III	CM	38.32	-88.39%	-84.29%	-83.51%
	CM/CH	34.84	-83.03%	-81.14%	-75.00%
	CM/MCG	23.94	-82.48%	-75.77%	-64.62%
	CM/F	40.82	-87.97%	-80.70%	-79.42%
	CM/MF	27.88	-82.85%	-78.37%	-73.24%

<u>Chapter 5</u> RESULTS and DISCUSSIONS of UPF on WET, RELAX and STRETCH SAMPLES

In this section, the UPF of the 20Ne cotton yarns, coolmax yarn and their combinations in wet (section 5.1) and stretched state (section 5.2) will be discussed. According to the fibre composition, three groups were summarized including Group I (single cotton yarn), Group II (cotton/cotton combinations) and Group III (coolmax/cotton combinations) for discussion. In addition, structural parameters affecting corresponding UPF values would be analysis and tried to compute and formulate multiple linear regression in order to predict UPF.

5.1 UPF at Wet and Relax State

5.1.1 UPF of Samples Wetted with Five Solutions at Three Pick-up Percentages in Group I (Single Cotton)

Samples CH, MCG, F and MF were wetted separately with five types of solution, i.e., (a) Chlorinated pool water, (b) Sea water, (c) Acidic perspiration, (d) Alkaline perspiration and (e) Deionized water (D.I. water). In addition, each sample was wetted separately at (a) 100%, (b) 75% and (c) 50% pick-up based on the sample weight.

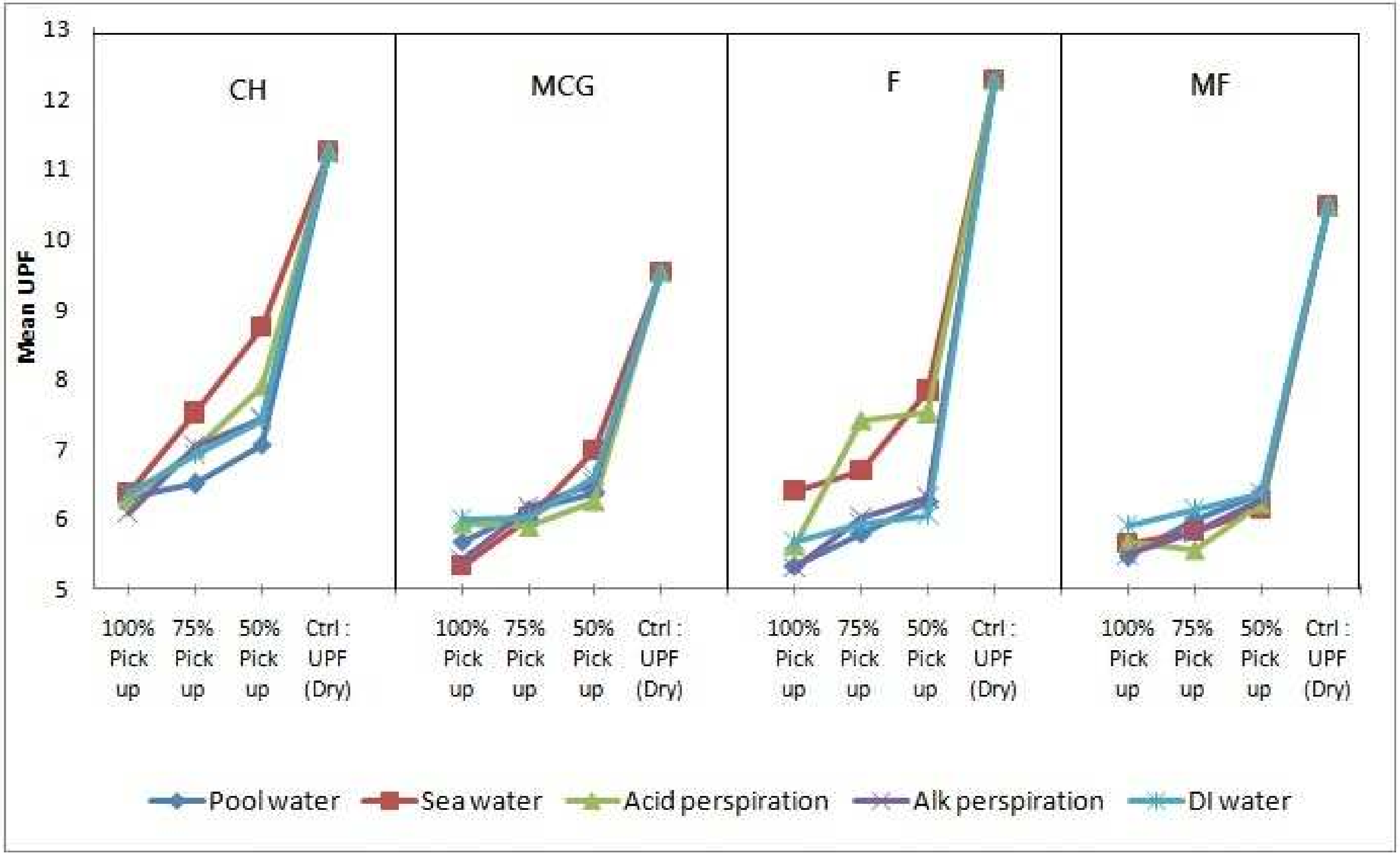
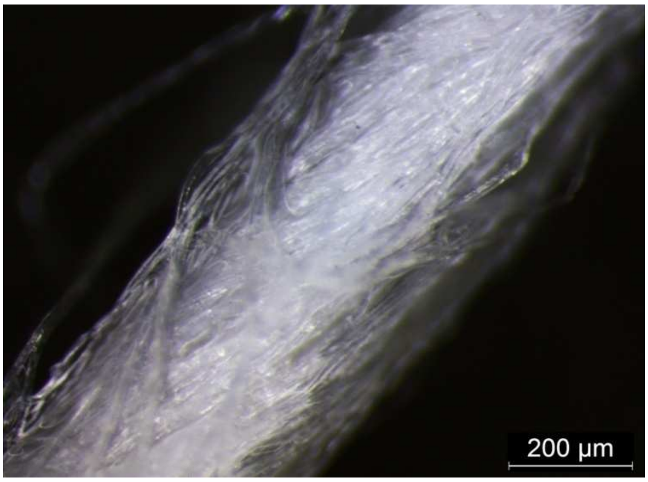


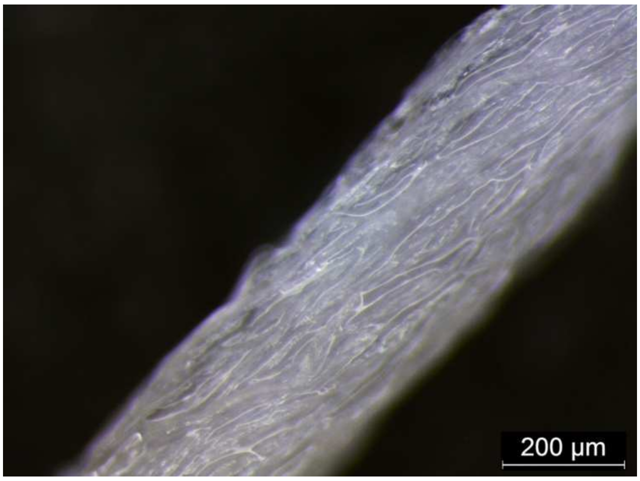
Figure 5-1 UPF of Group I (single cotton) samples after wetting with five solutions at three pick-up percentages

With reference to Figure 5-1, the first observation is low pick-up percentage associated with high UPF regardless of yarn type and it is applicable to the five solutions. Several researches supported that wetted fabric usually exhibit lower UPF values and variation of UV transmission because of the reduced optical scattering effect (Gambichler *et al.*, 2001b; Pairsi *et al.*, 2000; Moon and Pailthorpe, 1995; Pailthorpe, 1994 and Jevtic, 1990).

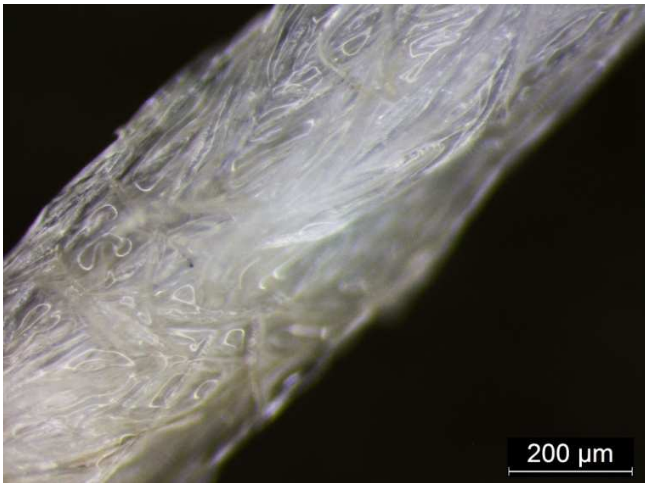
The second observation is a small variation of UPF found on wetted torque-free ring spun yarn samples (Figure 5-1) when compared with conventional ring spun yarn samples (Figure 5-1). In addition, torque-free ring spun yarn samples generally provided lower UPF than conventional ring spun yarn after wetting.

The magnitude of decrease in UPF after wetting at three different liquors pick up ratios were more severer on conventional ring spun samples, i.e. samples "MCG" and "MF" in Group I. It can be explained with reference to microscopic view of yarn types in Group I (wet state) as show in Figure 5-2.

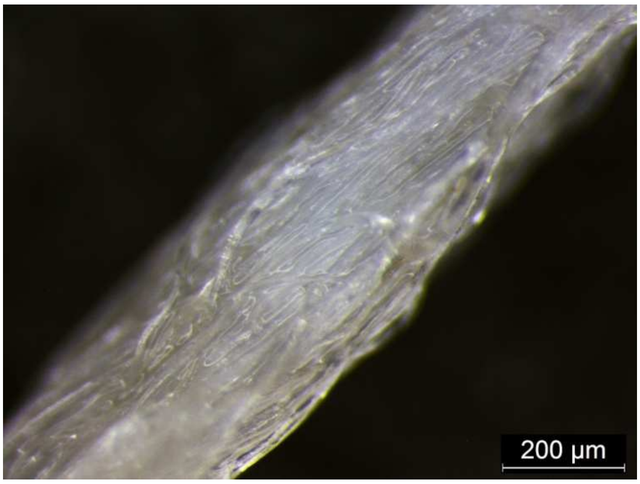




(a) CH



(b) MCG



(c) F

(d) MF

Figure 5-2 Microscopic view of (a) CH, (b) MCG, (c) F and (d) MF yarn wetted with D.I. water

Yarn produced from torque-free ring spinning (ESTex) method is generally with less yarn twist number than conventional ring spun yarn (Kan and Wong, 2011; Murrells *et al*, 2003 and Tao *et al*, 1997a,b). ESTex yarn is bulkier in dry state as less twist number present to bind fibre together. However, once the yarn is immersed in solution, the bulkiness presence in dry state disappear as the surface tension of solution tend to pull fibre close to each other and eventually fill up the bulkiness. The yarn diameters of torque-free spun yarns (MCG and MF) become smaller and only swell at a smaller extend than conventional spun yarns (CH and F) when wetted. Changes in yarn diameter before and after wetting are shown in Table 5-1. UV radiation no longer passes through torque-free spun yarn as easily as it is in dry state on a single yarn level. The yarn diameter of torque-free ring spun yarn (Figure 5-2) becomes smaller in wet state when compared to conventional ring spun yarn (Figure 5-2). Such observation helps to explain smaller variations in UPF of torque-free ring spun yarn samples (MCG" and "MF) in wet state.

