APPLICATION IN FASHION DESIGN

WITH CHITOSAN BASED YARN DEVELOPMENT

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Application in Fashion Design with Chitosan Based Yarn Development

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CERTIFICATE OF ORIGINALITY

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

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LAM Ngan Yi Kitty

ABSTRACT

The aim of this study is to develop a functional clothing design for Epidermolysis bullosa (EB) patients to accelerate the wound healing process by applying chitosan/cotton fibres through yarn spinning and fabric knitting. The research work comprises five stages: i) research; ii) experimental development; iii) development of a functional apparel design framework; iv) prototype development; and v) evaluation, so as to facilitate the development of a functional apparel system for EB patients.

The functional apparel system developed in this study combines functional, expressive and aesthetic considerations to provide antibacterial properties and enhance the rate of wound healing with chitosan/cotton blend yarn. In-depth research work has been carried out with a functional apparel design framework to examine the use of chitosan/cotton yarn and textile to meet the needs and concerns of the end users (EB patients).

It is found that the yarn tenacity deteriorates with increases in the length of the chitosan fibre. Chitosan fibres that are shorter in length (22 mm) or excessively long (46 mm) will bring about difficulties in yarn spinning. Chitosan fibres that are 30 and 38 mm in length are compatible for blending with long cotton fibres.

The results of fabric touch test show that chitosan fibers added to fabric has a good impact on handle and all of the physical properties of plain jersey fabric. With an increase in the blend ratio of chitosan fibers (50% or more), the rigidity of the fabric is reduced, and the inner surface has a softer handle.

In the interview with EB patients and their parents, they prefer long-sleeved tops and long pants to cover the body parts and protect the skin of EB patients, while fabric with cooling and deodorising effects improve on both parents and patients' quality of life by the use of apparel technology. They use compression bandages for better coverage of EB patients wound. Children patients prefer cartoons and fun graphics which fulfil their aesthetics expectations. The feedback from these patients and their parents therefore reflect the need for functionality yet also aesthetics in apparel for EB patients.

PUBLICATIONS ARISING FROM THE THESIS

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Chapter 1

Introduction

1.1 Background of Study

Epidermolysis bullosa (EB) is a hereditary skin disease which increases the risk of death in newborn babies and/or young children. The condition causes fragile skin which is easily injured, and the formation of fluid-filled blisters. Infants and young children with EB are called "butterfly children" because their skin is as fragile as a butterfly's wings. They require special wound dressings that protect their skin from friction and scratching, because these actions will cause painful blisters. Infections might develop even with proper care. Since there is no cure for EB, the only treatment for patients with EB is daily wound care and bandaging to maintain their skin integrity and avoid infection. Enhancing the wound healing rate would help to reduce pain and discomfort and this can be done with the use of chitosan yarns and fabric and functional wear design for EB.

Chitosan is a biocompatible and biodegradable material that is produced after a lengthy process that involves the deproteinization and deacetylation of the exoskeletons of crustaceans. The main sources are crabs and shrimps (Wani, Hasan, & Malik, 2010). Chitosan has a wide range of uses in medical applications because of its antibacterial ability and adsorption properties (M. N. V. Ravi Kumar, 2000; Wani et al., 2010). Academic scholars and researchers have been investigating the biomedical functionalities and applications of chitosan for nearly three decades. It has been used in wound healing products (Sparkes & Murray, 1986). In preliminary experiments on animals, it was found that chitosan/cotton fabric has advantages over traditional medical gauze, which is made of pure cotton, especially during the first stage of healing. It was also discovered that a higher percentage of the composition of chitosan in fabric offers better performance in wound healing. Chitosan is transformed into fibres by wet spinning and then used to make wound healing dressing through non-woven fabric technologies (Kifune, Yamaguchi, & Tanae, 1987). The resultant material is impenetrable to fluid and impermeable to bacteria (Smorada, 1985). However, the structure of non-woven fabric means that it has poor elasticity, wash durability and comfort. These properties of chitosan fabric could be improved by weaving and knitting through yarn spinning of chitosan fibres and their blends, and applications of chitosan in fashion could be expanded with better wear-ability and sustainability.

In this study, the aim is to develop a functional clothing design for EB patients to accelerate the wound healing process by applying chitosan-based fibres through yarn spinning and fabric knitting. First, the background information of EB, wound care and clothing requirements are studied by conducting a literature review. The research process in this study is facilitated by the investigation of related functional apparel design models. Besides, the characteristics and functionalities of chitosan-based fibres, fibre migration theory and comfort properties are studied to gain a better understanding of the knowledge for functional apparel development. In order to enhance the tensile properties of chitosan yarn with better yarn performance, chitosan/cotton blend yarn prototypes are developed by using ring spinning technology. A series of assessments and analyses on the yarn and fabric comfort are then conducted. A functional apparel system is developed by utilising chitosan/cotton blend yarn and textile, which provides antibacterial properties and enhance wound healing rates with an aesthetically pleasing design.

1.2 Problem Statement

EB patients have to face difficulties with purchasing appropriate clothing and wound caring product. In addition, when a new wound occurs, it is difficult to locate the wound and to give immediate treat. The formation of a blood clot of wound adheres to the clothing. Regardless of the subsequent treatment, the separation of the wound from the fabric causes pain to patients (Badger, O'Haver, & Price, 2013; J. E. Denyer, 2010; Goldschneider et al., 2014). These wound caring problems also occur on adult patients. However, few researches conducted of systematic studying in the textile based perspective of patients and caregivers to analyze the specified problems they have experienced during daily life (Abercrombie, Mather, Hon, Graham-King, & Pillay, 2008; Blanchet-Bardon & Bohbot, 2005; Krakowski & Ghasri, 2015; Pope et al., 2012).

In most of the existing published literature, the focus is on the solution preparation, the formation of chitosan fibres in wet spinning and the applications of this antibacterial material for medical uses in non-woven fabric development and wound healing substance, and the treatment and finishing of chitosan in different disciplines. There are few publications about yarn spinning and yarn applications of chitosan fibres in the textile industry in the literature. This might due to the high raw material cost (price ranges from US$ 50,000 to US$ 100,000 per ton depending on the degree of the deacetylation of the chitosan) and low tensile strength of chitosan fibres (Liu et al., 2015).

It is essential to provide a comprehensive system of EB functional apparel by the application of chitosan/cotton blend yarn to provide better wearing comfort with antibacterial properties that enhance their wound healing rate. The results would contribute to future research and development of clothing based wound dressings and healing products, to be used as a second layer of skin, which will offer EB patients more freedom of wound care during their daily life activities.

1.3 Project Aim and Objectives

This thesis aims to develop a functional clothing design for EB patients by systematically applying chitosan-based fibres through yarn spinning and fabric knitting. In order to achieve this goal, the objectives are as follows:

- To study the characteristics and symptoms of EB and understand their special needs for wound care, and existing medical apparel for EB patients,
- To investigate the properties and applications of chitosan materials and to study the fibre migration theory,
- To establish a functional apparel design framework that facilitates the development of a functional clothing prototype that meets the requirements of EB patients,
- To develop chitosan/cotton blend yarn prototypes and examine the mechanical properties of yarn and the fabric prototypes through a series of assessments,
- To develop a functional apparel system for EB patients by applying the chitosan/cotton blend yarn, and
- To evaluate the apparel system through interviews that address the functional and aesthetic needs of EB patients and their parents in clothing.

1.4 Methodologies

In this study, the research work comprises five stages: i) research; ii) experimental development; iii) development of a functional apparel design framework; iv) prototype development; and v) evaluation, so as to facilitate the development of a functional apparel system for EB patients. The functional apparel design framework for the application and development of chitosan/cotton yarn and textile was developed based on other related apparel design frameworks. The procedure is as follows: (1) identifying the problem; that is, to discover and seek a solution to a problem; (2) generating preliminary ideas; that is, to generate ideas to solve the stated problem; (3) refining the design by eliminating and modifying the previous ideas based on a functional, expressive, and aesthetic (FEA) model; (4) developing prototype of chitosan/cotton yarn to initiate yarn prototyping; (5) evaluation of chitosan/cotton yarn to assess the prototype according to the criteria; (6) prototype development of chitosan/cotton textile; that is, to initiate textile prototyping; (7) evaluating the chitosan/cotton textile; that is, to assess the prototype according to the criteria; (8) developing prototype of functional apparel system made of chitosan/cotton textile to initiate apparel prototype; and (9) evaluating the functional apparel system made of chitosan/cotton textile by interviewing EB patients.

1.5 Significance and Values

A comprehensive system has been developed in this study for medical and functional apparel designs with aesthetically pleasing details through the application of a chitosan/cotton blend yarn and fabric to provide an antibacterial function that enhances the wound healing rate of EB patients and wear comfort. The chitosan/cotton functional apparel system framework serves as a guideline for medical textile and apparel development in the future. There is a need to investigate other textile materials for blending with chitosan to reduce the production costs of yarns and extend the biocompatible and biodegradable uses in functional apparel. This research also provides evidence to support new functional materials with antibacterial properties in the textile industry and academic uses that will enable further applications in yarn development.

1.6 Organisation of Thesis

The organisation of this thesis is as follows.

Chapter One provides the general outline of this research work including the background information of the study, problem statement, project aim and objectives, methods, significance and value, and also the thesis organization.

Chapter Two presents the reviewed literature that is related to this study, such as the characteristics and symptoms of EB and their wound care management, medical apparel and wound dressings, related apparel design framework and the properties and applications of chitosan fibres. The research gaps in this study are identified.

Chapter Three outlines a five-step method which has been adopted in this thesis. A functional apparel design framework for the application and development of chitosan/cotton yarn and textile is developed based on other related apparel design frameworks.

Chapter Four provides an introduction on the material and equipment for the prototype development of chitosan/cotton yarn and textile, the assessment methods of chitosan/cotton yarn and fabric prototype examination.

Chapter Five focuses on the evaluation of the effect of tensile properties on chitosan/cotton 50:50 blend yarn with four different chitosan fibre lengths (22, 30, 38 and 46 mm) through the fibre-blending and sliver-blending methods in a ring spinning system.

Chapter Six focuses on the evaluation of chitosan/cotton jersey fabric with five different blend ratios (30:70, 50:50, 70:30, pure chitosan and pure cotton), and studies the relationship of percentage composition and comfort to facilitate further examination of medical textiles in both theoretical and practical aspects.

Chapter Seven focuses on the systematic evaluation of the functional apparel system prototypes with the use of a survey and analysis of the feedback from EB patients and their parents, and provide a foundation of knowledge for future apparel based medical material development.

Chapter Eight concludes that the investigation is accomplished in this study with major research findings which are summarized based on the developed chitosan/cotton yarn and textile prototype and functional apparel system. The limitations are stated, and recommendations for future research are proposed.

Chapter 2

Literature Review

2.1 Introduction

A literature review on the properties of chitosan is presented in this section. To develop a yarn prototype that can properly address the needs of EB patients, it is crucial to identify the appropriate types of textile fibres. As well, a cotton ring spinning system is suggested for yarn development along with an investigation on the blending methods of fibres and the fibre migration theory. Fundamental yarn properties are also examined as part of the literature review to provide knowledge for further prototype assessment. Since this research work aims to apply chitosan yarn to generate garment designs for EB patients who require clothing with special functionalities, the symptoms and the requirements of wound care and clothing will be included. After that, a review of the apparel design framework is presented to facilitate the application of chitosan yarn and textiles.

2.2 Epidermolysis Bullosa

This study focuses on Epidermolysis Bullosa (EB), which is a rare hereditary skin disease that causes skin fragility and blistering (Fine, 2007; Lanschützer et al., 2009). Understanding the special needs of patients and to facilitate the application of chitosan yarn and fabric is crucial. This skin disorder usually occurs at birth or soon afterwards. It increases the risk of death in new born babies and in early childhood in 20 out of 1 million live births. Due to the visibility of the symptoms of EB, patients not only suffer from physical pain but also psychological burden. The skin diseases make the skin too fragile and easy to injure, and it causes the fluid-filled blister to form, the affected genes inhibit the skin to fully return to its normal state (J. Denyer, 2009; J. E. Denyer, 2010; Diem, Austria, & In, 2009; Lucky et al., 2007).

There are at least 25 subtypes of EB defined by clinical findings, and below are the three major types of EB, simplex (EBS), junctional (JEB), and dystrophic (DEB) (Figure 2.1).

(1) EBS: blisters occur within the epidermis (outer layer of skin), on hands and feet, inheritance is autosomal dominant;

(2) JEB: blisters develop within the upper portion of the dermoepidermal junction (second part of skin, the tissue area between the outer layer and deep layer of skin), inheritance is either autosomal dominant or recessive, caused death in early infancy;

(3) DEB: blisters occur beneath the skin in the sublamina densa (the basement membrane area that attached to bones and blood vessels).Inheritance is autosomal dominant, and the disease causesdeath in early to middle adulthood (Eady & Tidman, 1983; Fine, 2007).

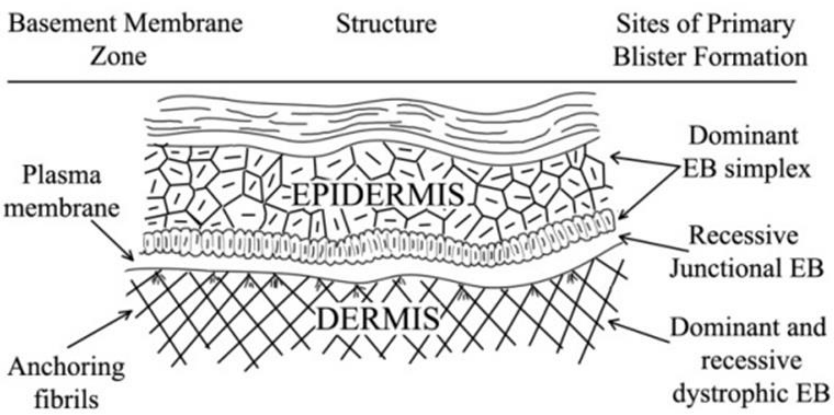


Figure 2.1 Skin structure diagram of EB and its types (Author, 2017)

Infants or younger children with EB are called “butterfly children” because their skin is as fragile as butterfly’s wings. Because there is no specific cure and therapy to help the patients, special wound care is very important. The wounded areas seem to have no indication of healing, and they require special wound dressing to protect the skin from friction and scratching, as these will cause painful blister formation. Infections might develop even with proper care.

2.2.1 Wound Care Management

It is difficult to reduce the body movement of newborn infants with EB and prevent injuries; thus, the burden of care lies on their family and medical personnel. Since there is currently no available medical technology that can cure this ailment, patients undergo a lifetime of suffering from the related physical and psychological pain (Fine, 2007; Goldschneider & Lucky, 2010). Horn and Tidman (2002a, 2002b) reported that some patients with EB will experience slight improvements as they become older; nevertheless, many patients still continue to suffer from the pain and inconvenience of EB. The prevention of injury is a life issue for EB patients (Lara-Corrales, Arbuckle, Zarinehbaf, & Pope, 2010; Moy, Caldwell-Brown, Lin, Pappa, & Carter, 1990). There are many bandages used to cover the body surface of EB patients which may cause the body to overheat (Gamelli, 1988; Gourgiotou et al., 2002; Labeille, Gineston, Denoeux, & Capron, 1988). The purpose of wound care for EB patients is to protect their fragile skin from friction and reduce physical pain by promoting healing. Appropriate management of wounds and their care are therefore extremely important (Abercrombie et al., 2008; Stevens, 2014).

However, the options for wound dressings are limited, with few that are suitable for severely fragile skin. Mellerio et al. (2007) concluded that trauma or friction to skin could affect wound healing and inappropriate management of wounds which will lead to further infection, and also physical pain and stress. Some dressings cause damage on the surface of the skin upon removal, and the thickness of the dressing edge can also cause blistering (Abercrombie et al., 2008).

2.2.2 Clothing Requirements of EB Patients

According to Diem et al. (2009) and J. E. Denyer (2010), the clothing of EB patients should meet the following requirements:

- very soft with breathable material,
- ease of donning and doffing with a wide neckline,
- no buttons, zippers, or buckles due to pressure points; velcro fastenings should be used instead,
- protective dressing under clothing to prevent rubbing and irritation,
- should not be overly warm or fit too tightly because sweat will contribute to the development of blisters,
- turned inside out to prevent the seams from rubbing if not flat seamed, and
- have an aesthetically pleasing design.

2.3 Skin Sensitive Functional Apparel System

2.3.1 General Review

Functional clothing is characterized by its own unique specifications, material requirements, technologies and processes involved to produce the final product. A functional apparel system that is sensitive to skin is defined as clothing that is especially designed and produced to deliver a specific performance or function to the final user. Medical garments comprise a functional apparel in this field. Gupta (2011) indicated that functional clothing is defined by the psychological or physiological requirements of the user. She suggested six classes of functional clothing: (1) protective-functional; (2) medical-functional; (3) sports-functional; (4) vanity-functional; (5) cross-functional assemblies; and (6) clothing for special needs.

Medical-functional classed clothing or functional medical clothing was previously used to primarily protect medical staff members from bodily fluids or germs. With technological advancements, functional medical clothing is now broader in scope, with applications that are therapeutic or bio-sensing, and used for emergency care or in rehabilitation activities. The following is a review of the current products available on the market. Since wound caring management is relative important to EB patients, therapeutic clothing for EB patients with the application of chitosan blend yarn is the aim of this study. Combining the function of wound healing and provide antibacterial functions to offer a healthy environment for skin cell growth. The following is a review of the current products available on the market .

2.3.2 Medical Garments

DermaSilk a textile developed patented by ALPRETEC in Italy, is specifically developed for individuals who suffer from skin diseases. This material is knitted with pure silk fibroin, followed by a permanent antimicrobial treatment which releases chemical substances that inhibit the growth of microorganisms, and prevent bacterial infection on skin when the individual has contact with the fabric (AL.PRE.TEC.S.r.l., 2015). ALPRETEC also offers therapeutic clothing, underwear and other garments to protect specific body parts (socks for the feet, masks for the face, etc.) for women, men and children (Figure 2.2).

Features of DermaSilk:

- Smooth and soft to prevent friction with skin
- Cool and dry to allow skin to breathe

- Permanent protection with antimicrobial treatment that is patented technology

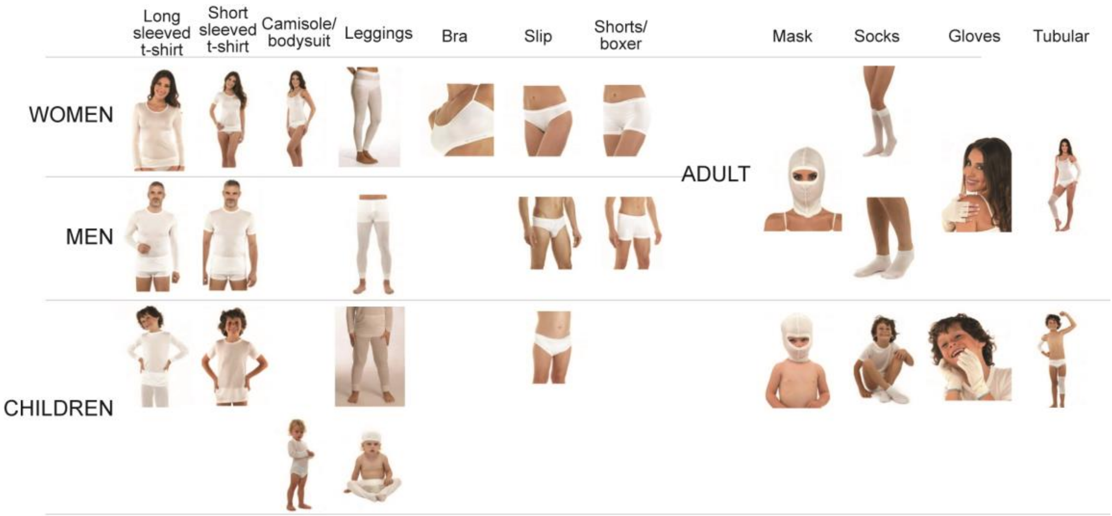


Figure 2.2 DermaSilk therapeutic clothing for women, men and children (AL.PRE.TEC.S.r.l., 2015)

Skinnies a brand of functional clothing offered by Dermacea Ltd in the United Kingdom. They offer protective clothing in a wide range of colours and materials (viscose, silk and WEB technology), which is made by using seamless knitting technology with the ability to stretch 360°. However, the sanitized antimicrobial treatment is used as a finishing on silk garments only (Skinnies, 2012). Since this is the case, only Skinnies silk garments will be discussed.

The features of Skinnies silk garments are as follows:

- seamless so that there is less friction and more freedom to move,
- sanitised antimicrobial treatment on garments,
- machine washable and tumble dryable, and
- endurance for more than 50 washes.

Figure 2.3 Skinnies silk garments for adults, children and babies (Skinnies, 2012)

Therapeutic clothing is therefore an option to provide daily comfort to patients with skin problems on various parts of their body.

2.3.3 Wound Dressings

Functional textiles have been utilized for medical, hygienic and health purposes, and new developments are being promoted with the medical application of antimicrobial finishing on clothing for patients (Buschmann, Dehabadi, & Wiegand, 2014). Traditional wound dressings are usually adhered onto skin with medical tape but this could cause secondary abrasion with the formation of blisters when the dressing is removed (Figure 2.4).