Table 5-1 Yarn diameter of yarns in Group I before and after wetting

	Before wetting	After wetting	Increased by
CH	220μm	410μm	46.34%
MCG	225μm	310μm	27.42%
F	240μm	440μm	45.45%
MF	300μm	380μm	21.05%

The reason for generally lower UPF of torque-free ring spun yarn samples (MCG and MF) could also refer to smaller yarn diameter after wetting.

Fibres are closely bound with each other on a single yarn level. However, when yarn diameter became smaller and holding all other factors being constant, the space and the hole in-between loops were bigger than before in dry state on the whole fabric level. This observation may help to explain why torque-free ring spun yarn sample could only yield comparative lower UPF than conventional ring spun yarn sample in wet state.

All in all, no significant variation in UPF after picking up with different solutions of samples find within this group (Figure 5-1).

5.1.2 UPF of Samples Wetted with Five Solutions at Three Pick-up Percentages in Group II (Cotton/cotton combination)

There are six samples in Group II, specifications are shown in Table 5-2.

Table 5-2 Specifications of samples in Group II

Code	Normal cotton	Supima cotton	Conventional ring spinning	Torque-free ring spinning
CH_MCG	CH , MCG	—	CH	MCG
CH_F	CH	F	CH , F	—
CH_MF	CH	MF	CH	MF
MCG_F	MCG	F	F	MCG
MCG_MF	MCG	MF	—	MCG , MF
F_MF	—	F , MF	F	MF

The overall performances regarding UPF in wet state of each sample of Group II are shown in Figure 5-3. The first observation from Figure 5-3 is that low pick-up percentage can yield comparatively high UPF than higher pick-up percentage of each sample that is similar to Group I. Sample "CH_MCG" (normal cotton/normal cotton combination) is the one provides the lowest UPF rating in Group II.

Another finding is only a relatively small variation in UPF when wetted with five types of solutions for two torque-free ring spun yarn combinations (MCG_MF). It may be due to the reduction in yarn diameter together with relatively uniform fibre orientation (Figure 5-2) than wetted conventional ring spun yarn after wetting that may facilitate scattering of UV-radiation . No significant conclusion on absorption of different solution among sample within Group II can be drawn (Figure 5-3 and 5-6).

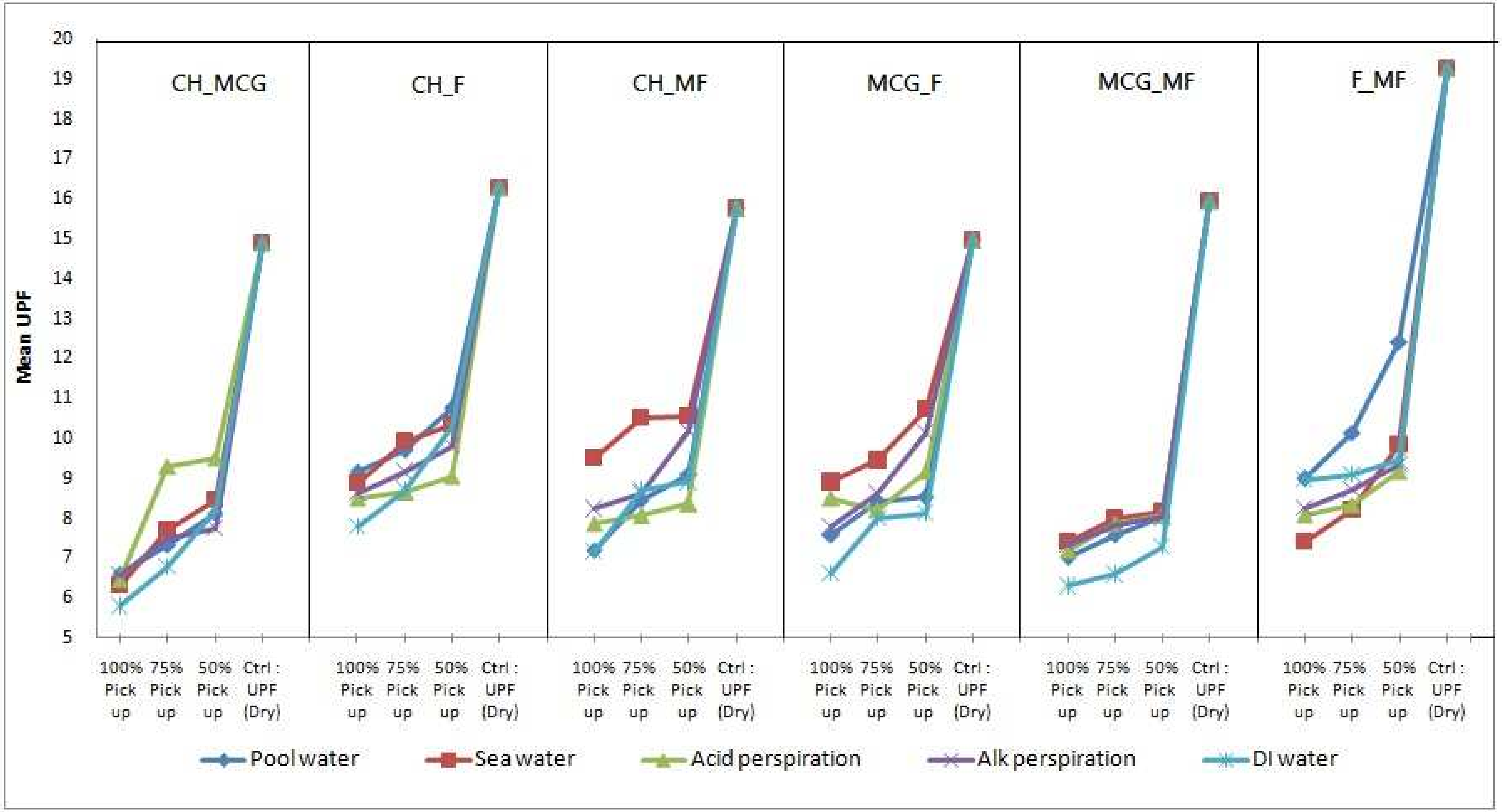


Figure 5-3 UPF of Group II (cotton/cotton combination) samples after wetting with five solutions at three pick-up percentages

5.1.3 UPF of Samples Wetted with Five Solutions at Three Pick-up Percentages in Group III (Coolmax/cotton combination)

Only sample "CM" is produced from pure Coolmax, the other four samples are Coolmax blended with different types of cotton yarns as in Group I. The overall results of samples in Group III were show below in Figure 5-4

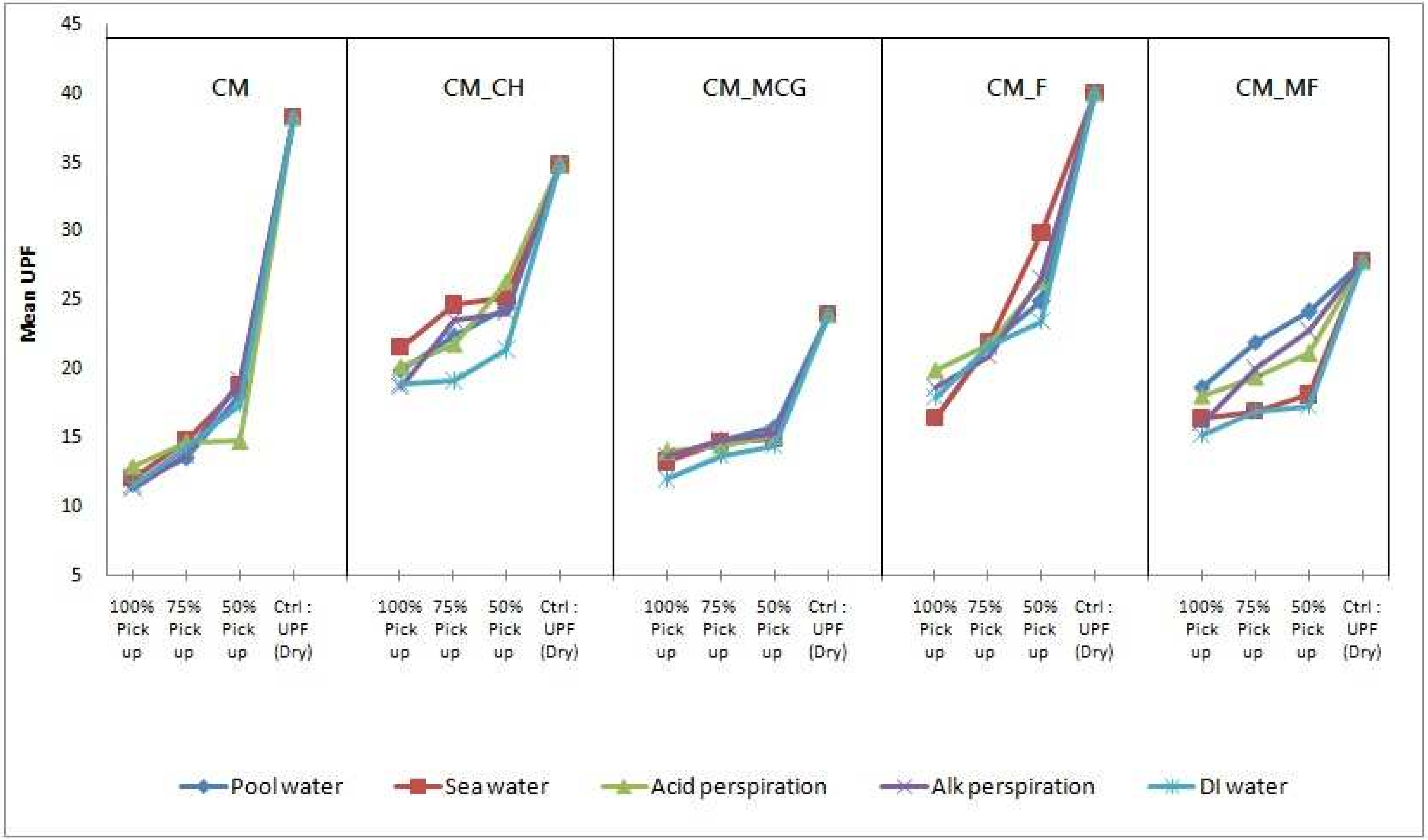


Figure 5-4 UPF of Group III (Coolmax/cotton combination) samples after wetting with five solutions at three pick-up percentages

The variation of UPF of sample "CM" (pure Coolmax sample) after wetting was comparatively small (Figure 5-4) when compared with the other coolmax/cotton combinations. It can be explained by pure coolmax sample itself will not affected by the influence of wetted cotton yarn as it will not absorb solutions but only retain it. Coolmax is hydrophobic in nature and it is different from hydrophilic cotton which will swell with absorption of solution (Welo *et al*., 1952).

5.1.4 Comparison on UPF of Samples wetted with Different Solutions

Section 5.1 shows the behavior of different types of sample after wetted with five solutions and seemingly the effect of each type of solution exerted are similar.

5.1.4.1 Analysis of Mean Values on Different Solution Types

In this section, one way analysis of variance (ANOVA) is carried out to compare mean values of samples after wetting with different solutions so as to examine the relationship among UPF measured after wetting. A general procedure for comparison on mean values starting from

(a) Homogeneity of variances test (section 5.1.4.2)

(b) One way ANOVA (section 5.1.4.3)

(c) Post hoc test (section 5.1.4.4)

Levene's test is used to test for homogeneity (equality) of variances. It can test the null hypothesis that states the variances from population are statistically similar (Gowda *et al*, 2012 and Levene, 1960). If the resulting *p*-value of the Levene's test was greater than the critical value, i.e. 0.05, the obtained variance was very likely (i.e. ≥ 95%) to occur based on random sampling of population with equal variance. Thus, the null hypothesis was not rejected, and it can be concluded there was no statistical differences between the variances of population. The assumption of homogeneity of variance is met. The variances of data in each set of population should be the same. If the variances of data were not the same, then the population may not suitable for undergoing ANOVA, as it is violating one of the assumptions of ANOVA.

After testing the homogeneity of variance of data and if it is not violated, ANOVA was performed. It is used to determine whether there are any significant statistical differences between the means of three or more independent groups. ANOVA is used to test the null hypothesis (H_0) that samples drawn from groups with the same mean values.

$$H_0 : \mu_1 = \mu_2 = \mu_3 \ldots = \mu_k$$

$$H_A : \mu_1 \neq \mu_2 \neq \mu_3 \ldots \neq \mu_k$$

Where "μ" is the mean value of population group and "k" is the number of groups.

The alternative hypothesis (H_A) states that at least two groups' means are statistically different from each other. Generally speaking, if the results of ANOVA are statistically significant, the alternative hypothesis (H_A) will be accepted or rejected the null hypothesis (H_0).

If the resulting p-value is smaller than the confidence level, i.e. 0.05 throughout the research, then the null hypothesis is thus rejected and can be concluded that there is statistically different in the mean values. The test aim to compare means of at least three groups, if there are only two groups, simple t-test was enough (Senn and Richardson, 1994). ANOVA will be study on the differences among various types of solutions.

Even ANOVA indicates there is a relationship among different types of solution, it will not tell how the mean value of one group differ from the other groups nor the exact relationship among different solution types, as ANOVA is a kind of omnibus statistic. Therefore, post hoc test is needed for multiple comparisons to find out mean values difference from each other (Lowry, 2008) in order to reveal the relationships.

5.1.4.2 Homogeneity of Variances Test (comparison on different solution types)

Table 5-3 is the Test of Homogeneity of Variances table that shows whether the variances of data are similar at 95% level of confidence.

Table 5-3 Test of Homogeneity of Variances

		Sig. (*p*-value)	>0.05 or Not	Homogeneity of Variance
Group I	CH	0.46	>0.05	Yes
	MCG	0.49	>0.05	Yes
	F	0.07	>0.05	Yes
	MF	0.77	>0.05	Yes
Group II	CH_MCG	0.30	>0.05	Yes
	CH_F	0.30	>0.05	Yes
	CH_MF	0.87	>0.05	Yes
	MCG_F	0.54	>0.05	Yes
	MCG_MF	0.96	>0.05	Yes
	F_MF	0.09	>0.05	Yes

Group III	CM	0.50	>0.05	Yes
	CM_CH	0.09	>0.05	Yes
	CM_MCG	0.50	>0.05	Yes
	CM_F	0.61	>0.05	Yes
	CM_MF	0.31	>0.05	Yes

In order to understand if the variances of data are homogeneous, the "Sig." (*p*-value) in Table 5-3 should be greater than 0.05 (p-value > 0.05). The null hypothesis that states variances of data in population are the same is not rejected, so the variances of the data set are statistically homogeneous. Thus, the data set is suitable for ANOVA as the assumption is not violated.

5.1.4.3 ANOVA on UPF Mean Values of Wetted with Different Solution Types

In the ANOVA analysis shown in Table 5-4, the *p*-values ("Sig." values in the table) are all greater than 0.05 (p-value > 0.05). It implies there are no statistical difference of each samples when wetted with five different solutions and the null hypothesis (mean values of different solutions absorption have no statistical differences at 95% level of confidence) is not rejected.

Table 5-4 ANOVA table

		df	Sig.(*p*-value)	>0.05 or Not	Interpretation
CH	Between Groups	4	0.48	>0.05	No statistical differences
	Within Groups	10			
MCG	Between Groups	4	0.99	>0.05	No statistical differences
	Within Groups	10			
F	Between Groups	4	0.13	>0.05	No statistical differences
	Within Groups	10			
MF	Between Groups	4	0.80	>0.05	No statistical differences
	Within Groups	10			
CH_MCG	Between Groups	4	0.60	>0.05	No statistical differences
	Within Groups	10			
CH_F	Between Groups	4	0.39	>0.05	No statistical differences
	Within Groups	10			
CH_MF	Between Groups	4	0.48	>0.05	No statistical differences
	Within Groups	10			
MCG_F	Between Groups	4	0.08	>0.05	No statistical differences
	Within Groups	10			
MCG_MF	Between Groups	4	0.07	>0.05	No statistical differences
	Within Groups	10			
F_MF	Between Groups	4	0.17	>0.05	No statistical differences
	Within Groups	10			
CM	Between Groups	4	0.99	>0.05	No statistical differences
	Within Groups	10			
CM_CH	Between Groups	4	0.20	>0.05	No statistical differences
	Within Groups	10			
CM_MCG	Between Groups	4	0.47	>0.05	No statistical differences
	Within Groups	10			
CM_F	Between Groups	4	0.98	>0.05	No statistical differences
	Within Groups	10			
CM_MF	Between Groups	4	0.09	>0.05	No statistical differences
	Within Groups	10			

5.1.4.4 Post hoc Test (comparison on different solution types)

With refer to the ANOVA results from previous section (section 5.1.4.3), as statistics showed that no statistical differences of various solutions absorption for all samples, therefore no post hoc test is thus needed to carry out for finding out statistical differences for all the mean values.

The aim of carrying out ANOVA is to test if the UPF after wetted with different solutions are similar. After ANOVA, it is confirmed that the wetted UPF values derived from different solutions are statistically no differences with each other.

5.1.5 Establish Regression Equation for Predicting $UPF_{\text{wet and relax}}$

UPF of samples wetted separately with 100%, 75% and 50% of its weight and then average to derive an average value. It is difficult to determine the pick-up percentage on a particular part of the clothing during wearing, so the three pick-up percentages are average to get the general value to become the dependant variable for prediction.

As the ANOVA in section 5.1.4.3 suggests that there is no statistical differences on UPF derive from samples wetted with the five types of solutions, D.I. water was chosen as the dependant variable for prediction. As clothing generally has greater chances come in contact with water than the other solution types during daily use. Table 5-5 is the Coefficients table of $UPF_{\text{wet and relax}}$ which shows

Intercept,

$a = 7.58$

Regression coefficients,

$b_1 = -6.37$, $b_2 = -1.15$, $b_3 = 0.17$, $b_4 = 3.49$

Table 5-5 Coefficients table ($UPF_{\text{wet and relax}}$)

Model	B	Sig.
(Constant)	7.58	0.00
Tightness Factor	-6.37	0.01
Pore Size Ratio	-1.15	0.03
Number of Stitches	0.17	0.02
Fibre Combination	3.49	0.03

The multiple regression equation of $UPF_{\text{wet and relax}}$:

$$Y = 7.58 + (-6.37\ X_1) + (-1.15\ X_2) + (0.17\ X_3) + (3.49\ X_4) \text{ …. Equation (9)}$$

$$UPF_{\text{wet and relax}} = 7.58 + (-6.37\ \textit{Tightness Factor}) + (-1.15\ \textit{Pore Size Ratio}) + (0.17\ \textit{Number of Stitches}) + (3.49\ \textit{Fibre Combination})$$

5.1.5.1 Model Summary ($UPF_{\text{wet and relax}}$)

Table 5-6 is the model summary where it shows the coefficient of determination is 0.818. This means 81.8% of the variation in the $UPF_{\text{wet and relax}}$ can be explained by the variables of Tightness Factor, Pore Size ratio, Number of Stitches and Fibre Combination.

Table 5-6 Model Summary table (*UPF* $_{wet\ and\ relax}$)

R Square (R^2)	
0.818	[interpreted as 81.8%]

a. Predictors: (Constant), Tightness Factor, Pore Size ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF D.I. and relax

5.1.5.2 F-test for overall linear Model Significance (*UPF* $_{wet\ and\ relax}$)

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

From the ANOVA (analysis of variance) table, the *p*-value ("Sig." in the ANOVA table) of the F-test is 0.00 (Table 5-7), so the value is smaller than α (which was the significance level and its typical value was 0.05). Therefore, the regression model has a significant linear relationship at a significance level of 0.05

Table 5-7 ANOVA table (*UPF* $_{wet\ and\ relax}$)

Model	Sig.	
Regression	0.00[a]	[*p* - value of F-test]

a. Predictors: (Constant), Tightness Factor, Pore Size ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF D.I. and relax

5.1.5.3 Verification of the Model Predictive Ability (UPF $_{wet\ and\ relax}$)

The *UPF* $_{wet\ and\ relax}$ can be predicted by using Tightness Factor, Pore Size ratio, Number of Stitches and Fibre Combination. In order to test how precise could the regression apply for prediction, verification of the regression is thus needed and results are shown in Table 5-8. The change in percentages were calculated by

(Predicted value - Actual value) / Actual value X 100%.

Table 5-8 Difference (%) between "Actual" and "Predicted" of $UPF_{wet\ and\ relax}$

	Sample code	UPF Predicted	UPF Actual	Differences (%) between "Actual" and "Predicted"
Group I	CH	6.46	6.90	+ 1.33%
	MCG	5.67	6.21	- 5.56%
	F	5.49	5.89	- 3.21%
	MF	6.43	6.14	+ 8.74%
Group II	CH _ MCG	5.77	6.93	- 0.48%
	CH_F	7.74	8.94	- 0.75%
	CH_MF	7.30	8.26	+ 1.62%
	MCG_F	6.48	7.58	- 2.14%
	MCG_MF	5.79	6.73	- 8.10%
	F_MF	8.55	9.18	- 4.77%
Group III	CM	12.97	14.41	+ 12.69%
	CM_CH	18.04	19.82	- 4.68%
	CM_MCG	13.28	13.36	+ 10.81%
	CM_F	19.47	21.01	+ 8.54%
	CM_MF	16.66	16.50	+ 9.68%
				Average : + 1.58 %

Remarks :

+ : predicted value was Overestimated

- : predicted value was Underestimated

Generally speaking, the multiple linear regression model tends to underestimate $UPF_{wet\ and\ relax}$ and the average differences of all samples are +1.58%. There are eight out of fifteen samples being underestimated. The worst prediction is +10.81% on sample CM_MCG, while the best prediction is -0.48% on sample CH_MCG. There are thirteen samples between actual and predicted UPF values within 10% variation, the coefficient of determination (R^2) of the model is 0.818, and this means 81.8% of the total variances can be explained by Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. The regression model can be concluded as a successful way in predicting $UPF_{wet\ and\ relax}$ state even for blended fibre combinations.