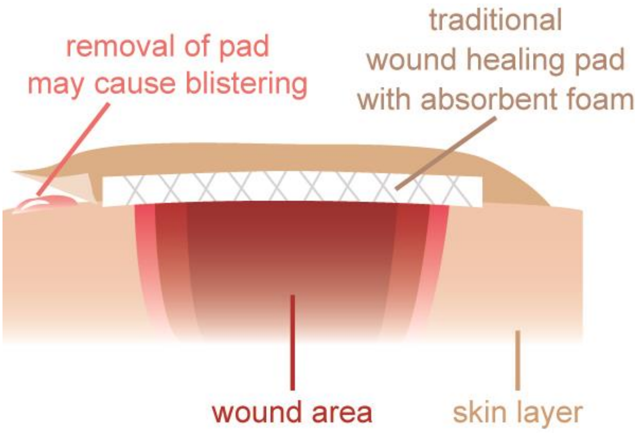


Figure 2.4 Traditional wound healing pad (Author, 2017)

EB patients suffer from the pain and difficulties of wound healing but the right product will alleviate the symptoms. Therefore, wound dressings are essential for their treatment and prevention of further skin injury caused by friction. To prevent the growth of bacteria, and enhance the rate of healing of wounds, functional textiles can be used. Functional textiles can be used as a type of wound dressing with a non-adhesive surface along with an absorbent foam which is suitable for EB patients, because there is no further damage to the skin surface with the removal of the adhesive bandages. However, adhesion can often be beneficial to the fixation of the dressing (Abercrombie et al., 2008).

For instance, Mepitel® One is a wound contact layer with one side that is adhered with the use of Safetac, which is developed by Mölnlycke Health Care. It is a flexible coated soft silicone that does not adhere to the wound (MölnlyckeHealthCare, 2016).

Figure 2.5 Mepitel® One - wound contact layer with one side that is adhered with Safetac (MölnlyckeHealthCare, 2016)

Another type of dressing that has a contact layer and is non adherent is Urgotul® , which is made of 100% polyester net to provide a high degree of flexibility (Blanchet-Bardon & Bohbot, 2005). Urgotul® can be left on a wound for up to 7 days (LaboratoiresURGO, 2009).

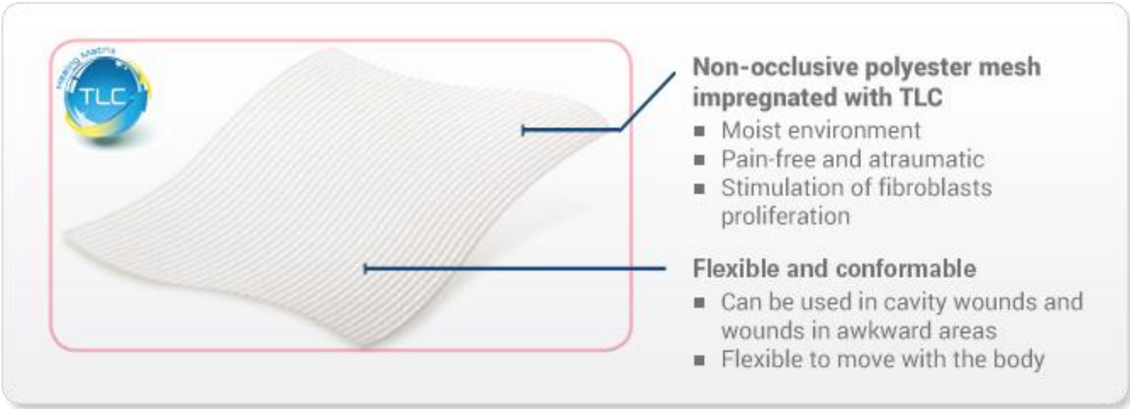


Figure 2.6 Urgo Tul dressing (UrgoMedical, 2016)

Both types of dressings are suitable and beneficial to EB patients in terms of convenience of use and wear comfort (Mellerio et al., 2007). However, when a new wound occurs, it is difficult to locate the wound and provide immediate treatment.

Blood clots from a wound resultant of blistering means that the skin will stick to clothing, so that regardless of the subsequent treatment, the separation of the wound from the fabric causes pain (Badger et al., 2013; J. E. Denyer, 2010; Goldschneider & Lucky, 2010). These wound care problems occur in both children and adult patients. However, little research has been conducted that systematically studies the perspective of patients and caregivers in the use of textile based treatment for skin diseases and analyzes the specific problems that they experience in daily life (Abercrombie et al., 2008; Blanchet-Bardon & Bohbot, 2005; Krakowski & Ghasri, 2015; Pope et al., 2012).

2.4 Related Apparel Design Framework

It is difficult for EB patients and their parents to find appropriate functional clothing with different styles, and the significance of this research is that functional garments with an aesthetically pleasing design will be developed which also inspired an apparel design framework. Since the management of wounds is relatively important to EB patients, therapeutic clothing that can facilitate the healing of wounds by incorporating a chitosan blend yarn is therefore the aim of this study. This yarn combines the functions of wound healing and antibacterial activity to offer a healthy environment for skin cell growth. Also, Kang, Johnson, and Kim (2013) indicated that apparel can affect the mood of the wearer in terms of the colour, material, texture, pattern, and garment shape. Therefore, in this study, a functional apparel system with wear comfort will be designed for EB patients so as to enhance their confidence, and provide them with a better quality life.

2.4.1 Design Process Framework

Watkins (1988) developed a design process framework that facilitates functional apparel designs by implementing seven steps as follows: (1) acceptance, in which the problem is accepted and the reason for the problem indicated; (2) analysis, in which the problems are examined; (3) definition, in which the problem is defined; (4) ideation, in which solution(s) are generated for the problems; (5) selection, in which the most suitable solution is chosen; (6) implementation, in which the generated solution is applied; and (7) evaluation, in which the result is assessed.

2.4.2 Functional, Expressive, and Aesthetic Considerations

Lamb and Kallal (1992) incorporated and emphasized the concepts of creative thinking proposed by Watkins (1988) into a new consumer needs model. Figure 2.7 shows the framework of the design criteria that takes into consideration functional, expressive, and aesthetic (FEA) considerations in the needs of consumers.

Figure 2.7 FEA model (Lamb & Kallal, 1992)

Functional factors are factors that are related to the utility of a garment, such as protection and comfort, and aesthetic factors refer to the use of creative elements to create an aesthetically pleasing design. The design process in terms of consumer needs which is taken from the work of several previous studies have been formulated into a six-step model which is summarized by Lamb and Kallal (1992) (Figure 2.8). They are as follows: (1) identify the problem and seek a solution; (2) generate preliminary ideas to attain goals; (3) refine the design by examining the preliminary ideas in depth, which could result in eliminating or modifying them; (4) developing the prototype; that is, producing samples after modifications are made to the preliminary ideas; (5) evaluation of the prototype based on the criteria when identifying the problem, but if the assessment is considered unsatisfactory, then further modifications and revisions are required; and (6) implementing the final design followed by production. Steps 1 and 5 are influenced by the FEA model to achieve the desired outcome.

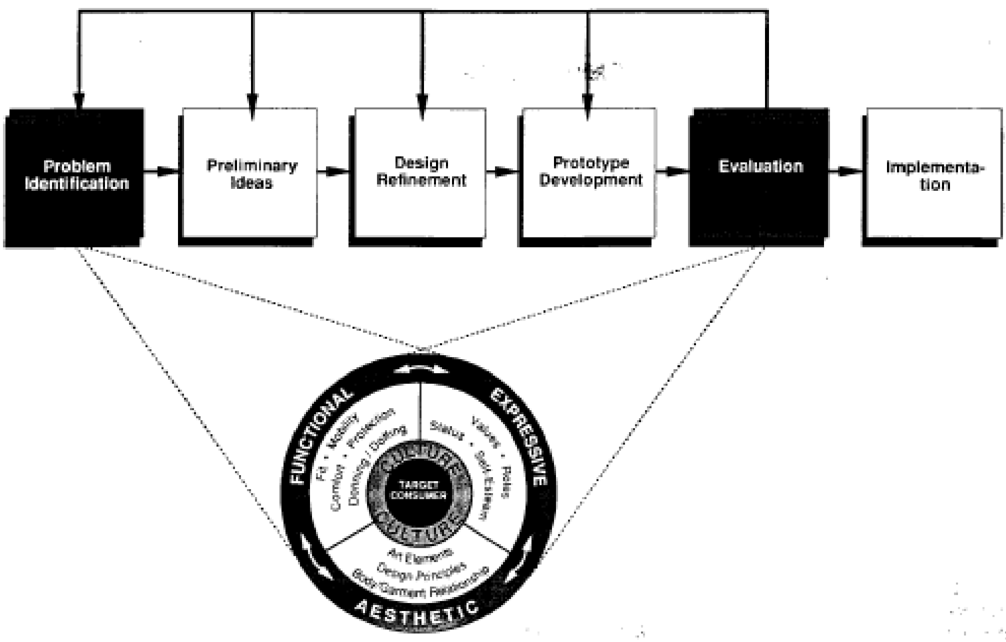


Figure 2.8 Design framework (apparel) (Lamb & Kallal, 1992)

2.4.3 Functional Apparel Design Process

Bergen, Capjack, McConnan, and Richards (1996) referred to the design process suggested by DeJonge (1984), authors outlined seven steps in the process of designing functional apparel as shown in Figure 2.9: (1) receiving a general request: for instance, clothing for neonate; (2) exploring the design situation: gathering information by examining the objective, through a literature search, and defining the problem; (3) problem structure perceived: for instance, a literature search, user surveys, and observation, material garment, and market analyses can be carried out; (4) design specifications: for instance, whether the design is for hospital safety, or functional requirements, or psychological requirements, or for production purposes; (5) interaction of design criteria established; (6) prototype developed; and (7) design evaluation by user trial, for instance, survey of comfort, access, safety and aesthetics.

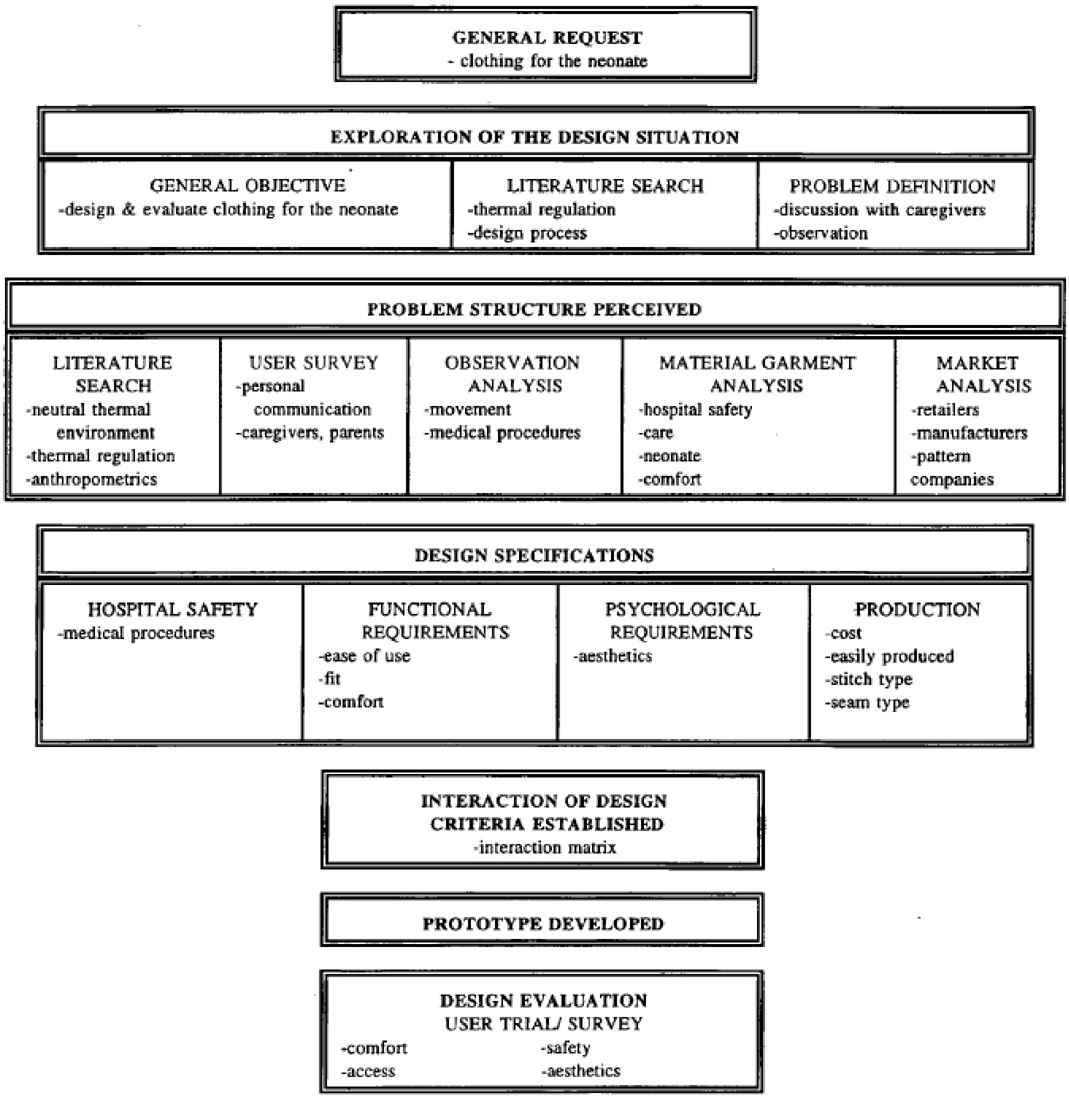


Figure 2.9 Functional apparel design process suggested by DeJonge (1984) (Bergen et al., 1996)

2.4.4 Apparel Design Process

Regan, Kincade, and Sheldon (1998) developed a seven-step apparel design process by incorporating the engineering design process theory of Lewis and Samuel (1991) as follows:

(1) Problem recognition: includes the problem statement, and generation of preliminary solutions;

(2) Problem definition: includes the establishment of objectives and design

boundaries, and identification of available resources, and identification of sub-problems;

(3) Exploration of the problem: incorporates a information search, making assumptions and estimations, design strategies, market and competition assessments, understanding the customer objectives, and determining cost for manufacture;

(4) Searching for alternatives: includes using one's own experience, finding the answers to the identified problem, understanding the customer requirements, and coming up with a design proposal;

(5) Making evaluation and decisions: determining the outcome for each proposal, feasibility and consequences, and evaluating the feasible proposals;

(6) Specification of solution: analyzing alternative proposals, and selecting the optimal proposal; and

(7) Communication of solution: done through verbal communication of design proposal, visual design proposal itself, and management staff/other people.

2.4.5 Summary

In this thesis, a design framework for functional apparel system was developed and based on the literature review of related apparel design frameworks. The design framework incorporated the concepts and ideas from various authors (Bergen et al., 1996; DeJonge, 1984; Lamb & Kallal, 1992; Regan et al., 1998; Watkins, 1988). Lamb and Kallal (1992) suggested a framework which takes into consideration of the needs of consumers, including functional, expressive, and aesthetic considerations, which summarised the design process framework of Watkins (1988). And, Bergen et al. (1996) developed a functional apparel design process suggested by DeJonge (1984), that incorporated the clothing with special function. It is important to combine the identified problems into the creative process of clothing. The development of design framework was introduced in Chapter 3.

2.5 Chitosan Fibre

Chitosan is a functional material produced in nature and used by man, especially in the biomedical sector (Guo & Conrad, 1989). It is known as a wound healer because of its excellent biocompatibility, biodegradability, non-toxicity, and adsorption properties. The material is formed by a natural polymer like cellulose (shown in Figure 2.10) and a natural nontoxic biopolymer derived by deacetylation of chitin, which is a major component of the shells of crustaceans such as crab, shrimp, and crawfish. Chitosan is the N-deacetylated and derivative of chitin, although this N-deacetylation is almost never completed (M. N. V. Ravi Kumar, 2000; Wani et al., 2010). According to Muzzarelli, Tanfani, and Scarpini (1980); M. N. V. Ravi Kumar (2000) chitosan is obtained by a long process involving demineralization with alkali, deprotenization and decalcification of Chitin, and spinning into chitosan filaments by wet spinning. The characteristics of chitosan fibre are affected by the degree of later processing and chemical treatments. chitosan is insoluble in water, but it is soluble in dilute acetic acid, formic acid, hydrochloric acid, or hydroiodic acid (Madhavan, 1992). Long filaments are processed as staple fibres, and those are suitable for yarn-to-textiles processing and other processes (Figure 2.11 and 2.12).

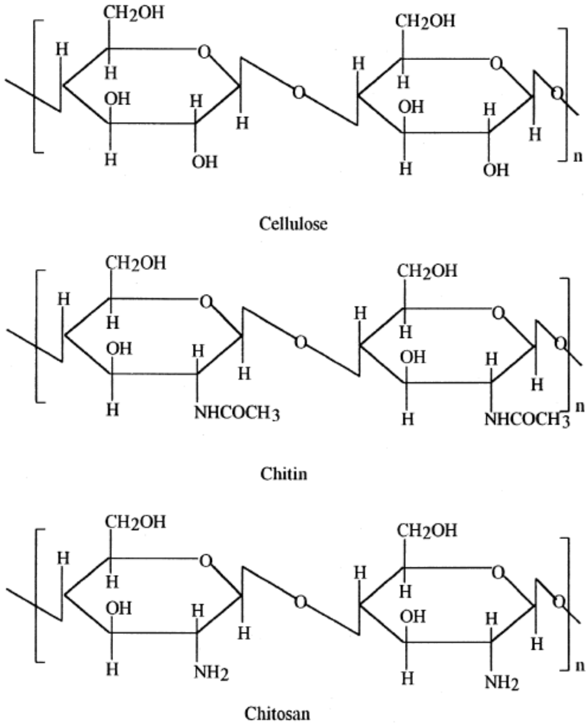


Figure 2.10 Chemical structure of cellulose, chitin and chitosan (M. N. V. Ravi Kumar, 2000)

Figure 2.11 Production of chitosan fibres and yarn (Author, 2017)

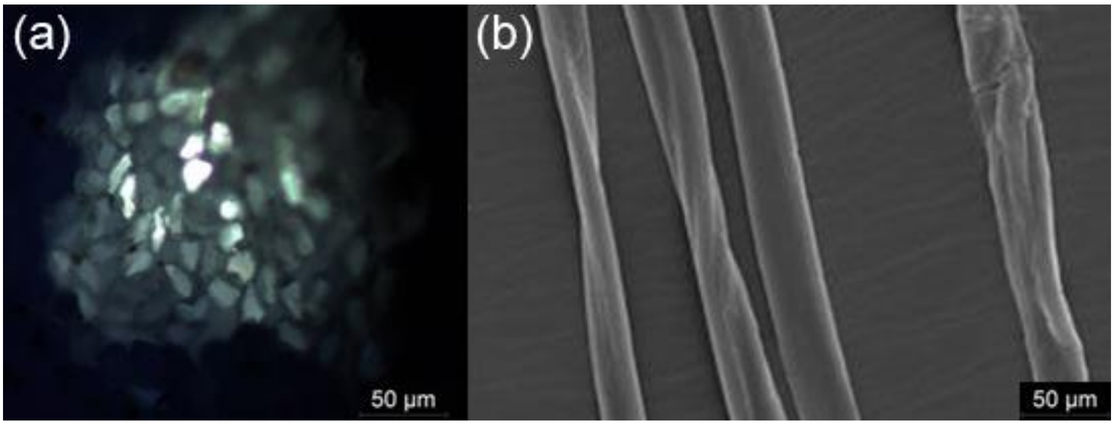


Figure 2.12 Scanning electron micrographs (SEM) of chitosan fibres (a) cross section of fibre (b) structure of fibre surface (scale bar: 50μm) (Liu et al., 2015)

2.5.1 Properties of Chitosan

Chitosan is well known for its haemostatic properties, cell proliferation and histo-architecture tissue organization stimulation, bacteriostatic and fungistatic properties (Guo & Conrad, 1989; Minami, Tanioka, & Shigemasa, 1992; Muzzarelli et al., 1980; Prudden, Migel, Hanson, Friedrich, & Balassa, 1970). It has antimicrobial activity that is facilitated by the polycationic nature of its amino group (Figure 2.13). The positively charged chitosan binds to the negatively charged cell membranes of bacterial surfaces, permeabilizing the membrane and causing leakage of intracellular substances and death of the bacteria (Seong, Kim, & Ko, 1999).