5.2 UPF at Wet and Stretch State

According to previous research (Osterwalder *et al.*, 2000) when the same fabric under stretched condition would exhibit remarkable decrease in UPF and summarized the findings in Figure 5-8.

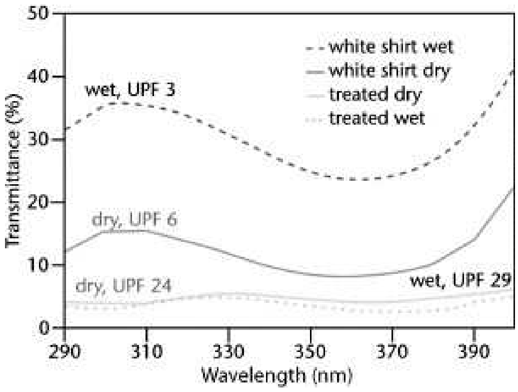


Figure 5-5 Transmission of UV through fabric when dry and wet
(Osterwalder *et al*, 2000)

After wetting the samples with solutions, the UPF dropped remarkable than in dry state. In order to understand how severs decrease in UPF when subjected to wetting and stretching at the same time, the most extreme condition was selected, i.e.

(a) Stretching 30% in both lengthwise and cross-machine directions

(b) Wetting at 100% pick-up

based on sample weight with the following solutions separately, (a) Chlorinated pool water, (b) Sea water, (c) Acidic perspiration, (d) Alkaline perspiration and (e) D.I. water.

As the synchronize effect of wetting and stretching does dominate and outweigh the effect of fibre types and spinning methods on a single yarn level, the overall performance of all three Groups would be discussed and illustrated altogether as a whole in the following Figure 5-9.

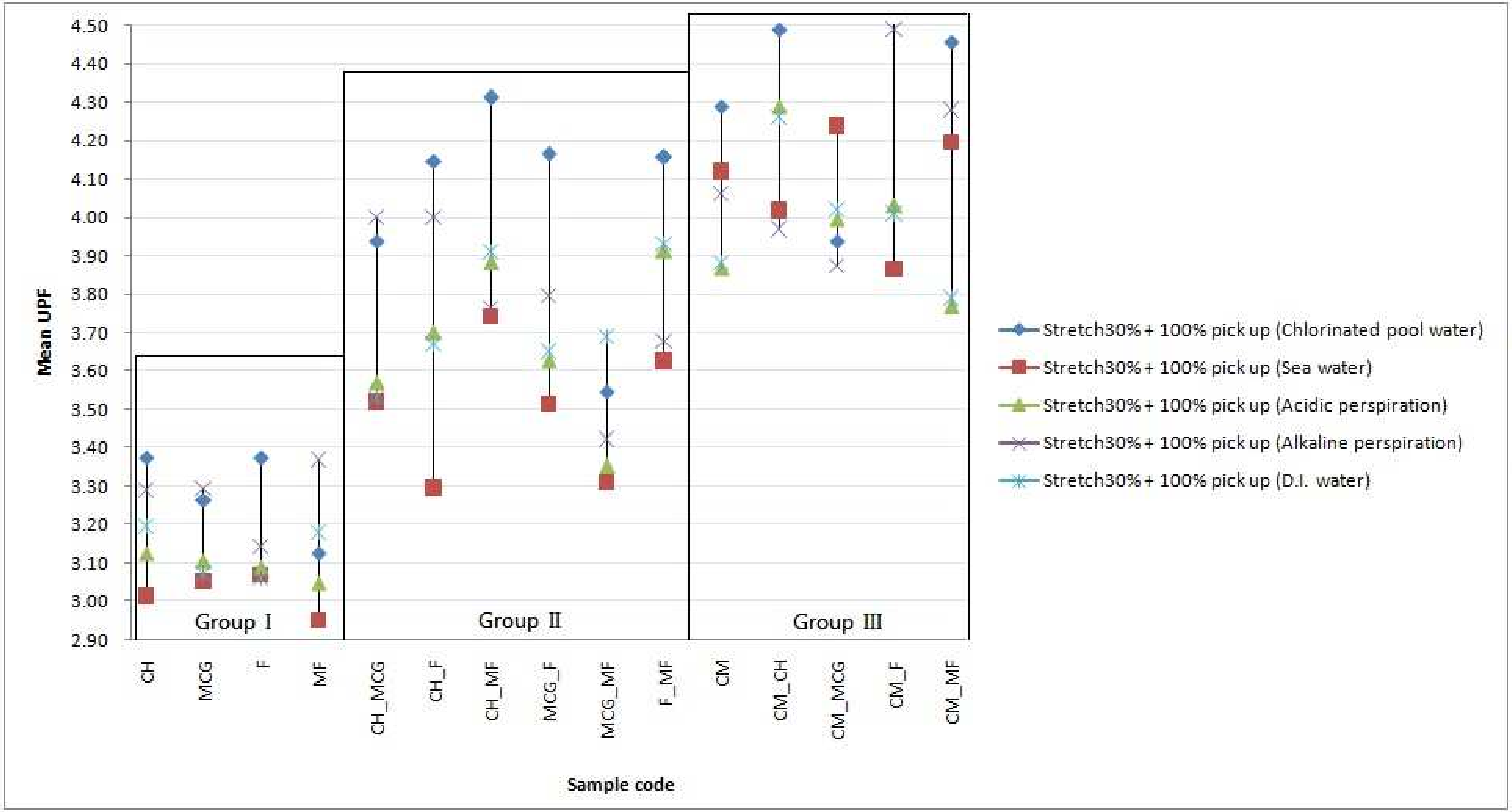


Figure 5-6 Overall performances of all samples subjected to 100% pick-up and 30% stretching

With reference to Figure 5-9, all samples are further reduced in their protective ability against UV radiation when subjected to wetting at 100% pick-up and 30% stretching in both lengthwise and cross machine directions at the same time.

The UPF_{sea} is generally lower in Group I (single cotton) and Group II (cotton/cotton combinations), no significant variation in Group III (coolmax/cotton combinations). It may be due to the surface rupture caused by sea water and thus reduce reflection. Above observation further suggested sea water did not affect synthetic fibre as severs as cellulose fibre. The surface ruptures were increase of cotton fibre (cellulose fibre) after exposure to sea water which is confirmed with the findings of Canetta *et al*. (2009).

The $UPF_{chlorinated\ pool}$ is generally higher than the UPF after absorption of the remaining solutions, especially profound in Group I and Group II, both of which are cotton fibres only. It may be explained by sodium hypochlorite is a kind of bleaching agent that whitening cotton fibre that may promote reflection.

Stretching may help to reveal the deteriorations bring out by solutions, as the UPF derive under both wetting and stretching show different from solution types.

5.2.1 Establish Regression Equation for Predicting $UPF_{wet\ and\ stretch}$

UPF of samples wetted 100%, 75% and 50% of its weight and then average to derive an average value. It is difficult to determine the pick-up percentage on a particular part of the clothing during wearing, so the three pick-up percentages are average to get the general value to become the dependant variable for prediction.

As the ANOVA in section 5.1.4.3 suggests that there are no statistical differences on UPF derive from samples wetted with the five types of solutions, therefore averaged values from 100%, 75% and 50% pick-up of D.I. water and 30% stretching of sample was chosen as the dependant variable for prediction. As clothing generally has greater chances come in contact with water and at the same time subjected to stretching during daily use.

Table 5-9 is the Coefficients table of $UPF_{\text{wet and stretch}}$ which shows the

Intercept,

$a = 7.85$

Regression coefficients,

$b_1 = -0.46$, $b_2 = -0.20$, $b_3 = -0.01$, $b_4 = 0.27$

Table 5-9 Coefficients table (*UPF* $_{wet\ and\ stretch}$)

Model	B	Sig.
(Constant)	7.85	0.00
Tightness Factor	-0.46	0.04
Pore Size Ratio	-0.20	0.02
Number of Stitches	-0.01	0.00
Fibre Combination	0.27	0.00

The multiple regression equation of *UPF* $_{wet\ and\ stretch}$:

Y = 7.85 + (-0.46 X_1) + (-0.20 X_2) + (-0.01 X_3) + (0.27 X_4) .... Equation (10)

UPF $_{wet\ and\ stretch}$ = 7.85 + (-0.46 *Tightness Factor*) + (-0.20 *Pore Size Ratio*) + (-0.01 *Number of Stitches*) + (0.27 *Fibre Combination*)

5.2.2 Model Summary (*UPF* $_{wet\ and\ stretch}$)

Table 5-10 is the model summary where it shows the coefficient of determination is 0.839. This means 83.9% of the variation in the *UPF* $_{wet\ and\ stretch}$ can be explained by the variables of Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.

Table 5-10 Model Summary table (*UPF* $_{wet\ and\ stretch}$)

R Square (R^2)	
0.839	[interpreted as 83.9%]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF D.I. and stretch

5.2.3 F-test for overall linear Model Significance (*UPF* $_{wet\ and\ stretch}$)

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

From the ANONA (analysis of variance) table, the *p*-value ("Sig." in the ANOVA table) of the F-test is 0.00 (Table 5-11), so the value is smaller than α (which was the significance level and its typical value was 0.05). Therefore, the regression model has a significant linear relationship at a significance level of 0.05

Table 5-11 ANOVA table (UPF $_{wet\ and\ stretch}$)

Model	Sig.	
Regression	0.00[a]	[*p* - value of F-test]

a. Predictors: (Constant), Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination

b. Dependent Variable: UPF D.I. & stretch

5.2.4 Verification of the Model Predictive Ability (*UPF* $_{wet\ and\ stretch}$)

The *UPF* $_{wet\ and\ stretch}$ can be predicted by using Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. In order to test how precise could the regression apply for prediction, verification of the regression is thus needed and results are shown in Table 5-12 as below. The change in percentages were calculated by (Predicted value - Actual value) / Actual value X 100%.

Table 5-12 Difference (%) between "Actual" and "Predicted" of *UPF* $_{wet\ and\ stretch}$

	Sample code	UPF		Differences (%) between
		Predicted	Actual	"Actual" and "Predicted"
Group I	CH	3.05	3.19	+ 1.45%
	MCG	3.05	3.05	+ 0.21%
	F	3.17	3.07	+ 0.77%
	MF	3.07	2.95	+ 0.66%
Group II	CH _ MCG	3.45	3.52	- -1.67%
	CH_F	3.54	3.29	+ 0.52%
	CH_MF	3.49	3.74	- -0.73%
	MCG_F	3.46	3.51	+ 2.63%
	MCG_MF	3.51	3.69	+ 0.65%
	F_MF	3.50	3.63	- -5.97%
Group III	CM	3.83	4.12	+ 0.63%
	CM_CH	4.09	4.02	+ 6.94%
	CM_MCG	4.26	4.24	+ 5.62%
	CM_F	4.09	3.86	+ 3.57%
	CM_MF	4.19	4.20	+ 12.79%
				Average : + 1.87 %

Remarks :

+ : predicted value was Overestimated

- : predicted value was Underestimated

Generally speaking, the multiple linear regression model tends to overestimate *UPF* $_{wet\ and\ stretch}$ and the overall differences of all samples are about +1.87%. There are three out of fifteen samples being underestimated. The worst prediction is +12.79% on sample CM_MF, while the best prediction is +0.21% on sample MCG. There were eleven samples between actual and predicted UPF values within 10% variation, the coefficient of determination (R^2) of the model is 0.839, and this mean 83.9% of the total variance can be explained by Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.. The regression model can be concluded as a successful way in predicting $UPF_{\ wet\ and\ stretch}$ state even for blended fibre combinations.

5.3 Conclusions on UPF of Wetted Samples in All three Groups

Fifteen kinds of plain knitted fabrics are produce for this research and further divide them into three groups mainly based on the nature of fibre type.

Group I consists of CH, MCG, F and MF (cotton fibre);

Group II consists of CH_MCG, CH_F, CH_MF, MCG_F, MCG_MF and F_MF;

Group III consists of CM (Coolmax), CM_CH, CM_MCG, CM_F, CM_MF.

5.3.1 UPF of Group I in Wet State

Effect of wetness can be concluded as high pick-up percentage of solution (chlorinated pool water, sea water, acidic perspiration, alkaline perspiration and D.I. water) provided low UPF regardless of solution type. It can be explained the fact that wetness and retention of liquor reduce scattering.

The second observation is a lower UPF and a small variation of UPF find on torque-free ring spun yarn in wet state. The bulkiness of torque-free ring spun yarn presence in dry state is bind by the surface tension of solution when wetted and pulls fibre close with each other, and eventually fills up the bulkiness. Thus, UV radiation could no longer pass through torque-free spun yarn as easily as it is in dry state on a single yarn level.

Comparative lower UPF of torque-free ring spun yarn may be explained by the yarn diameter become smaller of sample "MCG" and "MF" (torque-free ring spun yarn sample) after wetting. Fibres are eventually closely pulled with each other on a single yarn level. When the yarn diameter became smaller and holding all other factors being constant, the space and the hole in-between loops were bigger than before when it is in dry state on the whole fabric level. This observation may help to explain the reason for torque-free ring spun yarn sample can only yield comparative lower UPF than conventional ring spun yarn sample in wet state.

5.3.2 UPF of Group II in Wet State

The first observation is low pick-up percentage provided comparatively high UPF than wetted with higher pick-up percentage of each sample that is similar to Group I. Two normal cotton combination's samples "CH_MCG" is the one provided lowest UPF in Group II.

Another finding is two torque-free ring spun yarn combinations, sample "MCG_MF" behave steadily when wetted, i.e. only a relatively small variation in UPF when wetted with five types of solutions. It may be due to reduce in yarn diameter together with relatively uniform fibre orientation than wetted conventional ring spun yarn after wetting that may hinder UV radiation.

5.3.3 UPF of Group III in Wet State

The variation of UPF of sample "CM" (pure Coolmax sample) after wetting is comparatively small when compare with the other coolmax/cotton combinations. It can be explained by pure coolmax sample itself will not affected by the influence of wetted cotton yarn as it will not absorb solutions but only retain it. Coolmax is hydrophobic in nature and it is different from hydrophilic cotton which will swell with absorption of solution (Welo *et al*., 1952).

Table 5-13 Summary of decrease in UPF (%) after wetting

Samples	**UPF** in Dry & Relax State	**UPF** in Dry & Stretch State [1]	Decrease in UPF at relax / (stretching) after **wetting** [2] with :							
			Chlorinated Pool Water		Sea Water		Acidic Perspiration		Alkaline Perspiration		D.I. Water	
CH	11.2	(5.75)	-69.98%	(-41.25%)	-71.59%	(-44.40%)	-72.20%	(-45.60%)	-70.74%	(-42.73%)	-73.23%	(-47.61%)
MCG	9.5	(4.66)	-65.76%	(-29.89%)	-67.97%	(-34.42%)	-67.42%	(-33.30%)	-65.44%	(-29.24%)	-67.79%	(-34.06%)
F	12.3	(5.24)	-72.50%	(-35.63%)	-74.98%	(-41.44%)	-74.81%	(-41.05%)	-74.38%	(-40.04%)	-75.06%	(-41.63%)
MF	10.5	(4.54)	-70.11%	(-31.14%)	-71.79%	(-35.01%)	-70.87%	(-32.89%)	-67.79%	(-25.80%)	-69.60%	(-29.97%)
CH_MCG	14.9	(5.28)	-73.56%	(-25.39%)	-76.36%	(-33.31%)	-76.02%	(-32.34%)	-73.13%	(-24.20%)	-76.29%	(-33.11%)
CH_F	16.3	(5.94)	-74.54%	(-30.24%)	-79.77%	(-44.57%)	-77.28%	(-37.73%)	-75.45%	(-32.74%)	-77.47%	(-38.26%)
CH_MF	15.8	(5.84)	-72.64%	(-26.21%)	-76.26%	(-35.98%)	-75.36%	)-33.55%)	-76.12%	(-35.60%)	-75.19%	(-33.10%)
MCG_F	15.0	(5.65)	-72.14%	(-26.29%)	-76.52%	(-37.88%)	-75.74%	(-35.81%)	-74.64%	(-32.89%)	-75.60%	(-35.45%)
MCG_MF	16.0	(5.22)	-77.77%	(-32.02%)	-76.88%	(-29.29%)	-78.99%	(-35.75%)	-78.56%	(-34.43%)	-79.26%	(-36.57%)
F_MF	19.3	(5.81)	-78.43%	(-28.46%)	-81.18%	(-37.60%)	-79.69%	(-32.65%)	-80.92%	(-36.73%)	-79.61%	(-32.37%)

CM	38.3	(5.60)	-88.80%	(-23.35%)	-89.25%	(-26.38%)	-89.90%	(-30.85%)	-89.41%	(-27.46%)	-89.87%	(-30.67%)
CM_CH	34.8	(7.06)	-87.11%	(-36.42%)	-88.47%	(-43.12%)	-87.69%	(-39.28%)	-88.61%	(-43.81%)	-87.77%	(-39.69%)
CM_MCG	23.9	(6.15)	-83.55%	(-36.02%)	-82.30%	(-31.13%)	-83.31%	(-35.08%)	-83.82%	(-37.06%)	-83.21%	(-34.68%)
CM_F	40.8	(7.06)	-88.94%	(-36.08%)	-90.53%	(-45.30%)	-90.12%	(-42.93%)	-89.00%	(-36.42%)	-90.18%	(-43.23%)
CM_MF	27.9	(6.09)	-84.01%	(-26.82%)	-84.95%	(-31.11%)	-86.48%	(-38.12%)	-84.65%	(-29.73%)	-86.41%	(-37.77%)

[1] Averaged UPF value measured under 30%, 20% and 10% stretching in both directions at the same time at dry state

[2] Averaged UPF value measured at 100%, 75% and 50% pick-up of each solution type

5.3.4 UPF of Wetted and Stretched Samples in all three Groups

The UPF values are further reduced when samples subjected to wetted and stretched condition at the same time. Not only wetness on fibre generally reduce scattering, but also pores are opened up when stretching thirty percentages in both machine and cross machine directions. It may explain the reason of further reduce in UPF.

The UPF_{sea} is no longer the highest among wetted with other types of solutions when samples are stretched which is different from the observation find when samples subjected to wetting solely but not stretching.

Table 5-14 Summary of decrease in UPF (%) after wetting and stretching

Samples	**UPF** in Dry & Relax State	**UPF** in Dry & Stretch State	**UPF** in Wet & Relax State	Decrease in UPF after **stretching** and **wetting** with :														
				Chlorinated Pool Water			Sea Water			Acidic Perspiration			Alkaline Perspiration			D.I. Water		
CH	11.2	5.75	**6.38**	-69.98%	-37.63%	**-47.07%**	-71.59%	-40.97%	**-49.91%**	-72.20%	-42.25%	**-50.99%**	-70.74%	-39.20%	**-48.40%**	-73.23%	-44.37%	**-52.79%**
MCG	9.5	4.66	**6.00**	-65.76%	-28.19%	**-45.60%**	-67.97%	-32.82%	**-49.11%**	-67.42%	-31.67%	**-48.24%**	-65.44%	-27.52%	**-45.10%**	-67.79%	-32.45%	**-48.83%**
F	12.3	5.24	**5.67**	-72.50%	-42.82%	**-40.52%**	-74.98%	-47.98%	**-45.88%**	-74.81%	-47.64%	**-45.53%**	-74.38%	-46.73%	**-44.59%**	-75.06%	-48.14%	**-46.06%**
MF	10.5	4.54	**5.91**	-70.11%	-37.30%	**-47.12%**	-71.79%	-40.83%	**-50.09%**	-70.87%	-38.89%	**-48.46%**	-67.79%	-32.44%	**-43.02%**	-69.60%	-36.24%	**-46.22%**
CH_MCG	14.9	5.28	**5.80**	-73.56%	-44.93%	**-32.12%**	-76.36%	-50.77%	**-39.32%**	-76.02%	-50.06%	**-38.44%**	-73.13%	-44.05%	**-31.03%**	-76.29%	-50.63%	**-39.14%**
CH_F	16.3	5.94	**7.80**	-74.54%	-47.21%	**-46.85%**	-79.77%	-58.06%	**-57.77%**	-77.28%	-52.88%	**-52.55%**	-75.45%	-49.10%	**-48.75%**	-77.47%	-53.28%	**-52.96%**
CH_MF	15.8	5.84	**7.18**	-72.64%	-43.24%	**-39.92%**	-76.26%	-50.75%	**-47.87%**	-75.36%	-48.88%	**-45.89%**	-76.12%	-50.45%	**-47.55%**	-75.19%	-48.53%	**-45.52%**
MCG_F	15.0	5.65	**6.62**	-72.14%	-42.03%	**-37.02%**	-76.52%	-51.14%	**-46.92%**	-75.74%	-49.52%	**-45.15%**	-74.64%	-47.22%	**-42.66%**	-75.60%	-49.23%	**-44.84%**
MCG_MF	16.0	5.22	**6.30**	-77.77%	-53.80%	**-43.70%**	-76.88%	-51.94%	**-41.44%**	-78.99%	-56.33%	**-46.78%**	-78.56%	-55.44%	**-45.70%**	-79.26%	-56.89%	**-47.47%**
F_MF	19.3	5.81	**8.98**	-78.43%	-55.37%	**-53.70%**	-81.18%	-61.07%	**-59.61%**	-79.69%	-57.98%	**-56.41%**	-80.92%	-60.53%	**-59.05%**	-79.61%	-57.81%	**-56.23%**
CM	38.3	5.60	**11.51**	-88.80%	-77.11%	**-62.73%**	-89.25%	-78.02%	**-64.21%**	-89.90%	-79.35%	**-66.38%**	-89.41%	-78.34%	**-64.73%**	-89.87%	-79.30%	**-66.29%**
CM_CH	34.8	7.06	**18.93**	-87.11%	-73.65%	**-76.28%**	-88.47%	-76.43%	**-78.78%**	-87.69%	-74.84%	**-77.35%**	-88.61%	-76.71%	**-79.04%**	-87.77%	-75.01%	**-77.50%**
CM_MCG	23.9	6.15	**11.98**	-83.55%	-66.19%	**-67.14%**	-82.30%	-63.61%	**-64.63%**	-83.31%	-65.70%	**-66.66%**	-83.82%	-66.74%	**-67.67%**	-83.21%	-65.48%	**-66.45%**
CM_F	40.8	7.06	**17.94**	-88.94%	-77.44%	**-74.84%**	-90.53%	-80.69%	**-78.47%**	-90.12%	-79.86%	**-77.53%**	-89.00%	-77.56%	**-74.97%**	-90.18%	-79.96%	**-77.65%**
CM_MF	27.9	6.09	**15.19**	-84.01%	-67.16%	**-70.65%**	-84.95%	-69.09%	**-72.37%**	-86.48%	-72.24%	**-75.18%**	-84.65%	-68.47%	**-71.82%**	-86.41%	-72.08%	**-75.04%**