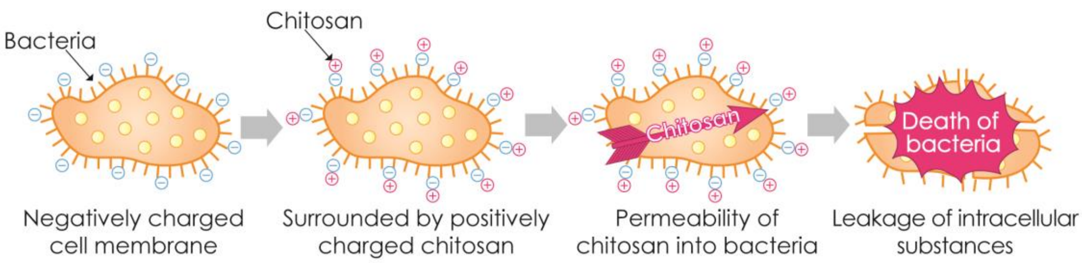


Figure 2.13 Antimicrobial activity of chitosan (Author, 2017)

There are several problems in the yarn production process that discourage the further development and application of chitosan, and these explain the lack of literature about chitosan fibres with high concentration in the yarn-to-textile industry. The relatively high cost of chitosan fibre (ranges from US$ 50,000 to US$ 100,000 per ton), blending with cotton fibre to balance the production cost and offer different functionality and promote production variety (Liu et al., 2015). Chitosan fibre has poor mechanical properties and weak tensile strength, which causes difficulties in yarn spinning. The second problem is that fibres stick to rollers due to static electricity, which may lead to problems and waste during yarn spinning. The problem of yarn spinning was examined by grounding and embedding the aluminium foil on the spinning roller, which showed that the grounding of spinning rollers decreases the fibre sticking problem and improves the spinning ability. During the spinning process of chitosan yarn, high electrostatic potential is created when fibres make contact with other fibres, and charge is transferred onto the fibre surface by friction between rollers (Figure 2.14).

Figure 2.14 Chitosan fibres stuck onto a spinning roller (Author, 2017)

Oxtoby (2013) has written about two mechanisms of electrification: (1) static is apparent on the surfaces if different substances are separated; (2) and charges generated after two substance rubbing together with heat. According to Figure 2.15, charges are generated after two different materials are rubbed together. The phenomena can be explained by the triboelectric series (Figure 2.16). A positive charge generated due to friction with the materials on the top of the list, and a negative charge is generated by the materials near the bottom of the list.

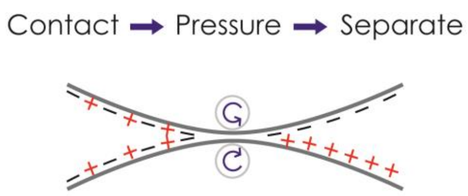


Figure 2.15 Triboelectric effect (Author, 2017)

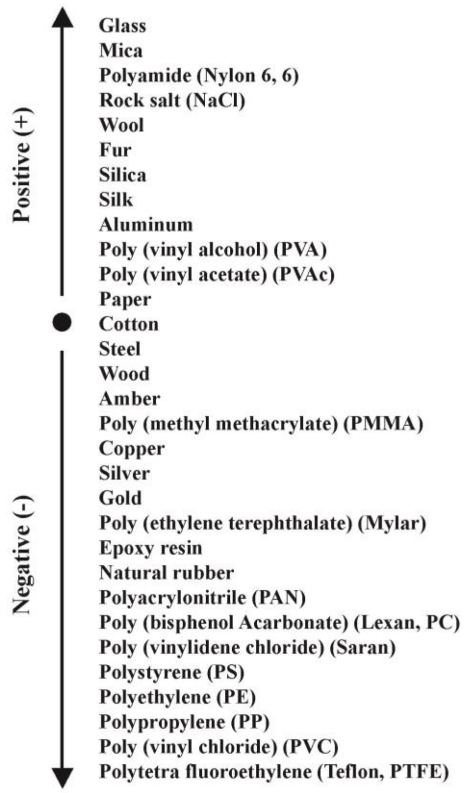


Figure 2.16 Triboelectric series (Sessler & Broadhurst, 1998)

Therefore, a series of electrostatic analysis of various fabrics used to examine the generated voltage after the fabric friction test, especially for chitosan fibres and to investigate the phenomena of fibre sticking on spinning rollers. An investigation of three more common textile fibres, such as cotton, silk and polyester was used as control samples in the electrostatic test. There are four types of pure yarn knitted to 14 gauge plain jersey fabrics (2-ply yarn inserted) (Figure 2.17) with a dimension of 60 cm x 50 cm on a STOLL CMS 822 computerized flat knitting machine (Figure 2.18), the fabric density was 26.1 to 36.7 WPI x CPI.

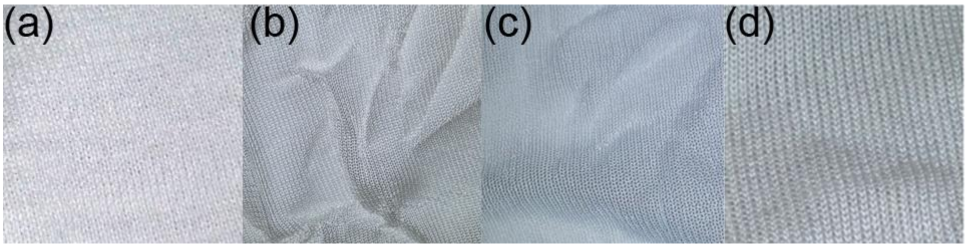


Figure 2.17 14 gauge plain jersey fabrics of pure (a) cotton (b) silk (c) polyester and (d) chitosan (Author, 2017)

Figure 2.18 STOLL CMS 822 computerized flat knitting machine (Author, 2017)

All samples were tested on the YG402 Fabrics Friction type Electro-static Measuring Tester (Figure 2.19). The machine settings were configured according to Chinese Standard GB/T12703.5-2010. The friction bas fabric was 100% Nylon, the rotation speed was 400 r/min, the friction time was 30 seconds and the load weight was 500 g.

Figure 2.19 YG402 Fabrics Friction type Electro-static Measuring Tester (Author, 2017)

Table 2.1 Peak voltage and half-life voltage of pure cotton, silk, polyester and chitosan plain jersey fabric (Author, 2017)

	Room temperature (℃)	**Relative humidity (%)**	**Peak voltage (v)**	**Half-life voltage (v)**
100% cotton				
Technical front	18.3	74	0	0
Technical back	18.3	74	0	0
100% silk				
Technical front	18.3	76	21	10
Technical back	18.3	75	53	26
100% polyester				
Technical front	18.2	72	159	79
Technical back	18.2	72	159	79
100% chitosan				
Technical front	18.4	76	169	84
Technical back	18.4	76	275	137

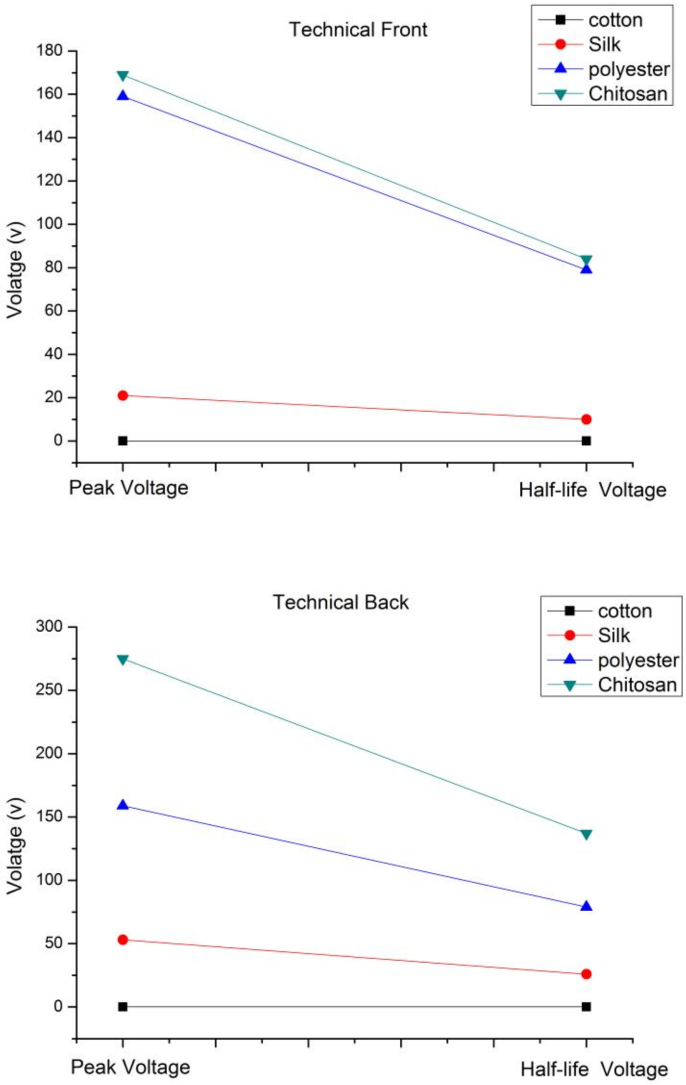


Figure 2.20 Peak voltages and half-life voltage of cotton, silk, polyester and chitosan: (upper) technical front and (bottom) technical back (Author, 2017)

During the processes of chitosan yarn spinning, chitosan fibres have the tendency to stick to the roller, which causes difficulties for yarn spinning. This phenomenon is similar to what happens with polyester fibres, so it is reasonable to speculate that the stickiness of chitosan fibres might be attributed to the generation of static electricity. The frictional static electricity of fabric was measured on both the front and back of the fabric. The results are presented in Table 2.1 and Figure 2.20. The peak voltage generated on both side of the fabrics following the same order, as from the least voltage to the highest, cotton, silk, polyester, chitosan. The voltage generated on the chitosan fabric after friction was close to that of polyester. These measurements provide persuasive evidences for our speculation that static electricity generation on chitosan fibre might have significant contributions to the roller-sticking phenomenon.

In the pure chitosan yarn sample, many fibres have been broken into shorter ones during yarn spinning. Most of the chitosan fibres that are 38 mm are broken into a length that ranges from 21 to 30 mm (shown in Figure 2.21), and elongated into 46 mm. The investigation of the effect of fibre length to chitosan yarn sample performance was proposed of fibre length with 22, 30 and 46 mm in this study.

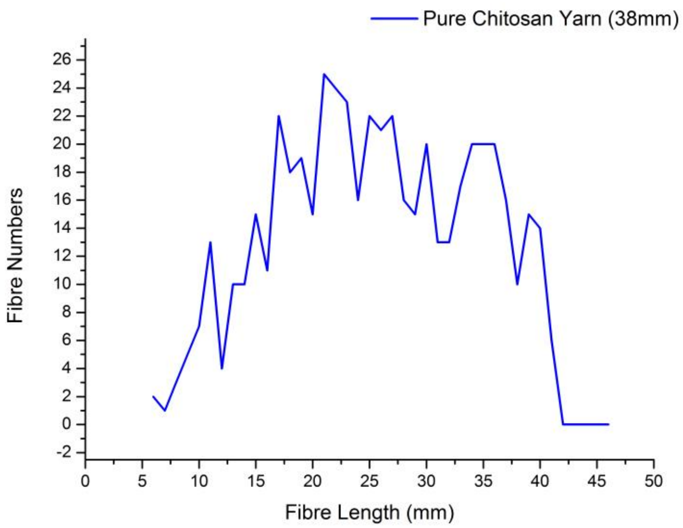


Figure 2.21 Fibre length distribution in pure chitosan yarn sample (yarn with chitosan fibre 38 mm in length) determined by manual untwisting of yarn and counting of fibres (Author, 2017)

2.5.2 Applications of Chitosan

Chitosan and its derivatives have a wide variety of applications because of their advantages as materials. For example, in contact lenses they provide ideal properties for the development of ocular bandage lenses (Markey, Bowman, & Bergamini, 1989), and they can be used for drug delivery systems with good biodegradability (M. N. V. Ravi Kumar, 2000). Apart from that, chitosan also contributes to photography due to its resistance to abrasion, its optical characteristics, and its film forming ability (Whistler & Smart, 1953). In cosmetics, it is useful for its fungicidal and fungistatic properties (Dutta, Dutta, & Tripathi, 2004). In food and nutrition research in Austin in 1989, a small amount of chitinous material or supplement was added to animal feed, and the utilization of whey was improved. chitosan has also contributed to solving numerous problems such as environmental protection in industries that facilitate the removal of mercury from solutions by adsorption of mercuric ions in wastewater (Nair & Madhavan, 1984; Peniche-Covas, Alvarez, & Argüelles-Monal, 1992). Because chitosan is one of the safest and most effective antimicrobial agents, it has had a wide variety of applications in the medical sector in the last three decades (Lee, Cho, & Cho, 1999; Peter, 1995; Yalpani, Johnson, & Robinson, 1992). It served as a non-woven wound healing dressing that inhibits fibroplasia and promotes tissue growth and differentiation in tissue culture (Muzzarelli, 2009). It has been used in artificial skin for individuals who have extensive skin loss, and it has similar chemical structure that could make it suitable for skin replacement (Le, Anand, & Horrocks, 1996; Olsen, Schwartzmiller, Weppner, & Winandy, 1989; Stinnes & Sandford, 1991). The explanation that chitosan non-woven fabric utilized in medical sector because the technology offers lower production cost and it would facilitate to the prototype production. The disadvantages of non-woven fabric are lacking of elasticity and hand by the formation structure of non-woven technology. These problems could be resolved by using the weaving and knitting technologies in the textile industry to create better construction of fabric formation and further apparel applications.

In the textile industry, there are various applications of chitosan, such as chitosan fibres, nanoparticles, and nano-fibres (Abidi, Cabrales, & Hequet, 2009; Qin, Zhu, Chen, & Zhong, 2007; Radetić, 2013; Ren et al., 2009; Shah, Mewada, & Mehta, 2013; Zakaria, Izzah, Jawaid, & Hassan, 2012), fabric pre-treatment, coating (Elsabee & Abdou, 2013; Mocanu, Nichifor, Mihai, & Oproiu, 2013; Xue, Chen, Yin, Jia, & Ma, 2012; Zhou et al., 2012), finishing, colour removal from textile mill wastewater by sorption of dyes (Crini & Badot, 2008; Öktem, 2003; M. Ravi Kumar, Rajakala Sridhari, Durga Bhavani, & Dutta, 1998; Sekar, 2000; Sumner, 1989), and antimicrobial treatment (El-Tahlawy, El-Bendary, Elhendawy, & Hudson, 2005; Fernandes et al., 2010; Kong, Chen, Xing, & Park, 2010). The existing literature says that chitosan fibres are normally blended with cotton or viscose fibres to achieve comfort and functionality with a blending ratio of 10/90 chitosan/cotton (Liu et al., 2015; Simoncic & Tomsic, 2010). It is claimed that fabric with a composition of 10% chitosan is sufficient for achieving a 99% antibacterial and hygienic effect by 20 washes (Öktem, 2003; Shanmugasundaram, 2006). The advantages of chitosan fibres nurse the yarn and fabric development which facilitate applications in sportswear, intimate apparel and infant wear those require high hygienic standard. However, because of the poor fibre strength and the high electrostatic generation of chitosan (Kim, Kim, Kim, Kwon, & Min, 2012; Liu et al., 2015), yarn-to-textile development with higher chitosan ratios has been limited. This could be the reason for the lack of chitosan yarns and blends. Increase the blending ratio of chitosan in the yarn composition can contribute to the future application on functional garment with medical purpose.

2.5.3 Fibre Migration Theory

There are many reasons for blending fibres in yarn production, such as mixing different grades of one material to produce yarn at a marketable price or to meet aesthetic requirements in the end-product by mixing different kinds of materials. To enhance the mechanical properties and balance the performance and production cost of textiles and the final product, blending of different fibres in yarns is the normal practice in the apparel industry (Cyniak, Czekalski, & Jackowski, 2006; Cyniak, Czekalski, Jackowski, & Popin, 2006; El-Behery & Batavia, 1971; Moghassem & Fakhrali, 2013; Pan, Chen, Monego, & Backer, 2000). Blending natural and man-made fibres in yarns enables a combination of wearability and functionality, which can increase the usage of fibres and improve product variety. Blending with cotton fibres provides good absorbency and comfort, whereas chitosan fibres offer antibacterial properties to fabric.

Furthermore, the method of fibre blending will also affect the desired characteristic and performance of yarn (Oxtoby, 1987). Fibre-blending before the carding stage provides the most intimate mixing of fibres. This is because the carded sliver is slightly uneven. Sliver-blending at draw frame gives the greatest evenness of fibre mixing. The fibre distribution of both components depends on the fibre alignment during yarn spinning by two different fibre mixing methods. For example, insufficient fibre strength would affect the yarn fabrication process and the fibre length is one of the critical key elements that could affect the quality of the yarn during production, such as load sharing between broken fibres during yarn breakage (Cai et al., 2013; Harlow & Phoenix, 1978; Pan, Hua, & Qiu, 2001). In a staple yarn structure, fibre slippage and breakage are the two main interactions that induce tensile deformation (Hearle & Goswami, 1968, 1970). When fibres have the tendency to slip, friction force is generated between them, which would induce tensile forces along the axial direction of the fibres. Due to the equilibrium of the forces, the tensile forces on different segments of fibres continuously vary, and the segment which is the farthest from the fibre ends would experience the largest tensile force. The tensile force would then increase along with the friction force between the fibres (Figure 2.22).

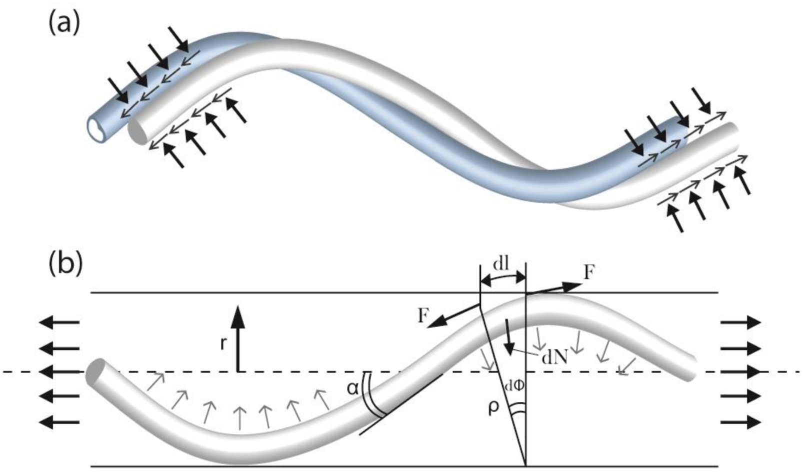


Figure 2.22 Schematic of (a) friction and tensile forces in fibre in the yarn matrix (b) centripetal force (Author, 2017)

The friction force is found to correspond with the breaking tenacity of the fibre.lc is defined as the length from the ends of the fibres when the friction force equals the breaking tenacity.

$$l_c = \frac{r\sigma_b}{2q\mu} \quad (1)$$

where r is the radius of the fibres, σ_b is the breaking force of the fibres, q is the transverse tension on the fibres, and μ is a coefficient of the fibre friction.

The slip coefficient (SF) is given by:

$$SF = \frac{\overline{F}}{F_b} = \frac{L - l_c}{L} = 1 - \frac{l_c}{L} \qquad (2)$$

Where $\overline{F}$ is the average stress of the fibres, F_b is the breaking force of the fibres, and L is the length of the fibres. SF indicates the efficiency of the fibres in the staple yarns. The tensile properties of blended yarns depend on two main factors: fibre properties (fibre length, line density, surface friction, etc.) and yarn structure (blend ratio, yarn twist, fabrication method, fibre migration, etc.) (Hamilton & Cooper, 1958; Mahmoudi, 2010; Oxtoby, 2013; Tyagi, 2010).

2.5.3.1 Fibre Migration Behaviour

The fibre migration behaviour can be defined by fibre migration theory (Figure 2.23). This refers to the radial distribution of fibre components in blended yarns during yarn manufacturing, based on observation of the cross-sections and calculation of the migration index. The migration index directly indicates that the particular fibre component has a tendency to migrate toward the surface or to the core of yarns.