UPF $_{\textit{wet and stretch}}$ compare with the UPF of averaged value of 100%, 75% and 50% pick-up of each solution type and Stretching 30% in both directions

Chapter 6 CONCLUSIONS and RECOMMENDATIONS

6.1 Conclusions on the UPF

Fifteen samples were divided into three groups based on the fibre composition. Group I (single cotton yarn), Group II (cotton/cotton combinations) and Group III (coolmax/cotton combinations) for discussion.

6.1.1 UPF at Dry and Relax State

For Group I (single cotton), the UPF ratings in this group were compared on two aspects, i.e. on spinning method and on fibre type. Cotton yarns produced from conventional ring spinning can better protect against UV radiation than torque-free ring spun yarn, and it is believed that the yarn twist number did play an important role in affecting corresponding UPF. It can conclude that spinning method can affect UPF.

While comparing on fibre type, Supima cotton yarn can provide better UPF than normal cotton yarn, holding spinning method was the same. It can be explained by better reflectance of Supima cotton fabric. In short, both fibre type and spinning method would affect UPF of fabrics.

For Group II (cotton/cotton combinations), results suggested that combination of two Supima cotton yarns knitted together could provide better UPF than either two normal cotton yarns blending or one normal cotton blended with a Supima cotton yarn. The spinning method became less important in affecting UPF in this group.

For Group III (coolmax/cotton combinations), the UPF values were the highest among the three groups. The results of each blending samples were similar to the samples in Group I but in a higher level, as the presence of Coolmax would increase the protective ability against UV radiation.

6.1.2 UPF at Dry and Stretch State

When samples were measured under stretched condition in dry state, it exhibited a remarkable reduce in protective power, as pores were open up and UV radiation is easily penetrate through the samples. In addition, no exception for greater stretch percentage came along with greater extend of reduce in UPF, it could be explained by the fact that the amount and the size of pores increased when samples were subjected to greater tension.

6.1.3 UPF at Wet and Relax State

The variation of UPF of sample "CM" (pure Coolmax sample) after wetting was comparatively small when compared with the other coolmax/cotton combinations. It can be explained by pure coolmax sample itself will not affected by the influence of wetted cotton yarn as it will not absorb solutions but only retain it. Coolmax was hydrophobic in nature and it was different from hydrophilic cotton which will swell with absorption of solution (Welo *et al*., 1952).

6.1.4 UPF at Wet and Stretch State

The UPF were further reduce when samples subjected to wetness and stretched condition at the same time. Not only wetness on fibre generally reduce scattering, but also pores were opened up when stretched thirty percentages in both machine and cross machine directions. It may explain the reason of further reduce in UPF.

The UPF_{sea} was no longer highest among wetted than other types of solutions. When samples were stretched which is different from the observations of samples in only wetted condition.

6.2 Conclusions on the Regression Models

Regression models were computed for prediction UPF at different end use conditions. Including

(a) Prediction on $UPF_{dry\ and\ relax}$ (section 6.2.1);

(b) Prediction on $UPF_{dry\ and\ stretch}$ (section 6.2.2);

(c) Prediction on $UPF_{wet\ and\ relax}$ (section 6.2.3);

(d) Prediction on $UPF_{wet\ and\ stretch}$ (section 6.2.4).

6.2.1 Regression Model for Predicting *UPF* $_{dry\ and\ relax}$

Several physical performances tests were performed on yarn and fabric to evaluate possible factors (physical properties) affecting UPF ratings. However, not all of the factors were significantly affecting the UPF. Regarding prediction on *UPF* $_{dry\ and\ relax}$, Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination, were the four factors used in the development of the multiple linear regression for predicting *UPF* $_{dry\ and\ relax}$.

Generally speaking, the multiple linear regression model (*UPF* $_{dry\ and\ relax}$) tends to underestimated by 2.55%. There are six out of fifteen samples being overestimated. The worst prediction was -17.01% on sample F_MF, while the best prediction was +0.92% on sample CM_CH. There are twelve samples differences between actual and predicted UPF values within 10% variation. The coefficient of determination (R^2) of the model is 0.900, that means it can explain 90.0% of the total variance by the variables of fibre combination, Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination, the regression model can be concluded as a successful way in predicting *UPF* $_{dry\ and\ relax}$ state even for blended fibre combinations.

6.2.2 Regression Model for Predicting *UPF* $_{dry\ and\ stretch}$

Regarding computing prediction model for *UPF* $_{dry\ and\ stretch}$, Tightness Factor, Pore

Size Ratio, Number of Stitches and Fibre Combination, were the four factors used in the development of the multiple linear regression for predicting $UPF_{\text{dry and stretch}}$.

The overall variation of the regression model was underestimated 3.92%, and there were ten out of fifteen samples being underestimated. The worst prediction is -10.00% on sample MCG_MF, while the best prediction is +0.11% on sample MF. All of the fifteen samples between actual and predicted UPF values within 10% variation, and the coefficient of determination (R^2) of the model is 0.856, that means the model can explain 85.6% of total variances by variable of Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. The regression model can be concluded as a successful way in predicting $UPF_{\text{dry and stretch}}$ state even for different fibre combinations.

6.2.3 Regression Model for Predicting $UPF_{\text{wet and relax}}$

Regarding computing prediction model for $UPF_{\text{wet and relax}}$, Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination were the four factors used in the development of the multiple linear regression for predicting $UPF_{\text{wet and relax}}$.

The overall variation of the regression model was overestimated by 1.58%. There are eight out of fifteen samples being underestimated. The worst prediction is +10.81% on sample CM_MCG, while the best prediction is -0.48% on sample CH_MCG. There are thirteen samples between actual and predicted UPF values within 10% variation, the coefficient of determination (R^2) of the model is 0.818, and this means 81.8% of the total variances can be explained by Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination. The regression model can be concluded as a successful way in predicting $UPF_{\textit{wet and relax}}$ state even for blended fibre combinations.

6.2.4 Regression Model for Predicting $UPF_{\textit{wet and stretch}}$

Regarding computing prediction model for $UPF_{\textit{wet and stretch}}$, Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Comination, were the four factors used in the development of the multiple linear regression for predicting $UPF_{\textit{wet and stretch}}$. The overall variation of the regression model was overestimated by 1.87%. There are three out of fifteen samples being underestimated. The worst prediction is +12.79% on sample CM_MF, while the best prediction is +0.21% on sample MCG. There were eleven samples between actual and predicted UPF values within 10% variation, the coefficient of determination (R^2) of the model is 0.839, and this mean 83.9% of the total variance can be explained by Tightness Factor, Pore Size Ratio, Number of Stitches and Fibre Combination.. The regression model can be concluded as a successful way in predicting $UPF_{\textit{wet and stretch}}$ state even for blended fibre combinations.

6.3 Recommendations

6.3.1 Yarn Materials for studying UPF

In this research only 20Ne cotton yarn cotton yarn and 150dtex Coolmax yarn were studied, it is recommended a more comprehensive range of different linear density of both cotton and Coolmax yarn can be used to produce plain knitted fabric. For example 10Ne, 30Ne, 40Ne, 50Ne for cotton yarn and 60Ne and 50dtex, 75dtex, 100dtex and 200dtex for synthetic fibre yarn.

Besides cotton and Coolmax combination, it is recommended other natural fibre types, for example bamboo fibre to be blended with other synthetic fibre.

6.3.2 Fabric Materials for studying UPF

Plain knitted fabric is one of the most common knitted structures and it is the only knitted structure being studied in this research. It is recommended that different combination of basic knitting unit, i.e. knit loop, tuck loop and miss loop can be study with different fibre blend to provide even better UPF ratings.

Apart from weft knitted structure, warp knitted structure can also be studied to reveal its UV protective ability.

6.3.3 Combination of Yarns

Only cotton/cotton and Coolmax/cotton combinations were studied for their respective UPF values. It is recommended that, combination of three types of yarn, e.g. normal cotton, Supima cotton and Coolmax can be studied. In addition, except for cotton and Coolmax, some other fibres can be introduced to explore the possibility of achieving even higher UPF values via different combinations.

6.3.4 Diversify Fibre Combination

Alternate fibre types yarn corns arrangement was the only technique for preparing cotton/cotton and Coolmax/cotton combinations samples in this study, so that a 50/50 ratio was achieve. However, possible 40/60 (two fibres combination) or 33/33/33 (three fibres combination) can be studied to evaluate corresponding UPF ratings.

6.3.5 Develop a System for UPF Prediction

An optimum system with data base of different yarn and specification, physical properties can be developed for future prediction of UPF protection before real fabric production.

References:

AATCC Test Method 183-2010, Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics

Abidi N., Cabrales L. and Hequet E. (2009), "Functionalization of a Cotton Fabric Surface with Titania Nanosols: Applications for Self-Cleaning and UV-Protection Properties", ACS Applied Materials & Interfaces, 1, 2141 - 2146

Abidi N., Hequet E., and Abdalah G. (2001), "Effects of dyeing and finishing on ultraviolet transmission of cotton fabrics", AATCC Book of Papers, Greenville, SC. 21- 24 Oct. AATCC, Research Triangle Park, NC, 105 - 109

Andrady A.L. (2007), "Ultraviolet Radiation and Polymers", Physical Properties of Polymers Handbook, Chapter 51, pp859 - 866

Algaba I. and Riva A. (2002), "In vitro measurement of the ultraviolet protection factor of apparel textiles", Coloration Technology, 118 (7), 52 - 58

AS/NZS 4399:1996, Sun Protective Clothing: Evaluation and Classification.