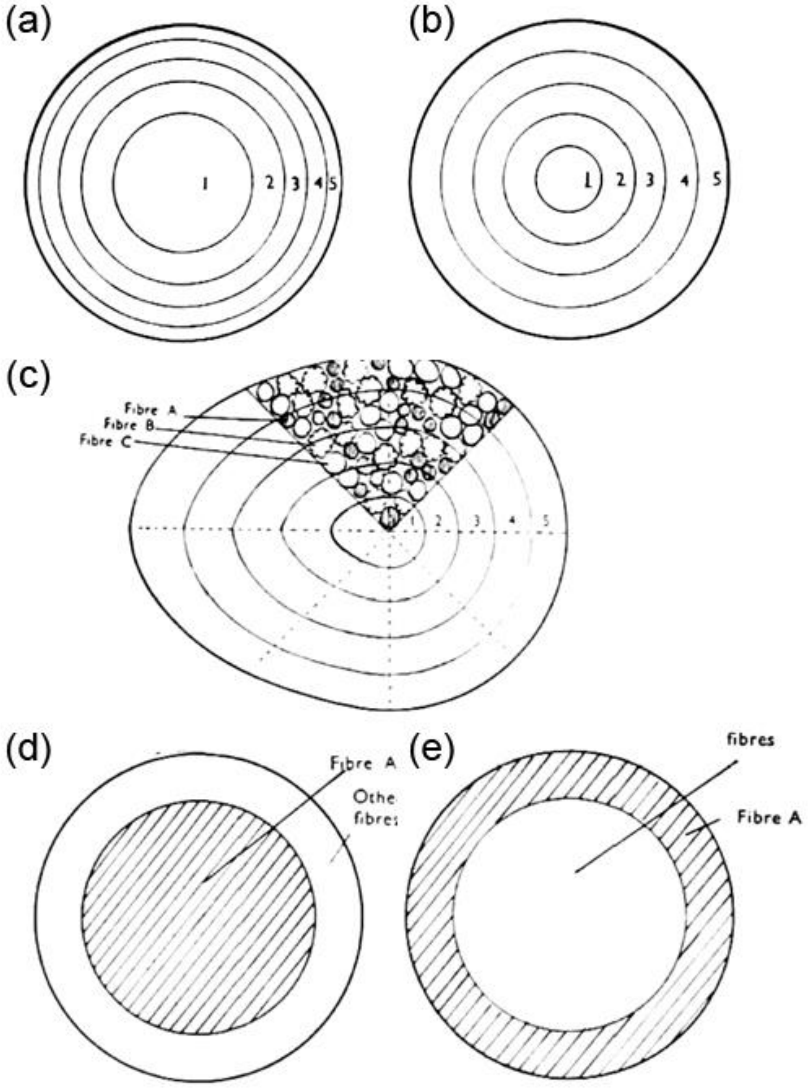


Figure 2.23 (a) Equal area zones (b) equal thickness zones (c) typical zoned yarn cross-section for a ternary blend (d) maximum inward migration (e) maximum outward migration (Hamilton, 1958)

The fibre migration index calculation method was proposed by Hamilton, and equations (1) to (6) are listed below Hamilton (1958); Hamilton and Cooper (1958). He suggested counting fibres on the yarn cross-section, which is divided into a series of zones concentric with the axis. Correction to volume distribution is applied to one component only. According to the equation (1), FM_a refers to the actual distribution, which is the sum of the fibre volume value.

$$FM_a = 2(a'_5 - a'_1) + (a'_4 - a'_2) \quad (1)$$

FM_u is the uniform distribution and it is assumed that the fibres are distributed uniformly throughout the yarn cross-section.

$$FM_u = \frac{A'}{T'}[2\ (t'_5 - t'_1) + \ (t'_4 - t'_2)] \quad (2)$$

FM_i and FM_o are corresponding to maximum inward or outward migration. The migration index (M) is calculated by either equation (4) or (6). If $FM_a < FM_u$, M is negative, and FM_i must be calculated by equation (3).It is used in equation (4), which means the fibre component has been inward.

$$FM_i = 2(t'_5 - t'_1) + (t'_4 - t'_2) \quad (3)$$

$$M = \frac{FM_a - FM_u}{FM_u - FM_i} \times 100\% \quad (4)$$

If $FM_a > FM_u$, M is positive, where FM_o is calculated by equation (5), and it is used in equation (6), which means the fibre component has been outward.

$$FM_o = 2\ (t'_5) + t'_4 \quad (5)$$

$$M = \frac{FM_a - FM_u}{FM_o - FM_u} \times 100\% \quad (6)$$

Fibres properties affect the migration of components in blended yarn. It was suggested that stronger fibres with a higher tensile modulus have a tendency to migrate inward (El-Behery & Batavia, 1971; Morton, 1956). Also, in most cases, coarser and stiffer fibres tend to migrate toward the surface of the yarn. As summarised, shorter and coarser fibres have a tendency to migrate outwards (Hamilton & Cooper, 1958).

2.5.4 Antibacterial Function

Chitosan has been applied on textile as a finishing to provide antibacterial properties on fabric, but there are limitations to its durability, which have been studied by various researchers; see for instance, Mocanu et al. (2013). Chitosan contributes to slowing the growth of Staphylococcus aureus (S. aureus), and which is one of the most common types of bacteria. The antibacterial performance of chitosan which was used to treat the surface of 50% polyester 50% cotton woven and knitted fabrics was studied by Öktem (2003), who found that the antibacterial properties are reduced after 5 to 10 washes. The bacterial reduction performance of S. aureus was also investigated by Cheng, Ma, Li, Ren, and Huang (2014) on chitosan coated cotton. It was found that there is a 98.5% in bacterial reduction on the samples that have a contact time for 30 and 50 minutes, and 100% for cotton coated with chlorine (Cl) with a contact time of 5, 10, 30 and 50 minutes. Besides, the degree of deacetylation of chitosan has certain effects on antibacterial efficiency, and the inhabitation of S. aureus is rapidly reduced when the deacetylation of chitosan is 80% (J. Li, Wu, & Zhao, 2016).

There are functional garments in the market for EB patients that provide antibacterial properties to wearers through the fabric surface after treatment or with a fabric coating. With the progress of science and technology, materials for wound dressings, such as chitosan, can be produced in the form of fibers, and the spinning ability of chitosan into fibers is also becoming more prevalent. This is especially the case for chitosan used in garment based products for wound healing of EB patients, which could provide them with more convenience of use and wear comfort (Azuma et al., 2015; Dai, Tanaka, Huang, & Hamblin, 2011).

2.5.5 Comfort Properties

Large amounts of bandages are covered on the body surface of EB patients and it caused body over heating, and at the same time, increases the chances to get secondary trauma of blistering by friction of clothing. Fabric comfort is directly affecting the friction on skin, and it is also related to wearing comfort. Smoothness, softness and stiffness of fabric is the features that reflect the fabric comfort (Liao, Hu, Li, Li, & Wu, 2011). There are 4 different physical properties were measured by using an Fabric Touch Tester (FTT) (Liao, Li, Hu, Wu, & Li, 2014). The physical properties included bending, compression, thermal conductivity, surface friction and roughness (Figure 2.24c). Before the testing, the samples are required to be cut into an "L" shape with specific dimensions and directions (Figure 2.19a). The modulus of two different directions on both the outer (technical front stitch: knit) and inner (technical back stitch: purl) surfaces of each specimen (Figure 2.24b) are tested. 5 specimens of each sample are required from each fabric sample. Conditioning of samples in standard atmosphere for 24 hours before the testing is necessary.

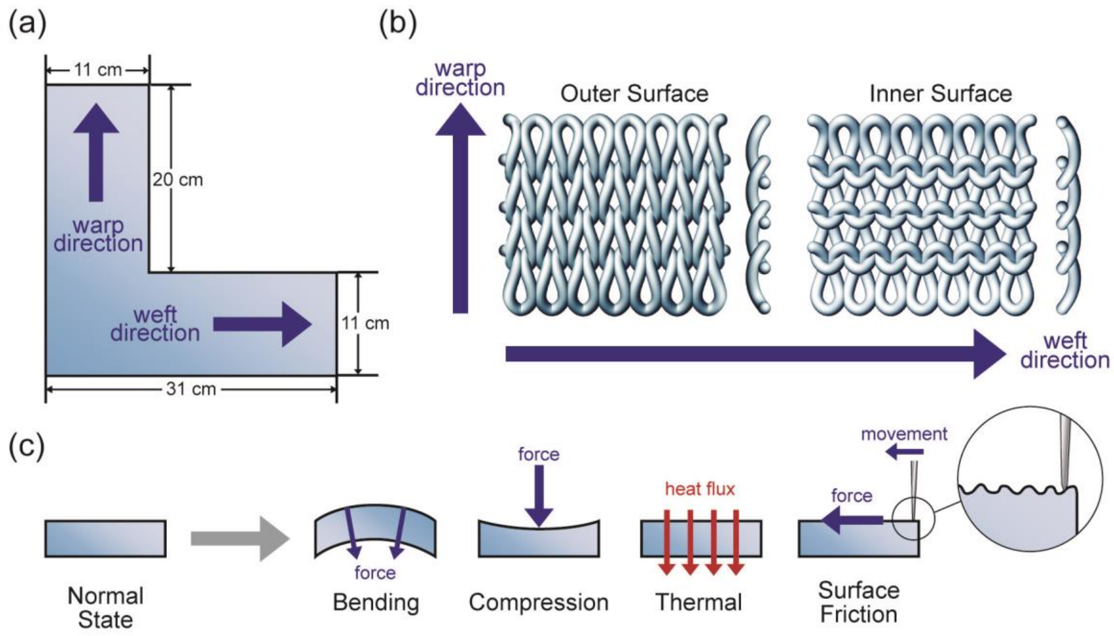


Figure 2.24 (a) Dimension and direction of fabric sample that is cut into L shape (vertical is warp direction and horizontal is weft direction). (b) Knit fabric structure of outer (knit stitch) and inner (purl stitch) surfaces. (c) Four different physical properties measured in each type of fabric. (Author, 2017)

Bending properties reflects the stiffness of a fabric which is also received by human skin as a stimulus. In the bending module, bending force was recorded during the measurement process and then convert into two indices, including the average bending rigidity (BAR) and bending work (BW), were defined and determined from the mechanical curve (moment/radian) measured. BAR is defined as the slope of the bending moment or bending radius curve in 60% of the centre region of the plot. BW was calculated as an integral of the curve.

The compression properties determine the fullness and elasticity of fabrics. In the compression module, four indices including compression work (CW), compression recovery rate (CRR), compression average rigidity (CAR), and average rigidity during recovery (RAR) were measured. Two curves and their integrals were used to describe the process of the compression and recovery. CW is the integral of the compression curve, CRR is the shape (area) formed by the curves divided by the CW. CW and CRR are the two indices to reflect the consumed energy during the measurement of compression process. CAR and RAR are defined as the slope of the compression pressure versus fabric thickness curve in the 60% of the centre region of the plot. These two indices used to present the changing rate of force during compression and recovery.

Thermal properties refer to the heat transfer between fabric and human skin and the perception of coolness. In the thermal module, three indices, including thermal conductivity when compressed (TCC), thermal conductivity during recovery (TCR) and thermal maximum flux (Qmax); they were measured and recorded the heat flux through fabrics during compression process. They used to define the thermal properties by plotting the heat flux versus thickness and to provide reference for coolness of fabric.

Surface properties refer to the texture and surface smoothness of fabric sample. In the surface module, surface friction coefficient (SFC) was defined as the average value of measured friction force by constant normal force. The surface roughness amplitude (SRA) and surface roughness wavelength (SRW) are two indices used to describe the basic plotted shape of force versus the distance of one repeat unit of the average peak and average trough measured in the testing. The indices defined by the FTT that characterize the physical properties of the fabric are listed in Table 2.2.

Table 2.2 Indices of physical properties defined by FTT

Physical Properties	Indices	Unit
Average Bending Rigidity	BAR	gf*mm/rad
Bending Work	BW	gf*mm*rad
Thickness	T	mm
Compression Work	CW	gf*mm
Compression Recovery Rate	CRR	-
Average Compression Rigidity	CAR	gf/(mm^3)
Average Rigidity during Recovery	RAR	gf/(mm^3)
Thermal Conductivity under Normal Pressure at 42 gf/cm^2	TCC	W/(m*℃)
Thermal Conductivity during Recovery	TCR	W/(m*℃)
Thermal Maximum Flux	Qmax	W/(m^2)
Surface Friction Coefficient	SFC	-
Surface Roughness Amplitude	SRA	µm
Surface Roughness Wavelength	SRW	mm

2.6 Research Gaps

A literature review in the related areas of this study has been conducted, including on the characteristics and symptoms of EB; functional apparel design frameworks; and properties and applications of chitosan materials. As EB patients experience daily blister formation because of their skin fragility, and there is currently no cure, only special management and care of wounds can reduce their physical pain. In this research, there are research gaps which need to be addressed in order to realize the development of the proposed functional apparel system that applies chitosan/cotton blend yarn and textile through a systematic approach inspired by functional apparel frameworks from previous research work. These gaps are as follows.

- The details of garment needs of EB patients have not been fully discussed in the literature.
- An apparel-based wound healing system for EB patients has not been explored and discussed in the literature
- The appropriate chitosan fibre length and blend ratio that would provide

sufficient yarn tensile strength and fabric comfort have not been discussed and the corresponding yarn and fabric prototypes have not been developed.

- A design framework for a functional medical apparel system is not yet available.
- The application of chitosan/cotton blend yarn and fabric to a functional apparel system has not been realized.
- The development of a functional medical apparel system that takes into account aesthetic and expressive considerations has not been fully explored and discussed.

2.7 Conclusion

The characteristics and symptoms of EB, including the garment requirement and wound care problems of the patients have been discussed. The related different functional apparel design frameworks for garment design have been reviewed, which have a strong influence on the research and prototype development process to meet the needs of EB patients. The properties and applications of chitosan material that provides antibacterial functions and enhances the rate of wound healing of EB patients to reduce their psychological and physical pain have been explored. A brief literature review has been provided, and the research gaps are identified.

Chapter 3

Research Methodology

3.1 Introduction

To accomplish the stated objectives, a range of research methods have been used in this study. There are five stages in the research work: i) the research stage; ii) experimental development; iii) development of functional apparel design framework; iv) prototype development; and v) evaluation. A qualitative approach is used in evaluating the functional apparel system by interviewing EB patients. A functional apparel design framework for the application and development of chitosan/cotton yarn and textile has been generated to facilitate the research process and accomplish the objectives.

3.2 Experimental Development

According to Cooper (1998), a theoretical review should be the target research method among the different types of literature reviews, which facilitates the presentation of theories to justify a particular phenomenon. It also provides internal consistency and describes the nature of the study prediction. Cooper (1998) also stated that a theoretical review contains descriptions of the crucial experiments already conducted and assessment of the theories to determine the one that is most specific, and therefore derive the most powerful and consistent method of study. Since EB patients suffer from skin fragility that leads to daily blistering and the wounds do not fully heal, and there is currently no available cure, therefore, it is important to provide functional apparel that improves their wear comfort and reduces their physical pain with applications of chitosan/cotton fibres and textile. A functional apparel design framework is developed with specific design requirements and contributes to the development of a medical system for EB patients. Also, since there is a paucity of studies in the literature that examine the processing of chitosan yarn and its blends through yarn spinning in the industry, therefore, chitosan/cotton blend yarn prototype development with different parameters is crucial and will be carried out in this research. A series of experiments will be used to examine the tensile properties of the yarns and provide sufficient evidence for the assessment. Furthermore, it is important to provide descriptions on the planning of the experiment, such as the principles, equipment used and work procedures.

3.3 Evaluation of Functional Apparel System

Skin-protective clothing was developed by the application of chitosan/cotton blend yarn. This system aimed to contribute to EB patients by providing information towards a more suitable apparel system that would enhance their quality of life by reducing their physical and psychological pain in daily life. The garment prototypes were donated to EB patients of the Taiwan Epidermolysis Bullosa Association, for evaluation.

A qualitative research design was adopted in the form of semi-structured interviews. The semi-structured interviews were carried out to collect data to gain an in-depth understanding of the problems encountered by EB patients and the parents of children with EB. Some of the interview topics and leading questions were defined after a comprehensive literature review on EB, wound healing acceleration and related textile development. The interview and survey questionnaire consisted of seven topics with functionality, expressive and aesthetic considerations including: (i) the importance and satisfaction with current garments available on the market; (ii) comfort and aesthetics considerations proposed in clothing for EB patients; (iii) the functions of garments for EB patients; (iv) materials used in clothing for EB patients;

(v) garment detailing and design for EB patients; (vi) special wound dressings for EB patients; and (vii) subjective and aesthetic concerns of garments for EB patients. Two sets of questions were designed; one set for the EB patients (Appendix 3.1, P.127) and one set for the parents (Appendix 3.2). For EB patients: 4 questions focused on personal demographics and type of EB. 20 of the questions focused on their preferences, as well as the difficulties that they face in terms of the issues in the seven topics. 4 out of the 20 questions on preferences and difficulties were open-ended, and 8 were closed while the remaining 8 were based on a 7-point Likert scale. For parents: 8 questions focused on personal demographics and type of EB. 20 of the questions focused on their preferences, as well as the difficulties that they face in terms of the issues in the seven topics. 4 out of the 20 questions on preferences and difficulties were open-ended, and 8 were closed while the remaining 8 were based on a 7-point Likert scale. The design was to obtain a better idea of the negativities and positivities of the various factors and their preferences (DeVellis, 2016; Djamba, 2002).

3.4 Credibility of Research Findings

Three refereed journal papers and three conference presentations (P. ii-iii) have been produced to provide support that lends credibility to the research findings in this study. "Investigation on Skin-Protective Clothing that Addresses Needs of Epidermolysis Bullosa Patients/Children with Epidermolysis Bullosa and their Parents" was submitted to the Health Policy in 2016; "A Pilot Intervention with Blended Yarn Apparel to provide Comfort and Improve Quality of Life for Epidermolysis Bullosa Patients" was submitted to the Textile Research Journal in 2016; "Effect of Fiber Length and Blending Methods on the Tensile Properties of Ring Chitosan-Cotton Blend Yarns" was published online on the Textile Research Journal on June 21, 2016. Conference poster paper called "Functional Garment

Development for Patients with Epidermolysis Bullosa with Application of Chitosan/Cotton Yarn" was presented in the TBIS-APCC 2016 International Symposium from July 12-15 in Melbourne, Australia, and was awarded "Outstanding Poster Presentation Award". A conference paper named "Apparel Design Framework for skin protective clothing development to facilitate functional needs of Epidermolysis Bullosa Patients" was presented in the Textile Summit and Postgraduate Student Conference 2016 during June 28-30 in Hong Kong. As well, a conference poster paper named "The Application of Chitosan/Cotton Blend Yarn for Addressing Functional Clothing Needs of Patients Suffering from Epidermolysis Bullosa" was presented in Fiber Society's Spring 2016 Conference on Textile Innovations—Opportunities and Challenges during May 25-27, 2016 in Mulhouse, France, and was awarded "Best Poster Award". Due to this research work, the author has also been awarded "HKAUW Nancy Woo-Chang Memorial Postgraduate Scholarship 2014" by the Hong Kong Association of University Women.

3.5 Development of Design Framework

In this research work, aesthetics and function are the key components of the design application. For EB patients, the function of clothing would override the aesthetics. The results of this research work indicate the importance of wear comfort and design, and the antibacterial property of chitosan for producing a functional apparel system that is suitable for EB patients. The development of appropriate garments for EB patients is based on the proposed functional apparel design framework. In this research, after developing the experiment and assessing the yarn prototypes, the next step is the fabrication of chitosan/cotton textiles and application and development in garment design with functionality and pleasing aesthetics, and then the apparel design framework is created as part of the research methodology.

Based on the concepts and ideas of the design model from various authors (Bergen et al., 1996; DeJonge, 1984; Lamb & Kallal, 1992; Regan et al., 1998; Watkins, 1988), a framework which takes into consideration of the needs of consumers, including functional, expressive, and aesthetic considerations was adopted. It is important to combine the identified problems into the creative process of clothing. Lamb and Kallal (1992) have identified the design model as the problem-solving approach to ensure that the outcome meets the needs of a functional apparel system for an aesthetically pleasing design. The research methodology is summarised as follows:

(1) identifying the problem; that is, to discover and seek a solution to a problem;
(2) generating preliminary ideas; that is, to generate ideas to solve the stated problem;
(3) refining the design by eliminating and modifying the previous ideas based on an FEA model;
(4) developing prototype of chitosan/cotton yarn to initiate yarn prototyping; and
(5) evaluating the chitosan/cotton yarn to assess the prototype according to the criteria; repetition carried out if the assessment is not passed at this stage.

A functional apparel design framework for the application and development of chitosan/cotton yarn and textile has been produced, see Figure 3.1. The process is as follows:

(1) Problem identification
(2) Preliminary ideas
(3) Design refinement
(4) Prototype development of chitosan/cotton yarn

(5) Evaluation of chitosan/cotton yarn

(6) Prototype development of chitosan/cotton textile

(7) Evaluation of chitosan/cotton textile

(8) Prototype development of functional apparel system made of chitosan/cotton textile

(9) Evaluation of functional apparel system made of chitosan/cotton textile

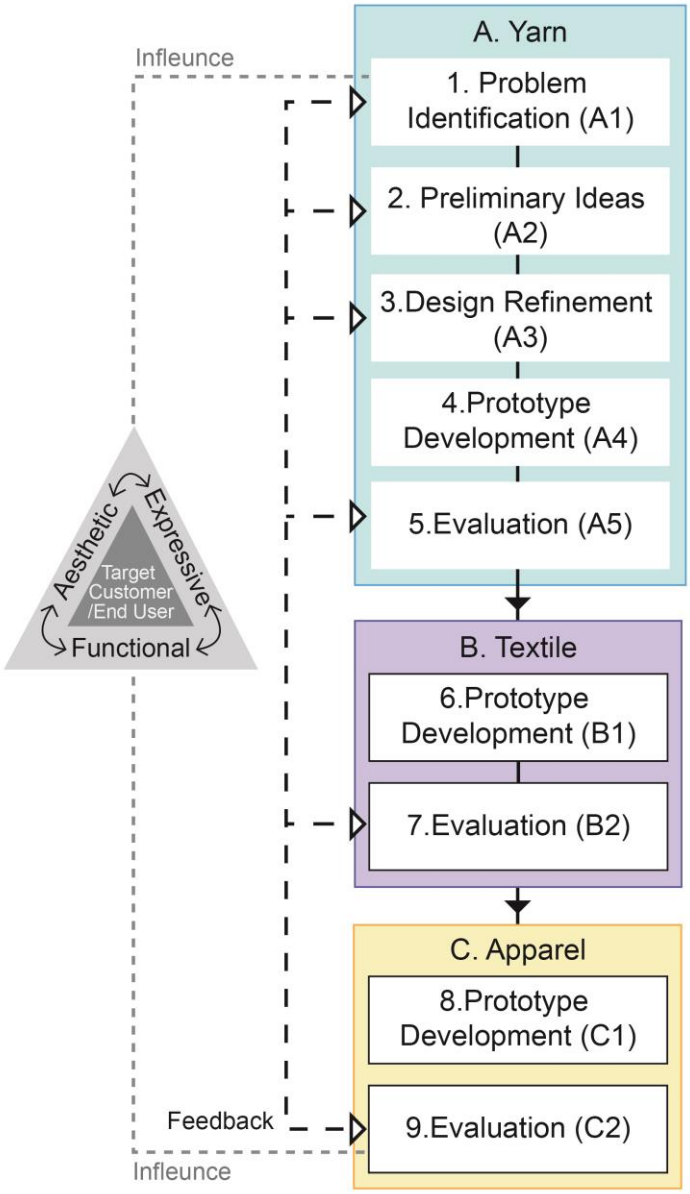


Figure 3.1 Functional apparel design framework for the application and development of chitosan/cotton yarn and textile (Author, 2017)

3.5.1 Problem identification

The aim of this research work is to systematically develop a functional apparel system that uses chitosan/cotton blend yarn and fabric in garment design that provides functionality and an aesthetically pleasing design. Through a literature review conducted on the symptoms of EB and the garment and wound care requirements of EB patients, the functionality and application of chitosan fibre in the textile industry, the research gaps are defined which include the lack of development of yarn with chitosan fibres, as well as the parameters that affect the development of chitosan yarn and yarn-to-textile applications. It is therefore crucial to produce garment designs that are aesthetically pleasing but combines the functionality of chitosan/cotton yarn and textile.