ASTM D 1422-99: Standard Test Method for Twist in Single Spun Yarns by the Untwist-Retwist Method (Reapproved 2008).

Baugh P.J. and Philips G.O. (1971), "Cellulose and Cellulose Derivatives", High Polymers part V, Bikales, N.M. and Segal L., Eds., John Wiley & Sons, New York, 5, pp1047

Bever M., Breiner U., Conzelmann G. and von Bernstorff, B.S. (2000), "Protection of polyamide against light", Chemical Fibers International, 50, 176 - 178

BS 7914:1998, Method of Test for Penetration of Erythemally Weighted Solar UV Radiation Through Clothing Fabrics

BS 7949:1999, Children's Clothing: Requirements for Protection against Erythemally Weighted Solar Ultraviolet Radiation

BS EN 13758 - 1:2002, Textiles, Solar UV Protective Properties, Part 1. Methods of Test for Apparel Fabrics: The standard described a method for the determination of the erythermally weighted UV radiation transmittance of apparel fabrics to assess solar UV protective properties.

Cambridge Advanced Learner's Dictionary

Canetta E., Montiel K. and Adya A.K. (2009), "Morphological changes in textile fibres exposed to environmental stresses: Atomic force microscopic examination", Forensic Science International,191 (1) , 6 - 14

Capjack L., Kerr N.N., Davis S., Fedosejevs R., Hatch K.L. and Markee N.L. (1994). "Protection of humans from ultraviolet radiation through the use of textiles: A review", Family and Consumer Sciences Research Journal, 23 (2), 198 - 218

Clark I.E.S., Grainger K.J.L., Agnew J.L. and Driscoll C.M.H. (2000), "Clothing protection measurements. Radiation Protection Dosimetry", 91 (1-3), 279 - 281

Cotton Incorporated and Textile World. 2003. U.S. cotton fibre chart for 2001 [Online]. Available at http://www.cottoninc.com/TextileWorldMap2001/homepage.cfm?PAGE=2902 [cited 20 Oct. 2003; verified 7 Apr. 2004]. Cotton Incorporated, Cary, NC, and Textile World, Atlanta, GA.

Coyle S., Lau K.T., Moyna N., O'Gorman D., Diamond D., Francesco F.D., Costanzo D., Salvo P., Trivella M.G., De Rossi D.E., Taccini N., Paradiso R., Jacque-Andr´e Porchet, Ridolfi A., Luprano J., Chuzel C., Lanier T., Fr´ed´eric Revol-Cavalier, Schoumacker S., Mourier V., Chartier I., Convert R., De-Moncuit H., and Bini C. (2010), BIOTEX -"Biosensing Textiles for Personalised Healthcare Management", IEEE Transactions on Information Technology in Biomedicine, 14 (2), 364 - 370

Crews P.C., Kachman S. and Beyer A.G. (1999), "Influence on UV radiation transmission of undyed woven fabrics", Textiles Chemist and Colorist, 31 (6), 17 - 26.

Darvill A., McNeil M., Albersheim P. and Delmer D.P. (1980), "The Biochemistry of Plants", Vol. 1, Academic Press, New York, pp91 - 161

Davis S., Capjack L., Kerr N. and Fedosejevs R. (1997), "Clothing as protection from ultraviolet radiation: Which fabric is the most effective?", International journal of Dermatology, 36 (5), 374 - 379

Day M. and Wiles D.M. (1972a), "Photochemical Degradation of Poly(ethylene Terephthalate). I. Irradiation Experiments With the Xenon and Carbon Arc", Journal of Applied Polymer Science, 16 (1), 175 - 189

Day M. and Wiles D.M. (1972b), Photochemical Degradation of Poly(ethylene Terephthalate). II. Effect of Wavelength and Environment on the Decomposition Process, Journal of Applied Polymer Science, 16 (1), 191 - 202

Day M. and Wiles D.M. (1972c), Photochemical Degradation of Poly(ethylene Terephthalate). III. Determination of Decomposition Products and Reaction Mechanism, Journal of Applied Polymer Science, 16 (1), 203 - 215

Diffey B.L. (2002), "What is Light?", Photodermatology, Photoimmunology & Photomedicine, 18 (20), 68 - 74

Dorée C.(1920), "The action of sea water on cotton and other textile fibres", Biochemical Journal, 14 (6), 709 - 714

East A.J. (2005), Synthetic fibres: nylon, polyester, acrylic, polyolefin, Chapter 3: Polyester Fibres, Woodhead Publishing in Textiles, pp95 - 157

Egerton G. S. (1949), "The Mechanism of the Photochemical Degradation of Textile Material", Journal of The Society of Dyers and Colorists, 65 (12), 764 -780

Fan L.T., Lee Y.H. and Gharpuray M.M. (1982), "The nature of lignocellulosics and their pretreatments for enzymatic hydrolysis", Advances in Biochemical Engineering, 23, 157 - 187

Freytag R. and Donze J.J. (1983), Alkali Treatment of Cellulose Fibres, in Handbook of Fibre Science and Technology: Volume 1, Chemical Processing of Fibres and Fabrics, Fundamentals and Preparation, Part A Marcel Dekker, NY, pp 94 - 120

Freitag J. (1989), The influence of moisture on polyamides, Chemifasern / Textilindustrie, Man-made Fibre Year Book, p58.

Ferrini R.L., Perlman M. and Hill L. (1998), "Skin Protection from Ultraviolet Light Exposure", http://www.acpm.org/pol_practice.htm (Washington: American College of Preventive Medicine)

Gies H.P., Roy C.R., Elliott G. and Wang Z.L. (1994), "Ultraviolet radiation protection factors for clothing", Health Physics, 67 (2), 131 - 139

Gies H.P., Roy C.R. and Elliott G. (1992), "Ultraviolet radiation protection factors for personal protection in both occupational and recreational situation", Radiation Protection In Australia, 10 (3), 59 - 66

Gies H.P., Roy C.R. and Holmes G. (2000), "Ultraviolet radiation protection by clothing: Comparison of in vivo and in vitro measurements", Radiation Protection Dosimetry, 91 (1–3), 247 - 250

Gambichler T., Hatch K.L., Avermaete A., Altmeyer P. and Hoffmann K. (2001a), "Ultraviolet protection by summer textiles. Ultraviolet transmission measurements verified by determination of the minimal erythema dose with solar-simulated radiation", British Journal of Dermatology, 144 (3), 484 - 489

Gambichler T., Hatch K.L., Avermaete A., Altmeyer P. and Hoffmann K. (2001b), "Sun protective clothes: Accuracy of laboratory testing", Journal of the European Academy of Dermatology & Venereololgy, 15 (4), 371 - 373

Gambichler T., Hatch K.L., Avermaete A., Altmeyer P. and Hoffmann K. (2002), "Influence of wetness on the ultraviolet protection factor (UPF) of textiles: in vitro and in vivo measurements", Photodermatol Photoimmunol Photomed, 18, 29 - 35

Gorensek M. and Sluga F. (2004), "Modifying the UV Blocking Effect of Polyester Fabric", Textile Research Journal, 74 (6), 469 - 474

Gowda S. M., Pardos Z. and Baker R. S. J. d. (2012), "Content learning analysis using the moment-by-moment learning detector", Intelligent Tutoring Systems Lecture Notes in Computer Science, 73 (15), 434 - 443

Hau T., Murrells C.M., Wong K.K., Xu B.G., Yang K., Wong S.K., Choi K.F., Cheng K.P.S. and Tao X.M. (2005), " A New Ring Spinning Technique", Textile Asia, 36 (1), 27- 28

Harvey H.J., LeBouf R.F. and Stefaniak A.B. (2010), "Formulation and stability of a novel artificial human sweat under conditions of storage and use, Toxicology in Vitro", 24 (6), 1790 - 1796

Hilfiker R., Kaufmann W., Reinert G. and Schmidt E. (1996), "Improving Sun Protection Factors of Fabrics by Applying UV Absorbers", Textile Research Journal, 66 (2), 61 - 70

Hilton A. and Armstrong R.A. (2006), "Is one set of data more variable than another?", Microbiologist, 7, 234 - 236

Hoffmann K., Kaspar K., Gambichler T., and Altmeyer P. (2000), "In vitro and in vivo determination of the UV protection factor for lightweight cotton and viscose summer fabrics: A preliminary study", Journal of the American Academy of Dermatology, 43 (6), 1009 - 1016

Hoffmann K., Kesners P., Bader A., Avermaete A., Altmeyer P. and Gambichler T. (2001a). "Repeatability of in vitro measurements of the ultraviolet protection factor (UPF) by spectrophotometry with automatic sampling", Skin Research and Technology, 7, 223 - 226

Hoffmann K., Laperre J., Avermaete A., Altmeyer P. and Gambichler T. (2001b), "Defined UV protection by apparel textiles", Archives of Dermatology, 137 (8), 1089 - 1094

http://www.centraltextiles.com/Files/ESTex%20Project%20Leaflet%20CTHKESTEX05-09-08.pdf

Hustvedt G. and Crews P.C. (2005), "The Ultraviolet Protection Factor of Naturally-pigmented Cotton", Journal of Cotton Science, 9, 47 - 55

Hsieh Y.L. (2007), Chemical structure and properties of cotton, Cotton: science and technology, Edited by Gordon S. and Hsieh Y.L., Woodhead Publishing in Textiles, pp 3 - 34

Ito M. and Nagaib K. (2008), "Degradation issues of polymer materials used in railway field", Polymer Degradation and Stability, 93 (10), 1723 - 1735

Jevtic A.P. (1990), "The sun protection effect of clothing, including beachwear", Australasian Journal of Dermatology, 31 (1), 5 - 7

Kan C.W. and Wong W.Y. (2011), "Color properties of cellulase-treated cotton denim fabric manufactured by torque-free ring spun yarn", Textile Research Journal, 81 (9), 875 - 882

Kimlin M.G., Parisi A.V. and Meldrum L.R. (1999), "Effect of stretch on the ultraviolet spectral transmission of one type of commonly used clothing", Photodermatology, Photoimmunology & Photomedicine, 15(5), 171 - 174

Kirk R.E. (1995), Experimental design: Procedures for the behavioral sciences (3rd ed.). Pacific Grove, CA: Brooks/Cole.

Kullavanijaya P. and Lim H.W. (2005), "Photoprotection", Journal of the American Academy of Dermatology, 52 (6), 937-958

Laga S.K. and Wasif A.I. (2010), "UV Protected Textiles: An Overview", fibre2fashion.com, published on 12th November

Laperre J., Gambichler T., Driscoll C., Bohringer B., Varieras S., Osterwalder U., Rieker J., Camenzind M. and Hoffmann K. (2001), "Determination of the ultraviolet protection factor of textile materials: Measurement precision", Photodermatology, Photoimmunology & Photomedicine, 17 (5), 223 - 229

Lau Y.M. and Tao X.M. (1997), "Torque Balanced Singles Knitting Yarns Spun by Unconventional System 2 Cotton Friction Spun Dref-III Yarn", Textile Research Journal, 67 (11), 815 - 828

Launer H.F. and Wilson, W.K. (1949), "The Photochemistry of Cellulose - Effects of Water Vapor and Oxygen in the Far and Near Ultraviolet Regions", Journal of the American Chemical Society, 71 (3), 958 - 962

Levene H. (1960), "Robust tests for equality of variances". In Ingram Olkin, Harold Hotelling, et al., Stanford University Press, pp 278 - 292.

Lewin M. (1998), Handbook of Fibre Chemistry, In International fibre science and technology series, 15, CRC Press, pp 2 - 71

Li Q., Kumar V., Li Y., Zhang H., Marks T. J. and Chang R.P.H. (2005), "Fabrication of ZnO Nanorods and Nanotubes in Aqueous Solutions", Chemistry of Materials, 17, 1001-1006

Lowe N. J., Bourget T., Hughes S. and Sayre R. M. (1995), "UV Protection Offered by Clothing: An in vitro and in vivo Assessment of Summer Clothing Fabrics", Skin Cancer Journal, 10, 89 - 96

Lowry R. (2000), One Way ANOVA for Independent Samples, Chapter 14, part 2, Vassar.edu.

Malanowski P., Huijser S., Scaltro F., Rolf A.T.M. van Benthem, Leendert G.J. van der Ven, Laven J., Gijsbertus de With (2009), "Molecular mechanism of photolysis and photooxidation of poly(neopentylisophthalate)", Polymer, 50, 1358 - 1368

Maybeck A. and Meybeck J. (1967), "Photo-oxidation of the Peptide group, I. Fibrous Proteins", Photochemistry and Photobiology, 6, 355 - 363

Murrells C.M., Tao X.M., Cheng K.P.S. and Wong K.K. (2003), "Production of Torque-free Singles Ring Yarns", Textile Asia, 34(8), 58 - 60.

McKellar J.F. (1971), "Phototendering of the antraquinone VAT dyes: A review", Radiation Research Review, Elsevier, Amsterdam, 3, 141 - 165

Menzies S.W., Lukins P.B., Greenoak G.E., Walker P.J., Pailthorpe M.T., Martin J.M., David S.K. and Georgouras K.E. (1992), "A Comparative Study of Fabric Protection against Ultraviolet, Induced Erythema Determined by Spectrophotometric and Human Skin Measurements", Photodermatology, Photoimmunology & Photomedicine, 8, 157 - 163

Millikin G. A. and Johnson D. E. (1984), Analysis of messy data, vol. 1, Designed experiments. Van Nostrand Reinhold, New York, NY.

Mo S. D. and Ching W. Y. (1995), "Electronic and Optical Properties of Three Phases of Titanium Dioxide: Rutile, Anatase, and Brookite", Physical Review B, 51, 13023 - 13032

Moon R. and Pailthorpe M. (1995), "Effects of stretch and wetting on the UPF of elastance fabrics", Australasian Textiles, 15, 39 - 42

Marcotte F. B., Campbell D. Cleaveland J. A. and Turner D.T. (1967), "Photolysis of poly(ethylene terephthalate)", Journal of Polymer Science Part A: Polymer Chemistry, 5 (3), 481 - 501

NIST Engineering Statistics handbook: Section 5.7. A Glossary of DOE Terminology (2003)

Osterwalder U., Schlenker W., Rohwer H., Martin E. and Schuh S. (2000), "Facts and fiction on UV protection by clothing", Radiation Protection Dosimetry, 91(1-3), 255 - 260

Parisi A.V., Kimlin M.G.., Meldrum L.R. and Relf C.M. (1999), "Field Measurements on Protection by Stockings from Solar Erythemal Ultraviolet Radiation", Radiation Protection Dosimetry, 86 (1), 69 - 72

Parisi A.V., Kimlin M.G.., Mulheran L., Meldrum L.R. and Randall C. (2000), "Field-based measurements of personal erythermal ultraviolet exposure through a common summer garment", Photodermatology, Photoimmunology & Photomedicine, 16, 134 - 138

Paithorpe M. (1994), "Textile and sun protection: The current situation", Australasian Textiles, 14, 54 - 66

Paul R., Bautista L., Varga M.D.L., Botet J.M., Casals E., Puntes V. and Marsal F. (2009), "Nano - cotton Fabrics with High Ultraviolet Protection", Textile Research Journal, 80 (5), 454 - 462

Phillips G.O. and Arthur J.C., Jr. (1964), "Chemical Effects of Light on Cotton Cellulose and Related Compounds : Part I: Primary Processes in Model Systems", Textile Research Journal, 34(6), 497 - 505

Phillips G.O. and Arthur J.C., Jr. (1964), "Chemical Effects of Light on Cotton Cellulose and Related Compounds Part II: Photodegradation of Cotton Cellulose", Textile Research Journal, 34 (7), 572 - 580

Phillips G.O. and Arthur J.C., Jr. (1985), "Photochemistry and radiation chemistry of cellulose, in Cellulose Chemistry and Its Applications", Nevell T.P. and Zeronian S.H., Eds., Ellis Horwood Ltd., Chichester, England, Chapter 12, pp 290 - 311

Phillips G.O. (1980), The Carbohydrates, 2nd ed., Vol. IB, Pigman, W. and Horton, D., Eds., Academic Press, New York, pp 1217- 1299

Phillips G.O., Baugh P.J., McKellar J.F. and Von S. C. (1977), Interaction of radiation with cellulose in the solid state, in Cellulose Chemistry and Technology, Arthur, J.C., Jr., Ed., ACS Symposium Series, No. 48, American Chemical Society, Washington, D.C., pp313

Preston J.M. and Nimkar J.V. (1949), "Measuring the swelling of fibres", Journal of The Textile Institute, 40(7), 674 - 688

Richards A.F. (2005), Nylon Fibres, Polyester Fibres, Synthetic fibres: nylon, polyester, acrylic, polyolefin, Chapter 2, Woodhead Publishing in Textiles

Ravishanker J. and Diffey B. (1997), "Laboratory testing of UV transmission through fabrics may underestimate protection", Photodermatology, Photoimmunology & Photomedicine, 13 (5-6), 202 - 203

Reese G. (2003), Polyester fibres, in Encyclopedia of Polymer Science & Technology, 3rd ed, Vol. 3, Wiley and Sons Inc., New York, pp 652 - 678

Reinert G.F., Hilfiker R. and Schmidt E. (1997), "UV-protection properties of textile fabrics and their improvement",. Textile Chemist and Colorist, 29 (12), 36 - 43

Riva A. (1999), ¿Qué es el UPF de un tejido? Revista de Química Textil, 144, pp 72 - 78

Robson J. and Diffey B. (1990), "Textiles and sun protection", Photodermatology, Photoimmunology & Photomedicine, 7, 32 - 34.

Senn S. and Richardson W. (1994), "The first t-test", Statistics in Medicine, 13(8), 785 - 803

Standford D.G., Georgouras K.E. and Pailthorpe M.T. (1995), "The effect of laundering on the sun protection afforded by a summer weight garment", Journal of the European Academy of Dermatology and Venerdology, 5, 28 - 30

Stankovic S.B., Popovic D., Poparic G.B. and Bizjak M. (2009), "Ultraviolet Protection Factor of Gray - state Plain Cotton Knitted Fabrics", Textile Research Journal, 79(11), 1034 - 1042

Stepanova G.A., Pakshver A.B., Kaller A.L., Polyakova G.V. and Goikhman A.S. (1981), "The swelling of alkali cellulose in sodium hydroxide solutions", Fibre Chemistry, 13 (6) , 405 - 407

Tao X.M., Lo W.K. and Lau Y.M. (1997a), "Torque - balanced singles knitting yarn spun by unconventional systems. Part I: cotton rotor spun yarn", Textile Research Journal, 67 (10), 739 - 746

Tao X.M., Lo W.K. and Lau Y.M. (1997b), "Torque - balanced singles knitting yarn spun by unconventional systems. Part II: cotton friction spun DREF III yarn", Textile Research Journal, 67(11), 815 - 828.

Tenkate T.D. (1998), Environ. Health, 61 (September) 9

UV Standard 80: 1999 General and Special Conditions

Viková M. (2004), Visual assessment of UV radiation by color changeable textile sensors, AIC 2004 Color and Paints, Interim Meeting of the International Color Association

Wan M.L., Kan C.W. and Choi K.F. (2010), "Comparative study of color yield of cotton knitted fabric made by torque-free ringspun yarns", Coloration Technology, 126(1), 18 - 23

Wang L.L., Zhang Z.T., Li B., Sun P.P., Yang J.K., Xu H.Y. and Liu Y.C. (2011), "Superhydrophobic and Ultraviolet-Blocking Cotton Textiles", ACS Applied Materials & Interfaces, 3, 1277 - 1281

Wang R. H., Xin J. H., Tao X. M., Daoud W.A. (2004), "ZnO Nanorods grown on cotton fabrics at low temperature", Chemical Physics Letters, 398, 250 - 255

Wang S.Q., Kopf A,W., Marx J., Bogdan A., Polsky D. and Bart R.S. (2001), "Reduction of ultraviolet transmission through cotton T-shirt fabrics with low ultraviolet protection by various laundering methods and dyeing: Clinical implications", Journal of the American Academy of Dermatology, 44 (5), 767 - 774

Warwicker J.O., Jeffries R., Colbran R.L. and Robinson R.N. (1996), A review of the literature on the effect of caustic soda and other swelling agents on the fine structure of cotton, Shirley Institute Pamphlet, No. 93, Manchester, U.K.

Wakelyn P.J., Bertoniere N.R., French A.D., et al. (2007), Cotton Fibre Chemistry: Technology. Boca Raton: CRC Press

Welch B. L. (1951), "Welch’s k-sample test", Biometrika, 38, pp 330 - 336

Welo L. A., Ziifle H. M. and Loeb L. (1952), "Swelling Capacities of Fibres in Water Part I: Desiccation Rate Measurements", Textile Research Journal, 22(4), 254 - 261

Welsh C. and Diffey B. (1981), "The protection against solar actinic radiation afforded by common clothing fabrics", Clinical and Experimental Dermatology, 6, 577 - 582

Xia X. (2004), Using Clothing as Protection against Ultraviolet Radiation, Department of Human Ecology, University of Alberta, Thesis (M. Sc.)

Yadav R. and Karolia A. (2011), "Testing Methods for Protection against Ultraviolet Radiation - A Review", Textile Review, May.

Yang H., Zhu S. and Pan N. (2004), "Studying the Mechanisms of Titanium Dioxide as Ultraviolet-Blocking Additive for Films and Fabrics by an Improved Scheme", Journal of Applied Polymer Science, 92 (5), 3201 - 3210

Zhou Y. and Crews P.C. (1998), "Effect of OBAs and repeated launderings on UV Radiation transmission through fabrics", Textile Chemist Colorist, 30 (11), 19 - 24

Zimmerman H. and Kim N.T. (1980), "Investigations on thermal and hydrolytic degradation of poly(ethyleneterephthalate)", Polymer Engineering and Science, 20(10), 680 - 683.