3.5.2 Preliminary Ideas

In this research, the development of functional apparel with the functionality of chitosan and an aesthetically pleasing design for EB patients is carried out by applying and using chitosan/cotton textiles and developing a prototype. The fibre length, blend ratio of chitosan and cotton, and blending methods are the key elements that contribute to the yarn tensile strength and fabric comfort of the prototype. The aesthetics of the garments in the functional apparel system is also important, as it affects the wear comfort of EB patients, their appearance and mood (Kang et al., 2013).

3.5.3 Design Refinement

The development of the prototype that uses chitosan/cotton yarn and textile is crucial in this research. The experimental development includes examining the current related technologies, fibre length on the influence of tensile properties, fibre blend ratio in the yarn samples, parameters of the yarn and development of textile prototype by using different blends of chitosan/cotton yarn. The aesthetics and functional requirements of an apparel system for EB patients with antibacterial properties from chitosan/cotton textile are therefore addressed in this research work.

3.5.4 Prototype Development

The prototype development stage consists of three different parts. First, different lengths of chitosan fibres are blended with cotton by using two different fibre blending methods, and prototypes with different blend ratios of chitosan/cotton yarn are developed based on the technological parameters of yarn spinning. Secondly, chitosan/cotton yarn is utilized in the fabric development that constitute different blend ratios after successful yarn development. Thirdly, chitosan/cotton yarn and textile is applied to a prototype for a functional apparel system for EB patients with antibacterial properties and is aesthetically pleasing.

3.5.5 Evaluation

An assessment of the yarn prototypes is carried out to examine the technological parameters of the yarn for further applications. Then, a fabric prototype is developed and fabric comfort is assessed so as to meet the basic requirement of EB patients. The prototype of the functional apparel system is evaluated based on its aesthetic value and the fabrication requirements and uses indicated by EB patients through interviews. According to Fiore (2010), new ideas generated are followed by the evaluation of the creation by the criteria at the beginning stage to achieve higher satisfactory.

3.6 Conclusion

In this chapter, a research approach that comprises three different components has been outlined and discussed. A qualitative method or interviews with EB patients are used to evaluate the functional apparel system. The credibility of previous research findings is justified for this research work. Finally, a functional apparel design framework for the development and application of chitosan/cotton yarn and textile is developed and implemented in this research work in order to meet the stated aim and objectives.

Chapter 4

Materials & Experiment Design

4.1 Introduction

For the purpose of application of chitosan/cotton blend yarn prototype of functional apparel system suggested in this research, a series of yarn and fabric assessment was conducted. Twelve types of 20 Ne yarn proposed for the experiment and investigation. Two separate batches of chitosan/cotton blend yarn prototypes were developed by ring spinning to study the different characteristics of chitosan fibre lengths and chitosan/cotton blend ratio by a systematic approach. Two batches of yarn prototypes were developed successfully. The first batch of yarn prototype was designed to study the effect of various chitosan fibre lengths in 50/50 blends with cotton and two different blending methods was carried out. The second batch focused on the comfort properties of chitosan/cotton blend yarn in different blend ratio. All yarn prototypes have been examined by several tensile property tests, and fabric comfort test was conducted on fabric prototypes.

4.2 Material for Yarn Prototype Spinning

To study the characteristics of chitosan fibres and determine the effects on spinning and tensile properties, various fibre lengths of chitosan, blending ratio and methods of fibres were examined through a series of yarn prototype production and experiments. This was done to provide a solution to enhance the tensile properties and allow further application of chitosan yarn, and various common textile fibres were used for yarn prototype production. Chitosan fibres in various lengths (22, 30, 38 and 46 mm) were occupied in the spinning experiment (Table 4.1 and Figure 4.1a), blended with 37 mm pre-dyed-blue Cotton (Figure 4.1b), which helps to provide significant vision for further cross section in the microscopy of studying the fibre distributions in yarn, and facilitate the surface observation on yarn prototype and fabric sample.

Table 4.1 Fibres specification for yarn prototype production

Fibre Types	Fibre Diameter	Fibre Length (mm)	Providers
Chitosan	1.81 D	22 30 38 46	Tianjin Zhongsheng Bio-technology Co., Ltd.
Cotton	1.6 D	(UHML) 38	Shaoxing Huatong Color Spun Co., Ltd.

UHML: Upper half mean length

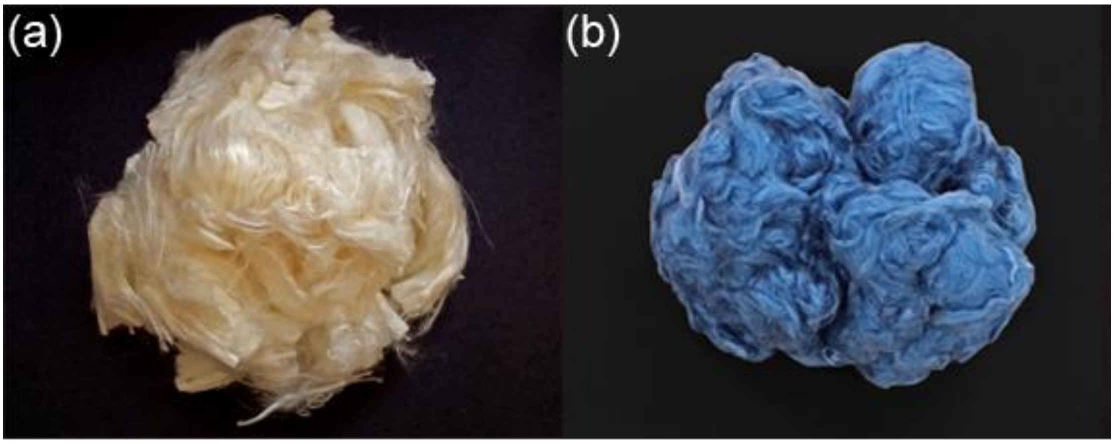


Figure 4.1 Fibres for yarn prototype production: (a) chitosan and (b) cotton (Author, 2017)

4.3 Yarn Prototype Spinning

Two batches of yarn prototypes were designed for studying the characteristics of chitosan yarn and its blend through different parameters of chitosan fibres.

4.3.1 First Batch: Investigation the effect of chitosan fibre length to tensile properties

The first batch was designed for investigating the effect of chitosan fibre length (22, 30, 38 & 46 mm) mixed with cotton (37 mm) in 50/50 blends on tensile properties of ring spun yarn through two different blending methods: fibre-blend and sliver-blend (Figure 4.2 and Table 4.2). Cotton fibres with a UHML of 38 mm and chitosan fibre lengths of 22, 30, 38, and 46 mm were used in the experiments. In order to clearly observe the fibre distribution in the yarn during the cross-section experiment with the use of optical microscopy, the cotton was pre-dyed with a navy blue colour before the fibres were blended.

Table 4.2 Specifications of first batch of chitosan blend yarn prototype spinning

Batch No.	Sample No.	Blending Method	Yarn Composition and Blend Ratio	Yarn Count	Feeding (kg)	Yarn (kg)
1	C50CS50-22-F	Fibre-blend	50% Cotton(37 mm), 50% Chitosan (22 mm)	20Ne	4	2.1
	C50CS50-30-F	Fibre-blend	50% Cotton (37 mm), 50% Chitosan (30 mm)	20Ne	3.6	2.3
	C50CS50-38-F	Fibre-blend	50% Cotton (37 mm), 50% Chitosan (38 mm)	20Ne	4	2.4
	C50CS50-46-F	Fibre-blend	50% Cotton (37 mm), 50% Chitosan (46 mm)	20Ne	4	2.2
	C50CS50-22-S	Sliver-blend	50% Cotton(37 mm), 50% Chitosan (22 mm)	20Ne	4	1.9
	C50CS50-30-S	Sliver-blend	50% Cotton (37 mm), 50% Chitosan (30 mm)	20Ne	4	1.5
	C50CS50-38-S	Sliver-blend	50% Cotton (37 mm), 50% Chitosan (38 mm)	20Ne	4	2.1
	C50CS50-46-S	Sliver-blend	50% Cotton (37 mm), 50% Chitosan (46 mm)	20Ne	4	3

C: Cotton, CS: Chitosan

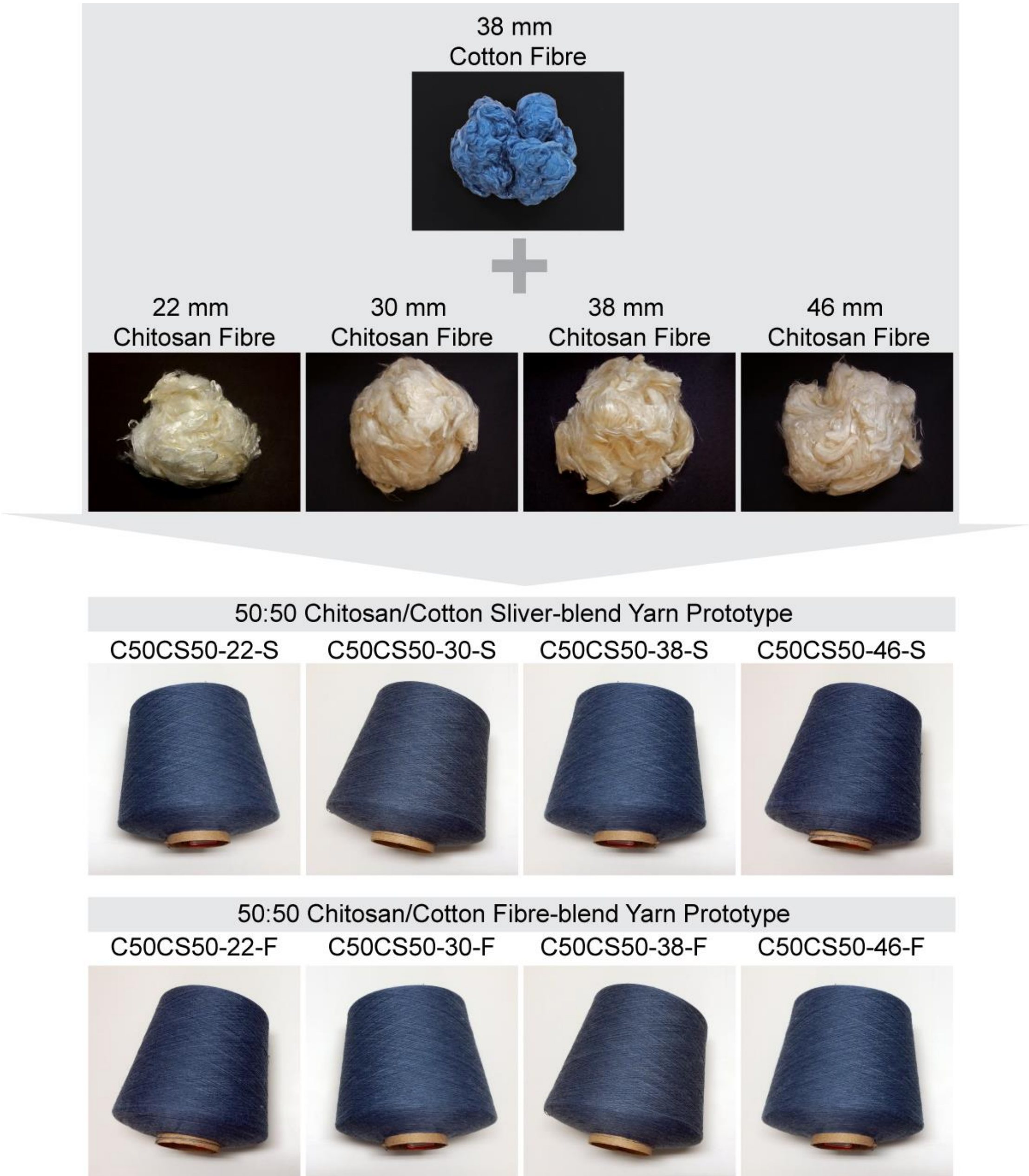


Figure 4.2 Fibre-blending and sliver-blending of chitosan/cotton with different fibre lengths (22, 30, 38 and 46 mm) (Author, 2017)

4.3.2 Second Batch: Investigation the effect of chitosan blending ratio to tensile properties

The second batch of yarn prototype was used to examine the tensile properties of yarns with different blending ratios of chitosan (38 mm) and cotton (37 mm) and to establish the relationship between percentage composition of chitosan and comfort to facilitate further examination of medical textiles in both theoretical and practical aspects (Table 4.3). The length of chitosan materials in this batch is selected based on yarn analysis of 1st batch that were carried out. 4 yarn samples of 20 Ne (4 kg of each sample) with the same blend were produced at different blend ratios. The 4 samples comprised 30:70, 70:30 of chitosan/cotton as well as 100% cotton and 100% chitosan (Figure 4.3).

Table 4.3 Specifications of second batch of chitosan blend yarn prototype spinning

Batch No.	Sample No.	Blending Method	Yarn Composition and Blend Ratio	Yarn Count	Feeding (kg)	Yarn (kg)
2	C100-38	Pure	100% Cotton (37 mm)	20Ne	4	2.55
	C70 CS 30-38-F	Fibre-blend	70% Cotton (37 mm), 30% chitosan(38 mm)	20Ne	4	2.48
	C30CS70-38-F	Fibre-blend	30% Cotton (37 mm), 70% chitosan (38 mm)	20Ne	4	2.26
	CS100-38	Pure	100% chitosan (38 mm)	20Ne	4	0.7

C: Cotton, CS: Chitosan

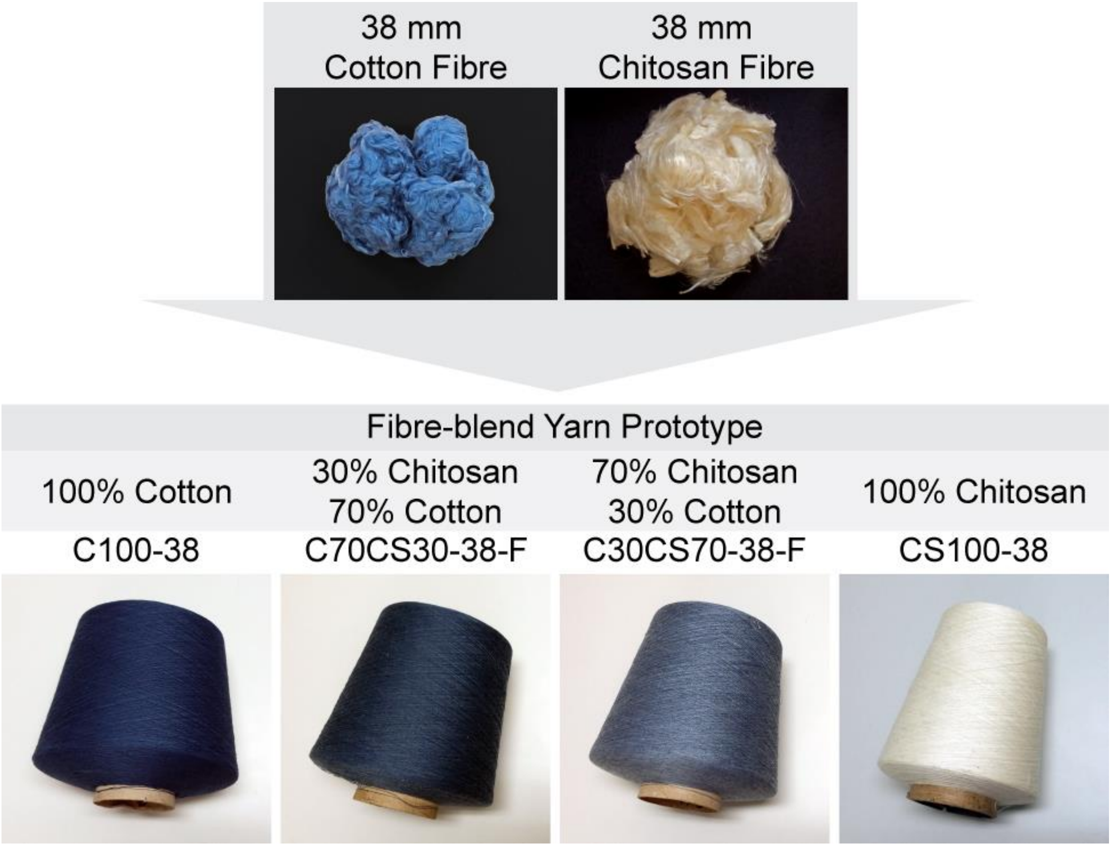


Figure 4.3 Yarn samples were made of 38 mm cotton fiber and 38 mm chitosan fiber with 4 different blend ratios, pure cotton and chitosan, 30:70 and 70:30 chitosan/cotton by fibre-blend method. (Author, 2017)

4.4 Spinning Machines for Yarn Prototype Production

For 1st batch of yarn prototype production, 8 different types of 20 Ne yarn blend samples (4 kg for each sample) were produced with a blend ratio of 50:50 by using a cotton ring spinning system at a traditional spinning mill. Standard spinning procedures were used to produce the yarn samples. The cotton and chitosan fibres were processed and blended on a short staple carding machine (Figure 4.4a) for the fibre blending. The cotton and chitosan were separately processed on the same carding machine for the sliver blending. Two passages of drawing were used for the eight chitosan or cotton slivers with a linear density of 4 ktex and the draft ratio was 8 (Figure 4.4b) for the fibre blending. The output sliver was 4 ktex. The card slivers of both types of fibres were then blended in a drawing machine with the same sliver thickness and draft ratio for the sliver blending. A roving sliver with a count of 0.68 ktex was then produced at a speed of 900rpm (Figure 4.4c). Eight kinds of yarn samples were spun on the ring spinning machine (Figure 4.4d) at a speed of 620rpm.

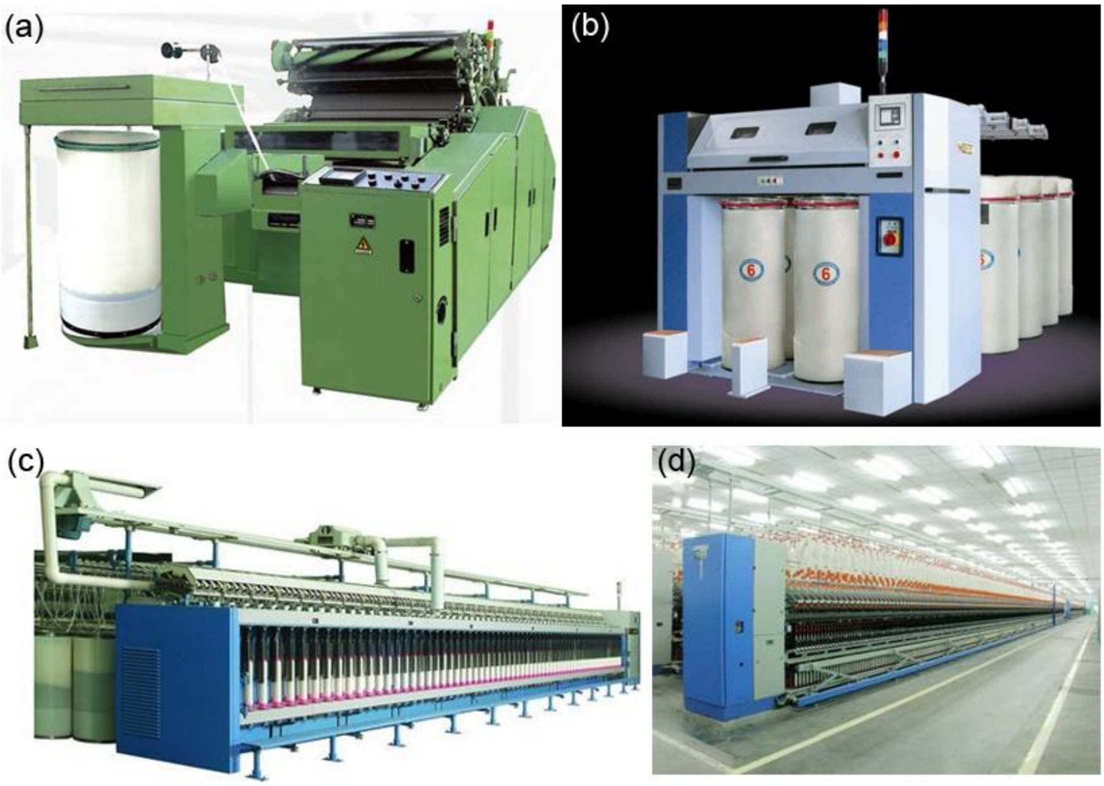


Figure 4.4 (a) Carding Machine #A186G (QingdaoTextileMachineryCo., 2011) (b) Drawing Machine #FA306A (ShenyangHongdaTextileMachineryCo., 2010) (c) Roving Machine #THFA4421 (HebeiTaihangMachineryIndustryCo., 2014) (d) Spinning Machine #FA506 (JingweiTextileMachineryCo., 2010)

For 2nd batch of yarn prototype, 4 yarn samples of 20 Ne (4 kg of each sample) with the same blend were produced at different blend ratios. The 4 samples comprised 30:70, 70:30 of chitosan/cotton as well as 100% cotton and 100% chitosan, which were produced by using a cotton ring spinning system at a traditional spinning mill with standard spinning procedures. The cotton and chitosan fibers were processed and blended on a short staple carding machine (Figure 4.4a). Two passages of drawing were used for eight slivers with a linear density of 4 ktex and the draft ratio was 8 (Figure 4.4b) for all of the samples. To produce the yarn samples with the stated blend ratios, the number of chitosan slivers was changed from 0 for pure cotton yarn to 8 for pure chitosan yarn. The output sliver was 4 ktex. A roving sliver with a count of 0.68 ktex was then produced at a speed of 900 rpm (Figure 4.4c). The designed yarn twist of five yarn samples were 600 tpm, they were spun on the ring spinning machine (Figure 4.4d) at a speed of 630 rpm.

4.5 Chitosan/Cotton Blend Jersey Fabric

14 gauge plain jersey fabrics (2-ply yarn inserted) were produced from chitosan/cotton blend yarn samples with a dimension of 60 cm x 50 cm on a STOLL CMS 822 computerized flat knitting machine (Figure 4.5), the fabric density was 26.1 to 36.7 WPI x CPI.

Figure 4.5 STOLL CMS 822 computerized flat knitting machine (Author, 2017)

4.6 Experiment Design

For the purpose of studying the characteristic and tensile properties of all yarn prototypes, a series of experiments were conducted, as summarized in Table 4.5. All yarn tests were conducted under standard laboratory conditions (20±2 ℃ and 65±2% relative humidity), and all test samples were conditioned for at least 24 hours before testing.

Table 4. 4 Experiments on yarn and fabric prototypes

	Experiment on yarn prototype		
	Test	**Standards**	**Equipment**
1	Fibre Strength	ASTM D1577	INSTRON 5566
2	Yarn Count	ASTM D1907	Mesdan Lab Electronic Wrap Reel
3	Yarn Twist	ASTM D1422	Mesdan Electronic Yarn Twist Tester
4	Yarn Tenacity & Elongation	ASTM D2256	UsterTensorapid III
5	Yarn Evenness	ASTM D1425	Uster Tester 3 Evenness Converter
6	Yarn Cross Section		Nikon Optiphot-POLOptical Microscope
7	Yarn Surface Observation		Leica M165C Optical Microscope
	Experiments on fabric prototypes		
	Test	**Standards**	**Equipment**
1	Fabric Touch Test		SDL ATLAS Fabric Touch Tester

4.6.1 Fibre Strength

The fibre strength, tensile strain and modulus of chitosan (22, 30, 38, and 46 mm) were measured by using an INSTRON 5566 tensile testing machine (Figure 4.6) in accordance with ASTM standard D3822. Pre-test preparation of the fibre samples on paper holder was needed to provide stability (Figure 4.7 and 4.8). Twenty-five samples that consisted of each type of fibre were measured. The testing speed was 50 mm/min, testing load 10 N and testing length 20 mm.

Figure 4.6 INSTRON 5566 tensile testing machine (Author, 2017)

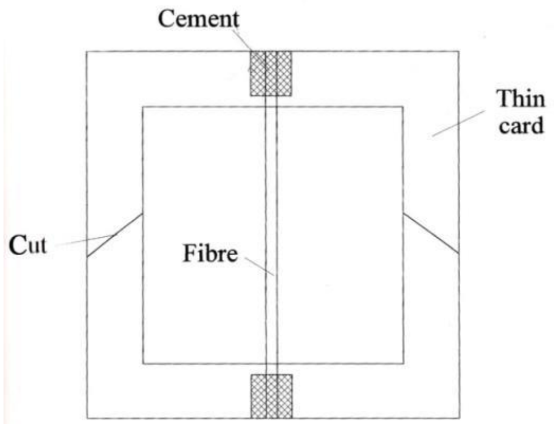


Figure 4.7 Cardboard frame for single fibre testing (Saville, 1999)

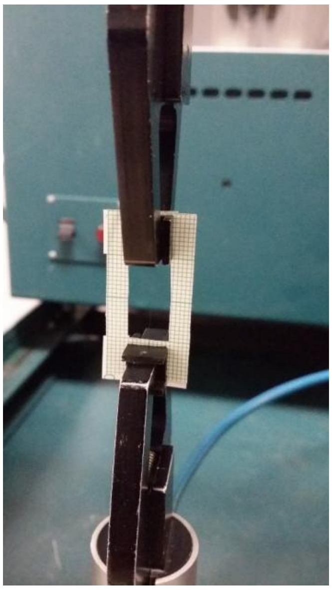


Figure 4.8 Sample preparation of paper holder for fibre strength test (Author, 2017)

4.6.2 Yarn Linear Density

The linear density of the yarn samples was measured by using a Mesdan Lab electronic wrap reel (Figure 4.9) in accordance with ASTM standard D1907 and 30 of each yarn sample (100 m) were examined.

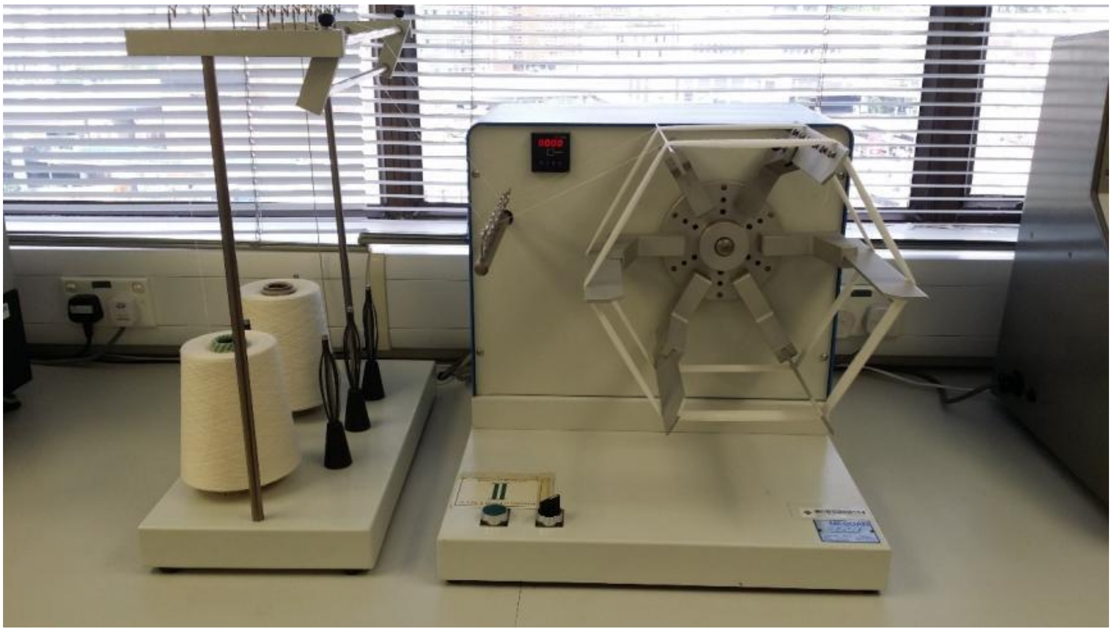


Figure 4.9 Mesdan Lab electronic wrap reel (Author, 2017)

4.6.3 Yarn Twist

The twist in the yarn samples was determined by using the untwist-retwist feature on an electronic yarn twist tester (Mesdan) (Figure 4.10) in accordance with ASTM standard D1422. Twenty-five specimens from each yarn sample were measured with clamps by using a gauge length of 250 mm and pre-tension of 4 grams.

Figure 4.10 Mesdan electronic yarn twist tester (Author, 2017)

4.6.4 Yarn Tenacity & Elongation

The yarn strength and elongation properties of all the yarn samples were tested on a UsterTensorapid III (Figure 4.11) in accordance with ASTM standard D2256. Data on 50 tested samples were acquired. The clamping length was 500 mm, pretension force 10cN/tex and testing speed 5,000 mm/min.

Figure 4.11 UsterTensorapid III for yarn strength test (Author, 2017)

4.6.5 Yarn Evenness

The yarn evenness was measured by using a Uster Tester III Evenness Converter (Figure 4.12) in accordance with ASTM standard D1425. The running speed for all of the yarn samples was 400 m/min for 5 times.

Figure 4.12 Uster Tester III Evenness Converter (Author, 2017)

4.6.6 Yarn Bending

The bending rigidity of all of the yarn samples was measured on a Kawabata pure bending tester KES-FB2 (Figure 4.13b). Before the testing, each yarn sample had to be prepared as follows. A 10 x 10 cm square was cut from a piece of paper (Figure 4.13a). Then, a 1 x 9 cm rectangular hole was cut from the square paper. 90 pieces of the same kind of yarn were fixed onto the square with double sided tape so that each piece of yarn is parallel to each other as shown in Figure 3a. 5 square samples were conditioned in standard atmosphere before the testing. For the yarn bending test, the square sample of each yarn samples was mounted on the chucks of the instrument. The testing mode at one cycle and the curvature at 2.5 cm^{-1}. Each sample was measured twice.

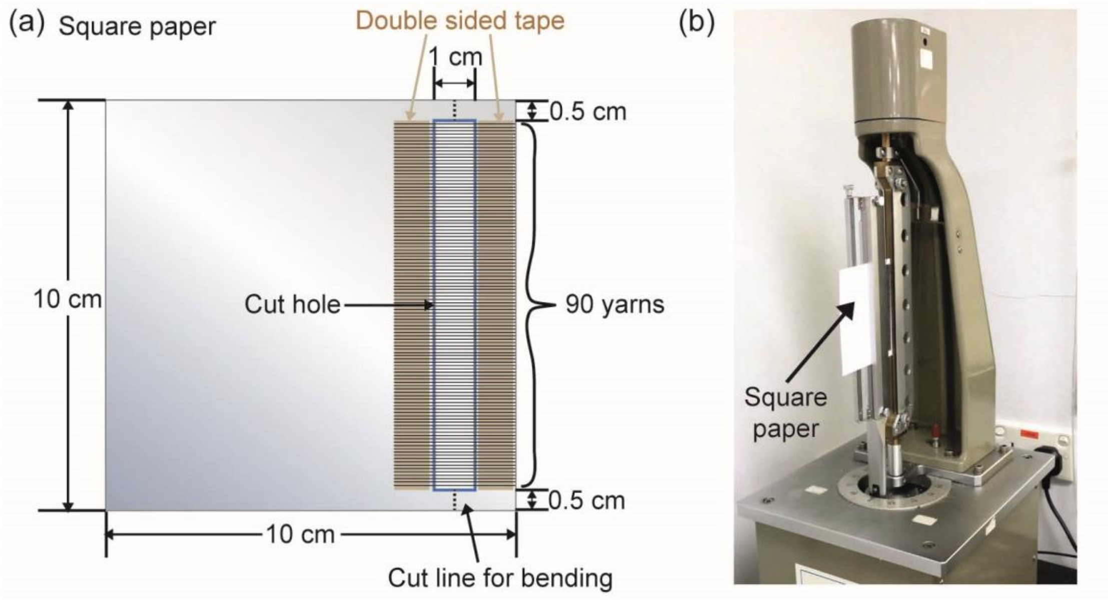


Figure 4.13 (a) Preparation of yarn samples onto a square piece of paper for bending rigidity test. (b) Square sample mounted onto Kawabata pure bending tester KES-FB2. (Author, 2017)

4.6.7 Yarn Cross Section

To investigate the fibre distributions of the yarns, cross sections of the yarn prototype were captured on a Nikon Optiphot-POL Optical Microscope (Figure 4.14).

Figure 4.14 Nikon Optiphot-POL Optical Microscope (Author, 2017)

4.6.8 Yarn Surface Observation

The surfaces of all yarns were observed on the Leica M165C Optical Microscope (Figure 4.15).

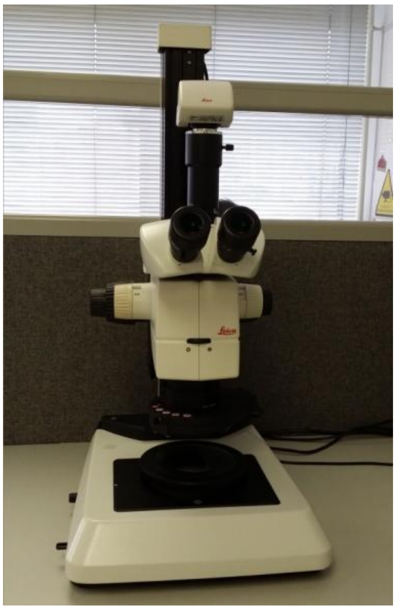


Figure 4.15 Leica M165C Optical Microscope (Author, 2017)

4.6.9 Fabric Touch Test

Fabric comfort properties were examined by SDL ATLAS Fabric Touch Tester (FTT) M293 (Figure 4.16). Before testing, preparation of fabric sample is needed with special requirement. Fabric sample was cut into an “L” shape with specific dimensions and directions (31 x 31 cm, 11 cm width x 20cm height of tails) (Figure 4.17). 5 specimens of each sample are required from each fabric sample. Samples were conditioned in standard atmosphere for 24 hours before the testing.

Figure 4.16 SDL ATLAS Fabric Touch Tester M293 (Author, 2017)

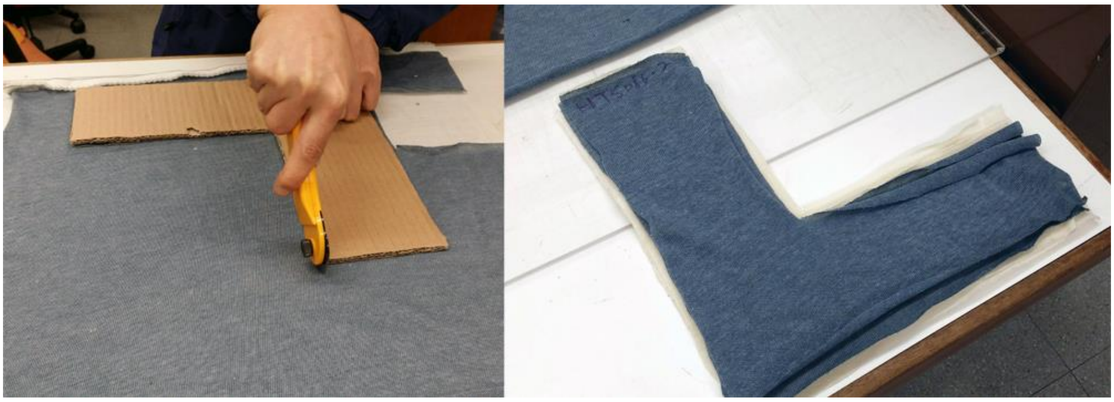


Figure 4.17 “L” shape fabric sample preparation for Fabric Touch test (Author, 2017)

4.7 Conclusions

In this section, chitosan and cotton fibres utilised in this study were introduced. Twelve types of 20 Ne chitosan/cotton blend yarn proposed for the experiment were ring spun by two separate batches in order to study the effect of chitosan fibre lengths and chitosan/cotton blend ratio by a systematic approach. Five types of fabric sample made of 20 Ne chitosan/cotton blend yarn with pure chitosan and cotton were examined by fabric comfort test. All yarn samples were examined through a series of assessment to investigate tensile properties of yarn, while fabric samples were examined by fabric comfort test.

Chapter 5

The Effect of Fibre Lengths and Blending Methods on Tensile Properties of Ring Spun Chitosan-Cotton Blended Yarns

5.1 Introduction

This chapter explained the relationship between fibre length, fibre interaction and yarn performance by using a blend of chitosan/cotton fibres with the fibre-blending and sliver-blending methods. For practical purposes, fibre-blending and sliver-blending are the two general blending methods used in yarn spinning. The former provides the most intimate mixing of fibres in terms of fibre distribution, while the latter provides an alternative way to manipulate the fibre distribution thus affecting the quality of the final products (Cyniak, Czekalski, & Jackowski, 2006; El-Behery & Batavia, 1971; Moghassem & Fakhrali, 2013). The selection of chitosan fibre length is based on the preliminary experiment of manual untwisting fibre counting of pure chitosan yarn in Chapter 2. It is found that in the pure chitosan yarn sample, many fibres have been broken into shorter ones during yarn spinning. Most of the chitosan fibres that are 38 mm are broken into a length that ranges from 21 to 30 mm, and elongated into 46 mm. In order to investigate the effect of chitosan fibre length on the fibre distribution in the yarn, four different fibre lengths have utilised: 22, 30, 38, and 46 mm with a 50:50 blend ratio through the fibre-blending and sliver-blending methods in a ring spinning system in accordance with the principles of scaling in fracture mechanics and real life industry situations. The blending ratio of 50% cotton and 50% chitosan is purposed to study the fibre distribution and yarn performances based on the even blend ratio with long cotton fibre, so to contribute to further functional apparel application. Eight types of 20 Ne chitosan/cotton blend yarn samples are examined in terms of their tensile strength, elongation, count, twist and evenness. The fibre distribution was obtained by cross-section observation, to study the fibre migration behaviour of both blending methods and it depends on the fibre alignment during yarn spinning. Moreover, the fibre blending method is affected the characteristics and performance of the yarn, such as the antibacterial properties to apparel. The composition of each fibre component and interactions between them affect the performance of the final yarn.

5.2 Materials

Yarn samples C50CS50-22-F, C50CS50-30-F, C50CS50-38-F, and C50CS50-46-F are the fibre-blended yarn with different lengths of chitosan fibres (C50CS50-22-F: 22 mm, C50CS50-30-F: 30 mm, C50CS50-38-F: 38 mm, and C50CS50-46-F: 46 mm), while yarn samples C50CS50-22-S, C50CS50-30-S, C50CS50-38-S, and C50CS50-46-S are the sliver-blended yarn with different lengths of chitosan fibres (C50CS50-22-S: 22 mm, C50CS50-30-S: 30 mm, C50CS50-38-S: 38 mm, and C50CS50-46-S: 46 mm, see Figure 5.1 and Table 5.1).

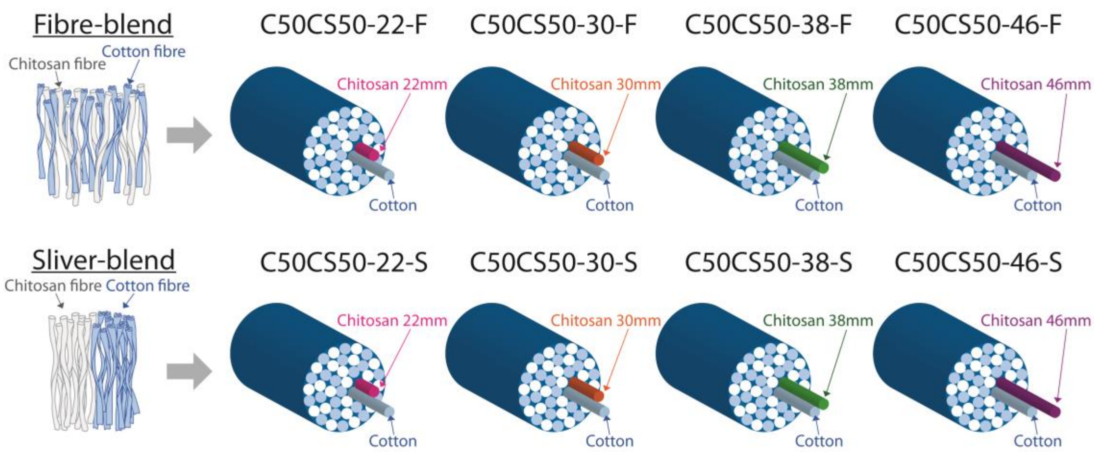


Figure 5.1 Fibre-blending and sliver-blending of chitosan/cotton with different fibre lengths (22, 30, 38 and 46 mm) (Author, 2017)

Table 5.1 Coding of 50:50 chitosan/cotton blend yarn

CottonFibre Length (mm)	Chitosan Fibre Length (mm)	Fibre-blend	Sliver-blend
38	22	C50CS50-22-F	C50CS50-22-S
38	30	C50CS50-30-F	C50CS50-30-S
38	38	C50CS50-38-F	C50CS50-38-S
38	46	C50CS50-46-F	C50CS50-46-S

5.3 Statistical Analysis

To analyse the correlation between different fibre blending methods and yarn strength, different fibre blending methods and yarn elongation, and different fibre blending methods and migration index within a 95% confidence limit (level of significance $\alpha_{0.05}$), a one-way analysis of variance (ANOVA) was carried out by using SPSS Statistics 22 software. The analysis reflected that the yarn strength, elongation, and migration index between the different fibre blending methods are significant (Table 5.2).

Table 5.2 ANOVA carried out between 50:50 chitosan/cotton blend yarn and strength, elongation, and migration index (MI)

Source of variance	ANOVA Level of Significance ($\alpha_{0.05}$)
Different fibre blending method-strength	significant
Fibre-blended yarn-strength	significant
Sliver-blended yarn-strength	significant
Different fibre blending method-elongation	significant
Fibre-blended yarn-elongation	significant
Sliver-blended yarn-elongation	significant
Different fibre blending method-MI	significant
Fibre-blended yarn-MI	significant
Sliver-blended yarn-MI	significant

5.4 Tenacity of chitosan and cotton fibres

In normal practice, most blended yarns with long fibres are expected to have higher tensile properties. Besides, similar lengths of fibres better facilitate the production of blended yarns in the industry (Baykal, Babaarslan, & Erol, 2006; Duckett, Goswami, & Ramey, 1979; Pan et al., 2000). In this study, cotton fibres with long lengths were selected in the blend with chitosan. To reflect real life production, four different lengths of chitosan fibres were selected for the experiment: 22, 30, 38, and 46mm respectively. The breaking tenacity of the cotton fibres was 47 g/tex (Table 5.3), while that of the chitosan fibres was 15.85 (22 mm), 14.90 (30 mm), 15.49 (38 mm), and 16.20 (46 mm) cN/tex (Table 5.4). Compared to the chitosan fibres, cotton fibres have greater strength in the blended yarn structure.

Table 5.3 High volume instrument (HVI) test results for cotton fibres used in 50:50 chitosan/cotton blend yarn

Fibres	Micronaire	UHML (mm)	Uniformity Index (%)	Short Fibre Index	Strength (g/tex)	Elongation (%)
Mean	3.96	38.04	87.0	6.0	47.0	7.0
CV%	3.79	2.94	1.38	8.33	3.62	8.57

UHML: upper half mean length

Table 5.4 Fibre specifications, tenacity, tensile strain and modulus of chitosan fibres used in 50:50 chitosan/cotton blend yarn

Fibres	Fibre Length (mm) [CV%]	Fineness (Denier) [CV%]	Tenacity (cN/tex) [CV%]	Tensile Strain (%) [CV%]	Modulus (%) [CV%]
Chitosan	22	1.81	15.85 [13.71]	15.26 [29.26]	465.58 [88.74]
	30	1.81	14.90 [27.63]	16.69 [46.63]	480.01 [44.22]
	38 [6]	1.81 [14]	15.49 [29.45]	16.27 [46.06]	521.24 [27.33]
	46	1.81	16.20 [28.07]	19.06 [48.09]	614.79 [75.23]

In order to explain the fibre breakage of chitosan, the tenacity and strain of the fibres were plotted. The plotting of the tenacity and strain of the chitosan fibres of four different lengths showed low linear regions. The chitosan fibres had high moduli and strong resistance to tensile force, however, upon further stress, they showed yielding points at around 1.2 cN/dtex before they broke. In comparison to the chitosan fibres, the cotton had lower modulus and elongation but higher strength (Figure 5.2).When the strain passed the yielding points, plastic deformation would occur until the fibres broke. Thus, this proves that cotton fibres provide better physical strength in a blended yarn structure.

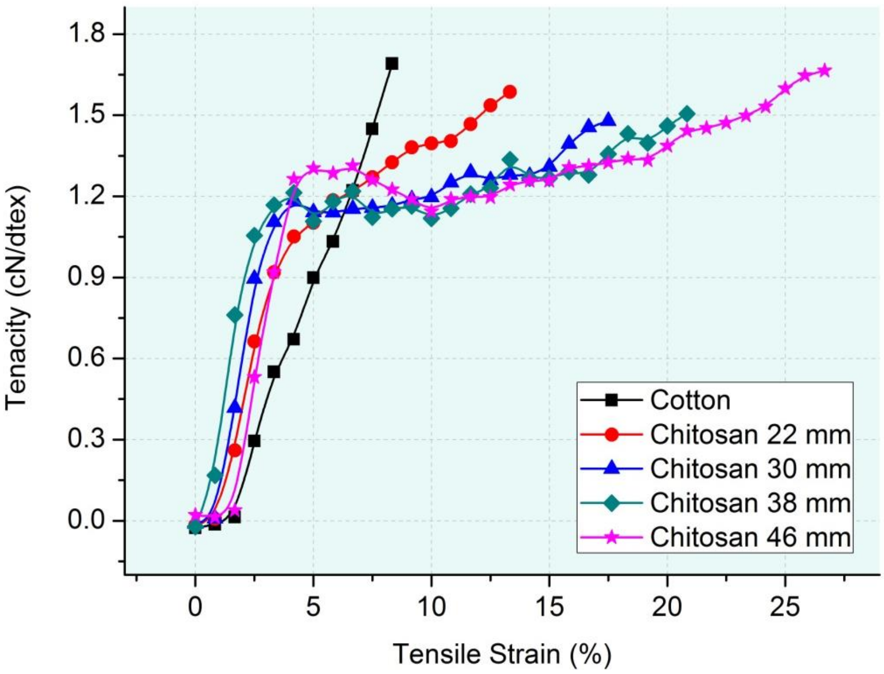


Figure 5.2 Tenacity versus tensile strain of blue-dyed-cotton and chitosan fibres used in 50:50 chitosan/cotton blend yarn (Author, 2017)

5.5 Physical properties of fibre-blended and sliver-blended chitosan/cotton yarn

In consideration of the performance and functionality of chitosan yarn and the possibilities of yarn spinning, a blend ratio of 50:50 was adopted in the experiment. The fibre-blending and sliver-blending methods were used in the blending process of ring spinning. The measured physical properties of the yarn samples, including linear density, twist, evenness, tenacity and elongation, are shown in Tables 5.5 to 5.8.

Table 5.5 Yarn tenacity and elongation of 50:50 chitosan/cotton blend yarn

Fibre-blended			**Sliver-blended**		
Yarn Samples	**Tenacity (cN/tex) [CV%]**	**Elongation (%)[CV%]**	**Yarn Samples**	**Tenacity (cN/tex) [CV%]**	**Elongation (%)[CV%]**
C50CS50-22-F	15.19 [7.9]	6.01 [8.5]	**C50CS50-22-S**	16.46 [8.3]	5.94 [8.2]
C50CS50-30-F	13.40 [11.2]	5.11 [6.8]	**C50CS50-30-S**	16.59 [7.2]	5.09 [8.5]
C50CS50-38-F	13.26[12.9]	4.89 [9.3]	**C50CS50-38-S**	16.73 [9]	5.44 [9]
C50CS50-46-F	7.46 [12]	3.65 [11.9]	**C50CS50-46-S**	8.2 [11.8]	4.09 [25.2]

Table 5.6 Yarn linear density and twist of 50:50 chitosan/cotton blend yarn

Fibre-blended			Sliver-blended		
Yarn Samples	**Yarn Count (Ne) [CV%]**	**Twist (tpm)[CV%]**	**Yarn Samples**	**Yarn Count (Ne) [CV%]**	**Twist (tpm)[CV%]**
C50CS50-22-F	19.6 [1.54]	635 [6.84]	**C50CS50-22-S**	19.3 [0.78]	649 [4.68]
C50CS50-30-F	24.3 [0.08]	582 [4.36]	**C50CS50-30-S**	19.4 [2.27]	642 [3.05]
C50CS50-38-F	20.6 [2.01]	566 [5.16]	**C50CS50-38-S**	20.0 [2.41]	632 [4.88]
C50CS50-46-F	20.4 [1.98]	561 [5.47]	**C50CS50-46-S**	19.7 [3.44]	632 [4.78]

Table 5.7 Yarn evenness of 50:50 chitosan/cotton fibre-blended yarn

Fibre-blended					
Yarn Samples	**CVm (%) [CV %]**	**Thin Places (-50%) /km [CV %]**	**Thick Places (+50%) /km [CV %]**	**Neps (+280%)/km [CV %]**	**Hairiness (-) [CV %]**
C50CS50-22-F	14.41 [4.26]	32 [62.4]	60 [25.1]	11 [65.6]	5.27 [3.55]
C50CS50-30-F	15.85 [7.15]	6 [98.5]	165 [31.9]	23 [23.3]	6.88 [1.15]
C50CS50-38-F	14.34 [1.22]	1 [104.6]	121 [17]	22 [44.1]	6.25 [0.78]
C50CS50-46-F	13.38 [3.14]	0 [0]	99 [51.2]	30 [62.3]	6.99 [2.68]

Table 5.8 Yarn evenness of 50:50 chitosan/cotton sliver-blended yarn

Sliver-blended					
Yarn Samples	**CVm (%) [CV %]**	**Thin Places (-50%) /km [CV %]**	**Thick Places (+50%) /km [CV %]**	**Neps (+280%)/km [CV %]**	**Hairiness (-) [CV %]**
C50CS50-22-S	16.45 [4.2]	48 [85.5]	233 [22.1]	10 [38.7]	5.64 [6.19]
C50CS50-30-S	13.76 [6.74]	16 [162.3]	100 [33.8]	20 [36.8]	4.95 [6.62]
C50CS50-38-S	14.81 [5.51]	20 [106.4]	253 [16.6]	94 [16.5]	5.1 [5.11]
C50CS50-46-S	17.78 [5.33]	26 [50.6]	768 [5.2]	295 [11.5]	5.3 [3.21]

5.6 Tensile properties and length of chitosan fibres

Yarn fabricated by using both types of blending methods exhibited similar tensile properties in terms of the length of the chitosan fibres (Figure 5.3a). For both types of blending methods, the tenacity of the yarn was relatively stable and the variant was less than 13% with increased length of the chitosan fibres from 22 to 38mm.However, when the length of the chitosan fibre was46 mm, the tenacity rapidly decreased by about 51%. In terms of the sliver-blending, when the length of the chitosan fibre was 46 mm, the tenacity decreased by 50.2% in comparison to that of the chitosan fibre of 22 mm.

The elongation of the yarn samples was also reduced with increased lengths of thechitosan fibres (Figure 5.3b).With a fibre length less than 38mm, the breaking elongation did not increase or decrease. However, when the fibre length is longer than 38mm, the breaking elongation rapidly decreased, which is similar to the case of the yarn tenacity, and reflected the deterioration of the yarn quality due to the change in the fibre length. The elongation at break of the C50CS50-46-F and C50CS50-46-S samples, which are 44 mm in length, decreases by 37.8% and 32.4% respectively in comparison to the C50CS50-22-F and C50CS50-22-S samples, which are 22 mm in length.

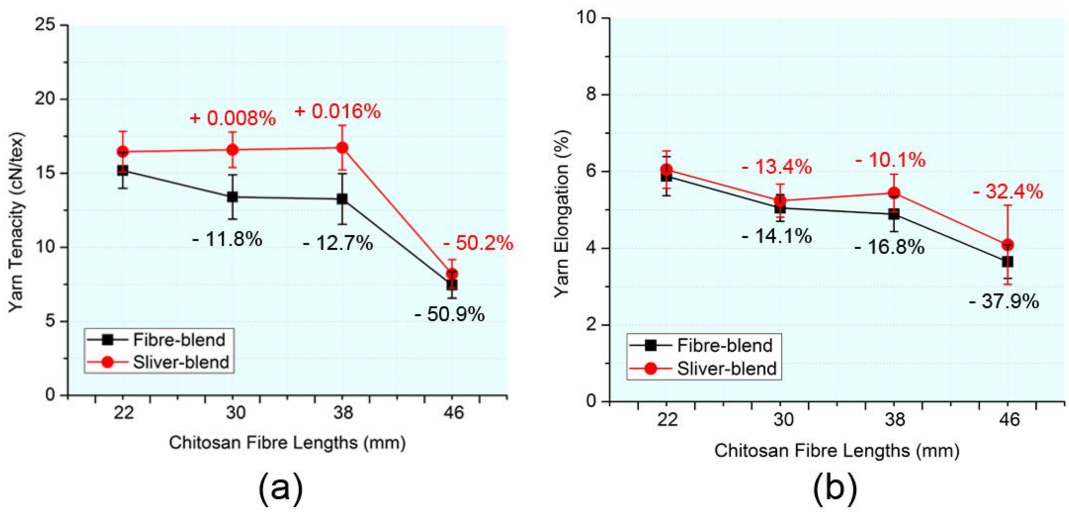


Figure 5.3 Yarn sample properties: (a) yarn tenacity (b) yarn elongation (Author, 2017)

The deterioration of the yarn quality with a longer length of 46 mm might be induced by the production process (Liu et al., 2015). The results from the manual fibre counting for obtaining the fibre length distribution for the C50CS50-46-F sample verified the hypothesis (Figure 5.4). In yarn, most of the fibres break into shorter ones during the spinning process and these short fibres lead to insufficient strength of the yarn.

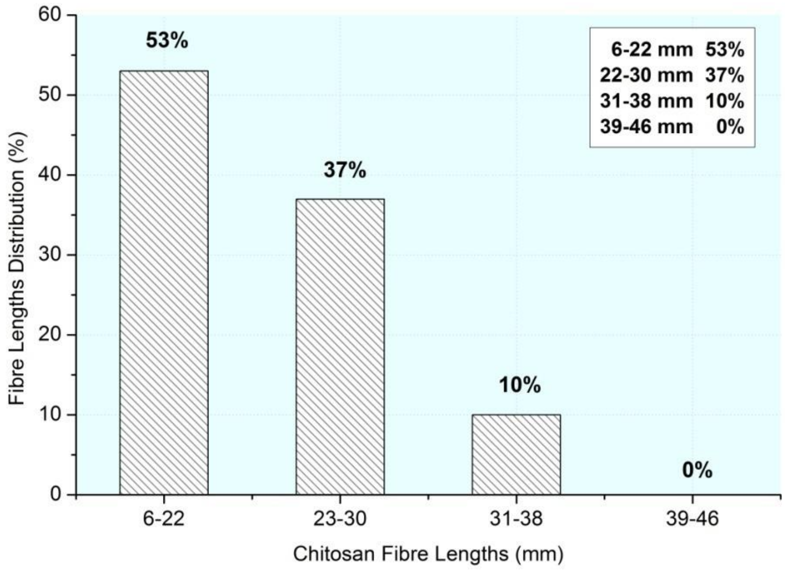


Figure 5.4 Fibre length distribution in 50:50 chitosan/cotton blend yarn composed of chitosan fibres with length of 46 mm determined by manual fibre counting of untwisted yarn (Author, 2017)

5.7 Fibre distribution in the blended yarns

The fibre radial distribution, which is affected by different blending methods, is determined through observations of the cross-sections and based on migration index calculation. Fibre migration could influence the tensile properties of blended yarns, which means that the control of migration could be a means to improve yarn properties. In this study, the migration behaviour of the chitosan/cotton blend yarns with different fibre lengths and blended through two different methods is characterized by using the Hamilton migration index (Hamilton, 1958; Hamilton & Cooper, 1958) . The calculation method is as follows.

The cross-sections of each yarn sample were observed by using an optical microscope (Nikon Optiphot-POL) and recorded with a charged couple device (CCD) camera, and then processed with the Leica Application Suite software on a computer

(Figure 5.5a). The cross-sections were divided into five regions with equal radial spacing and labelled as 1, 2, 3, 4, and 5 (Figure 5.5b).

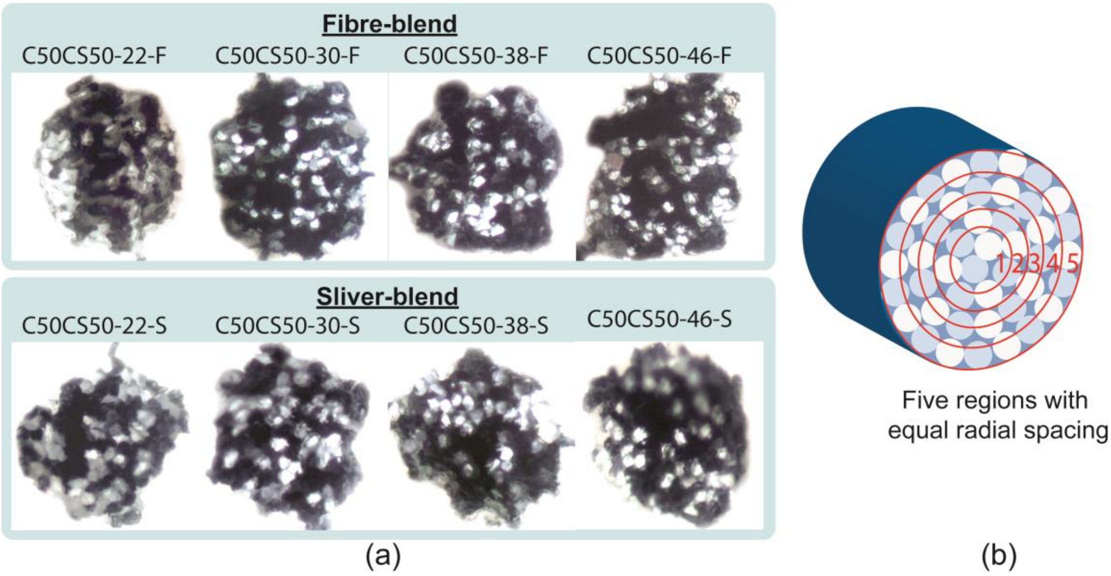


Figure 5.5 (a) Cross section of each yarn sample: Fibre-blended (C50CS50-22-F, C50CS50-30-F, C50CS50-38-F, and C50CS50-46-F); Sliver-blended (C50CS50-22-S, C50CS50-30-S, C50CS50-38-S, and C50CS50-46-S) (b) Five regions with equal radial spacing for yarn cross-section observations (Author, 2017)

The volume of the chitosan and cotton fibres for all 5 regions was determined by using ImageJ, an image processing software. The fibres were identified according to the different colours (cotton fibres were navy blue and chitosan fibres were white) From the counts, the migration index, *M*, was determined with Equations 1a and1b:

$$M = \frac{\mathrm{FM_a} - \mathrm{FM_u}}{\mathrm{FM_u} - \mathrm{FM_i}} \times 100 \qquad \mathrm{FM_a} > \mathrm{FM_u} \tag{1a}$$

$$M = \frac{\mathrm{FM_a} - \mathrm{FM_u}}{\mathrm{FM_o} - \mathrm{FM_u}} \times 100 \qquad \mathrm{FM_a} < \mathrm{FM_u} \tag{1b}$$

where FM_a is the fibre distribution, FM_u the ideal uniform distribution, FM_i the maximum inward migration, and FM_o the maximum outward migration. If $FM_a<FM_u$, M is negative, and FM_i must be calculated; if $FM_a>FM_u$, M is positive, then FM_o is calculated. Positive and negative migration indexes denote the preferential migration of the fibres outward to the surface of the yarn and inward to the core of the yarn respectively. A migration index of zero denotes an even and uniform distribution of the fibres between the core and surface.

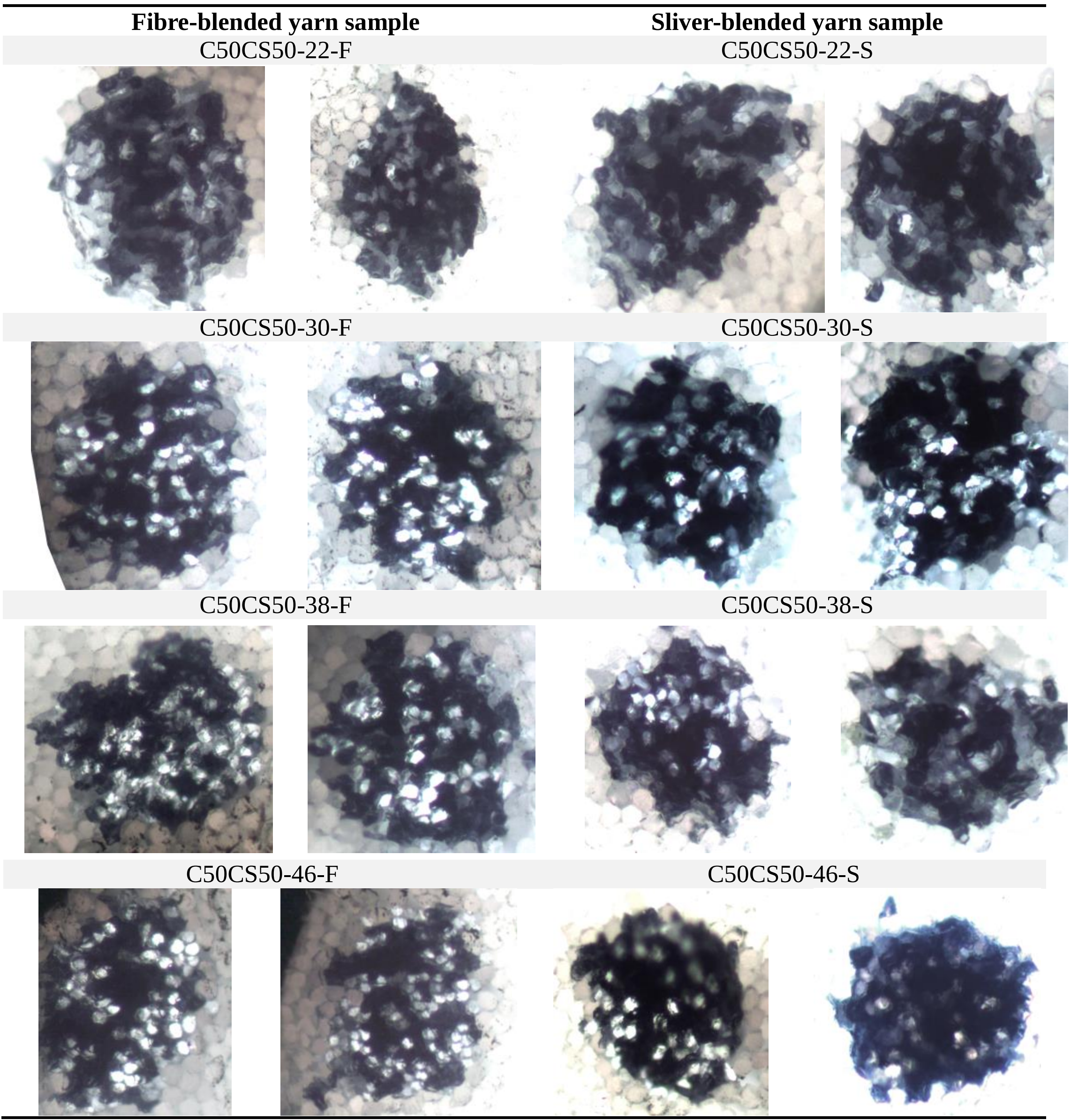


Figure 5.6 Cross section of each yarn sample: Fibre-blended (C50CS50-22-F, C50CS50-30-F, C50CS50-38-F, and C50CS50-46-F); Sliver-blended (C50CS50-22-S, C50CS50-30-S, C50CS50-38-S, and C50CS50-46-S)

In order to study the influence of chitosan fibre parameters on the yarn properties, the migration index of the fibre-blended and sliver-blended chitosan/cotton yarn samples (Figure 5.6) was determined (Tables 5.9 and 5.10), and the results are shown in Table 5.11. The formation and the structure of the yarns are the key factors that define the mechanical properties of the yarn, such as yarn bulkiness, tensile properties, and abrasion. Due to different blending methods and fibre lengths, the yarns would have different radial distributions of the fibre components. According to Hamilton and Cooper (1958), fibres that are short and coarse tend to migrate outwards towards the yarn surface, which improves the strength of yarns. Meanwhile, if the fineness and length of the fibres are consistent, fibres with higher tenacity are expected to migrate to the inner surface of yarns.

Table 5.9 Fibre volume distribution of fibre-blended 50:50 chitosan/cotton yarn

Zone No.	1 (core)	2	3	4	5(surface)	Totals
Fibres	**Yarn sample C50CS50-22-F**					
Cotton	600	1423	2415	3425	2261	10125
(%)	70	53	54	55	26	44
Chitosan	260	1277	2071	2838	6502	12948
(%)	30	47	46	45	74	56
Zone totals	860	2700	4485	6263	8763	23072
Fibres	**Yarn sample C50CS50-30-F**					
Cotton	422	1773	2309	2890	3336	10729
(%)	46	69	51	45	40	47
Chitosan	498	811	2212	3551	5070	12143
(%)	54	31	49	55	60	53
Zone totals	920	2584	4521	6441	8406	22871
Fibres	**Yarn sample C50CS50-38-F**					
Cotton	521	1571	2404	3136	3600	11231
(%)	59	59	54	49	43	49
Chitosan	366	1080	2085	3223	4718	11473
(%)	41	41	46	51	57	51
Zone totals	887	2651	4489	6359	8318	22704
Fibres	**Yarn sample C50CS50-46-F**					
Cotton	580	1583	2708	2776	2958	10605
(%)	67	60	62	43	35	46
Chitosan	287	1064	1680	3702	5574	12308
(%)	33	40	38	57	65	54
Zone totals	867	2647	4388	6479	8532	22913

Table 5.10 Fibre volume distribution of sliver-blended 50:50 chitosan/cotton yarn

Zone No.	1 (core)	2	3	4	5(surface)	Totals
Fibres			**Yarn sample C50CS50-22-S**			
Cotton	681	1702	3018	3531	3318	12250
(%)	82	65	70	57	39	55
Chitosan	153	906	1266	2697	5094	10115
(%)	18	35	30	43	61	45
Zone totals	834	2608	4285	6228	8412	22365
Fibres			**Yarn sample C50CS50-30-S**			
Cotton	576	1585	3005	3443	3702	12311
(%)	66	60	70	55	45	55
Chitosan	293	1061	1284	2814	4582	10034
(%)	34	40	30	45	55	45
Zone totals	868	2646	4289	6257	8284	22345
Fibres			**Yarn sample C50CS50-38-S**			
Cotton	449	1724	2748	3351	3592	11865
(%)	49	66	63	53	43	53
Chitosan	461	876	1626	2936	4728	10628
(%)	51	34	37	47	57	47
Zone totals	911	2600	4374	6287	8321	22493
Fibres			**Yarn sample C50CS50-46-S**			
Cotton	646	1830	2912	3769	3476	12633
(%)	76	71	67	61	42	57
Chitosan	199	735	1408	2379	4883	9604
(%)	24	29	33	39	58	43
Zone totals	845	2565	4320	6148	8359	22238

Table 5.11 Migration index of 50:50 chitosan/cotton blend yarn

		Fibre-blended Yarn		
Yarn samples	C50CS50-22-F	C50CS50-30-F	C50CS50-38-F	C50CS50-46-F
Cotton	-29.29	-17.88	-14.06	-27.69
Chitosan	+29.29	+17.88	+14.06	+27.69
		Sliver-blended Yarn		
Yarn samples	C50CS50-22-S	C50CS50-30-S	C50CS50-38-S	C50CS50-46-S
Cotton	-31.70	-20.44	-18.12	-29.96
Chitosan	+31.70	+20.44	+18.12	+29.96

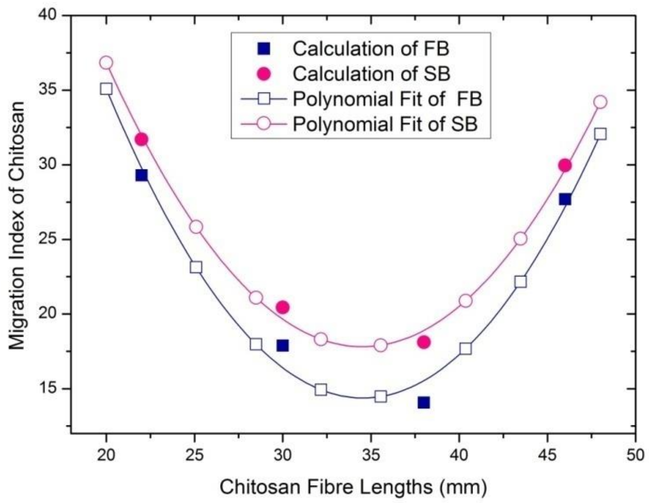
Negative number (-) refers to inward migration of the particular fibre and positive number (+) refers to outward migration of the particular fibre.

Chitosan fibres have the tendency to migrate towards to the surface of yarn, and the findings in this study have confirmed those of previous studies in that coarser fibres tendto migrate outwards towards the yarn surface (Aghasian, Ghareaghaji, Ghane, & Parsian, 2008; Cyniak, Czekalski, & Jackowski, 2006; El-Behery & Batavia, 1971; Hamilton, 1958; Morton, 1956). On the other hand, cotton fibres have greater strength than any of the chitosan fibres used in the experiments in this study, so that it is expected that cotton fibres would congregate in the core area rather than the surface, which is shown in the results.

Besides, one phenomenon that is worth noting is that compared with fibre blended yarns, sliver blended yarns have better tensile properties. The yarn samples in this study that are fibre-blended have a lower migration index than the sliver-blended samples for each different length of the chitosan fibres, which means that the fibres migrate towards the inside surface compared to the fibre-blended yarns. It is considered that in spinning systems, sliver-blending lacks efficiency in fibre separation compared to the fibre-blending method. It is reasonable to speculate that the fibre-blending method provides higher uniformity of fibre distribution than sliver-blending. On the other hand, the sliver-blending method could be an alternative means to manipulate the migration of chitosan fibres in blended yarns (Anandjiwala, Goswami, Bragg, & Bargeron, 1999). In this case, the cotton fibres in sliver-blended yarns have the tendency to migrate into the core area of the yarn structure, as opposed to cotton fibres in fibre blended yarns.

5.8 Simulation

A regression analysis was conducted based on the experimental results (Figure 5.7 and Table 5.11). The regression analysis provides a possible means of predicting the migration behaviour of fibre components according to the length of the chitosan fibres and blending methods.



*FB: fibre-blend, SB: sliver-blend

Figure 5.7 Length of chitosan fibres vs. migration index (Author, 2017)

Table 5.12 Fit and regression equations forl ength of chitosan fibres and yarn properties of 50:50 chitosan/cotton blend yarn

	Blending Methods	**Fit model**
Migration index	Fibre-blend	$0.09781*L^2- 6.759*L + 131.13975$
	Sliver-blend	$0.09023*L^2-6.23019*L +125.35169$

(L is the length of chitosan fibre.)

A secondary order polynomial model was used to fit the relationship between the migration index value and length of the chitosan fibres (Figure 5.7):

$$MI = A_1L^2 + B_1L + C_1 \quad (6)$$

where *MI* is the migration index, *L* is the fibre length, and A_1, B_1, and C_1 are coefficients of the function.

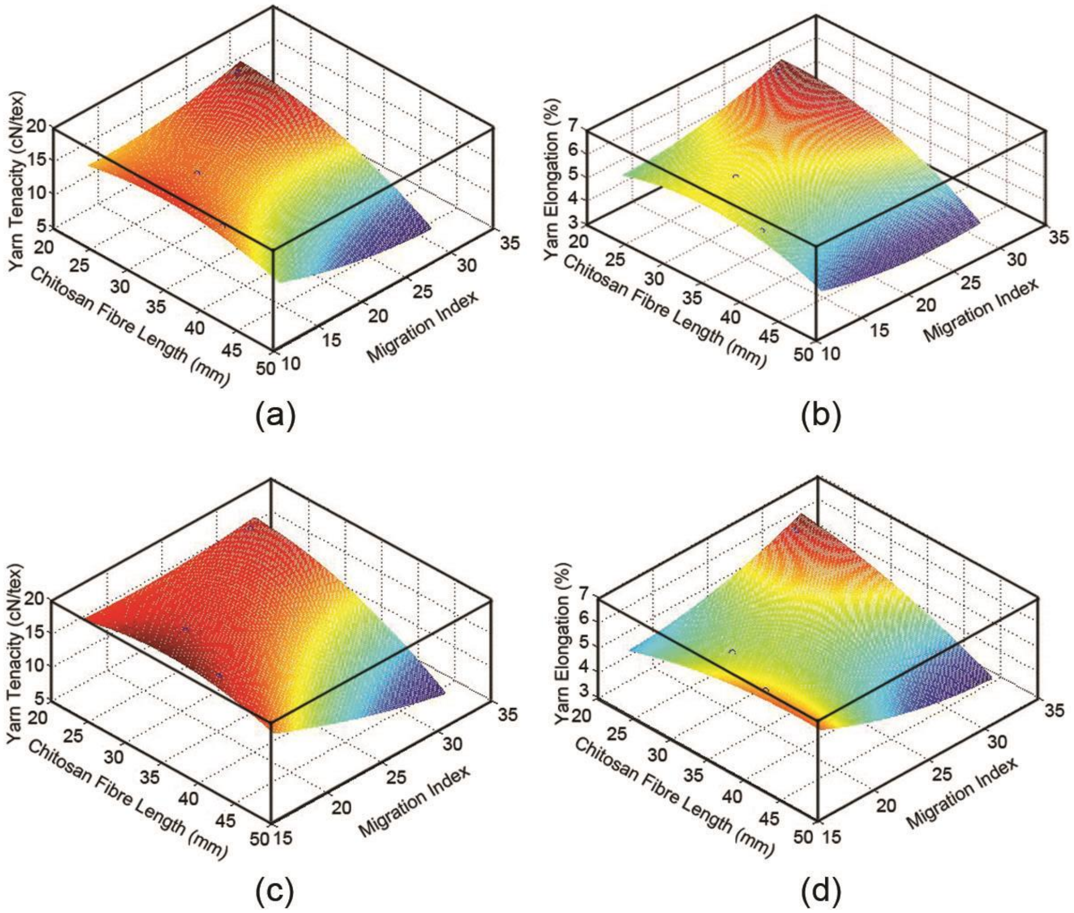


Figure 5.8 Effect of the length of chitosan fibres and migration index on (a) yarn tenacity and (b) elongation of fibre-blended samples;(c) yarn tenacity and (d) elongation of sliver-blended samples (Author, 2017)

Table 5.13 Relationships among chitosan length, migration index and yarn properties of 50:50 chitosan/cotton blend yarn

Yarn Properties	**Blending Methods**	**Fit Model**
Tenacity	Fibre-blend	$0.0119MI^2 - 0.0166L*MI - 0.012L^2 + 0.9789L$
	Sliver-blend	$0.0042MI^2 - 0.0045L*MI - 0.0045L^2 + 0.3412L$
Elongation	Fibre-blend	$0.0109MI^2 - 0.0229L*MI -0.0136L^2 +1.2775L$
	Sliver-blend	$0.0056MI^2 - 0.0084L*MI - 0.002L^2 + 0.3234L$

(L is the length of chitosan fibre.)

Both the fibre-blended and sliver-blended yarns have a parabolic curve as shown in Figures 5.8a and 5.8c. When the fibre length is less than the inflection point (around

35mm), the migration index of the cotton fibres decreases with a longer fibre length. However, across the inflection point, the migration index is proportional to the fibre length, which indicates congregation of cotton fibres in the core area. It is worth noting that the long cotton fibres (UHML >38 mm, mean length around 33 mm) used in the experiments are close to the inflection point. For the blended yarns, longer fibres have a larger ratio (around 60 to75%) in the core of the yarn (Zones 1 and 2) (see Tables 5.9 and 5.10) except for the yarns spun with chitosan fibres that are 46 mm in length, which might be attributed to the increased evenness, faults, hairiness, and breaking during yarn spinning.

5.9 Tensile properties and fibre distribution

As shown in Figure 5.3, chitosan/cotton yarns with the same blend ratio have very different performances due to the different blending methods. The breaking tenacity of sliver blended yarns is increased by 8.36%, 23.81%, 26.17%, and 9.92% with fibre lengths of the chitosan of 22, 30, 38, and 46 mm, respectively. Meanwhile, the migration index of the chitosan fibres increases by 8.22%, 14.32%, 28.87%, and 8.2% respectively. The preferential distributions of the chitosan/cotton yarns have a positive effect on improving the yarn strength. In this case, the tensile property of blended yarn is determined by both the length of the chitosan fibre and the migration index. The length of the chitosan fibre, *L*, and migration index, *MI*, are taken into consideration as parameters that influence the tensile properties of the yarns.By neglecting the mutual effect of these two factors, a binary quadratic model is adopted for the simulation of the length and migration vs. tenacity and elongation relationships:

$$\sigma = A_2 MI^2 + B_2 L \bullet MI + C_2 L^2 + D_2 L + E_2 MI + F_2 \qquad (7)$$

$$E = A_3 MI^2 + B_3 L \bullet MI + C_3 L^2 + D_3 L + E_3 MI + F_3 \qquad (8)$$

where σ is the breaking tenacity of the yarn, E is the breaking elongation of the yarns, L is the length of chitosan fibres, and A_2, B_2, C_2, D_2, E_2, F_2,A_3, B_3, C_3, D_3, E_3, and F_3 are coefficients of the functions. The fitting results are shown in Table 12 and Figure 8. From these equations, the yarn tenacity and elongation can be predicted with fibre length and fibre distribution. From Figure 5.8, it can be speculated that in the red regions, the blended yarn would achieve the optimum performance, while the blue region indicates poor mechanical performance.

5.10 Conclusions

The relationships among the length of the chitosan fibres, strength, elongation and fibre migration behaviours have been studied by producing yarn samples of four different fibre lengths of chitosan with cotton with a blending ratio of 50:50 in a ring spinning system. It is found that the yarn tenacity deteriorates with increases in the length of the chitosan fibre. Besides, chitosan fibres that are shorter in length (22 mm) or excessively long (46 mm) will bring about difficulties in yarn spinning, such as electrostaticity and fibres that stick. Chitosan fibres that are 30 and 38 mm in length are compatible for blending with long cotton fibres. It is found that, in the group of yarn samples spun by using the fibre-blending method, the yarn sample that contains chitosan fibre with a length of 30 mm provides better yarn strength and elongation among all the other lengths, while in the group of yarn samples spun by using the sliver-blending method, the yarn sample that contains chitosan fibre that is 38 mm in length has better yarn strength and elongation. Furthermore, this paper has provided evidence that the tensile properties are affected by the fibre distribution in yarn through migration index calculation. The blending method of fibre components (fibre- or sliver-blending) directly influences the yarn tenacity. Fibre-blending offers more evenness in the fibre distribution in the spinning process as opposed to the sliver-blending method. Since the arrangement of spinning rollers can be adjusted for an optimal fibre distribution, fibre distribution can be manipulated during the yarn spinning production process. The value of this paper will be reflected by the price-performance ratio of antibacterial functionality and cost control, because it is found that there is a non-linear relationship between the inhibitory effect of chitosan and the ratio of fibre composition (in accordance with standard AATCC 100, compared to the ratio of chitosan fibres in the fibre composition, the distribution of fibres has a greater influence on the antibacterial activity).In addition, the relationship between fibre distribution and the length of the chitosan fibres in the chitosan/cotton blend yarn has been studied and fitted by using polynomial modeling. It is found that the yarn tensile properties are affected by the length of each fibre component and its distribution in the yarn structure. Finally, a binary quadratic model is used to describe the relationships between length and migration vs. tenacity and elongation. The proposed formula in this paper could serve as guidance for the yarn manufacturers and producers in the textile industry in terms of the effect of the length of the chitosan fibres on the fibre distribution in yarn.

Chapter 6

A Pilot Intervention with Chitosan/Cotton Knitted Jersey Fabric to provide Comfort for Epidermolysis Bullosa Patients

6.1 Introduction

EB is a rare hereditary skin disease that causes skin fragility and blistering. Since the wounds of EB do not fully heal and there is currently no available medical technology that can cure this ailment, patients suffer a lifetime from the related physical and psychological pain. It is therefore important that skin-protective apparel with protective functions is specifically developed for EB patients to improve their wear comfort and reduce their chances of further skin injuries through the interaction of clothing as a "second skin" and the human skin. This chapter determines the role of chitosan based yarn in providing comfort to EB patients to scientifically determine the association between textile comfort and medical treatment, and establish the relationship between percentage composition and comfort to facilitate further examination of medical textiles in both theoretical and practical aspects. Liu et al. (2015) studied the chitosan/cotton blend ratio at below 50%. And in order to study the influence of fabric performance with higher chitosan blend ratio in the fabric composition, and to consider the balance of yarn production cost of further functional apparel development, five blend ratios including pure cotton and chitosan is proposed.

6.2 Materials

20 Ne Fibre-blend yarn samples with different blend ratios 30:70, 50:50, and 70:30 of chitosan/cotton as well as pure chitosan and cotton were examined and analysed in this chapter (Figure 6.1). 14 gauge jersey fabrics were fabricated by using different ratios of chitosan/cotton blended yarns (30:70, 50:50, and 70:30, as well as

pure chitosan and pure cotton), in which the physical properties such as blend, compression, thermal conductivity and surface roughness have been measured and analysed to determine the comfort of the investigated cotton/chitosan fabrics.

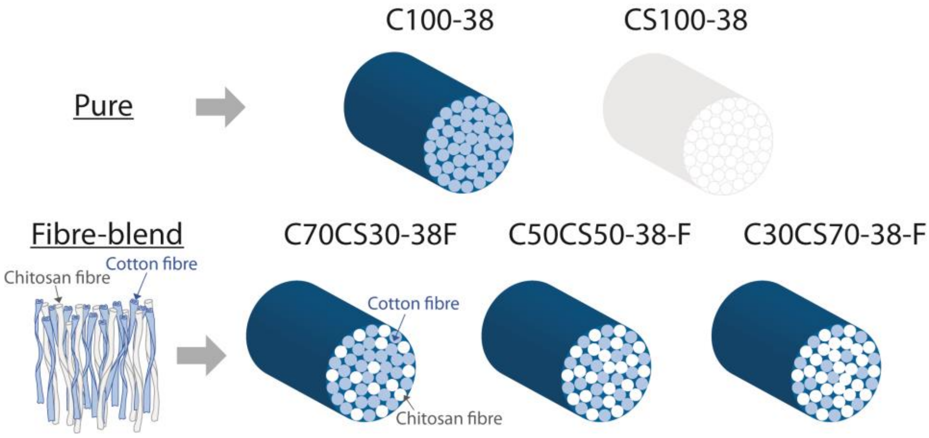


Figure 6.1 Pure cotton and chitosan, and fibre-blending of chitosan/cotton with different blend ratio (30:70, 50:50, and 70:30) (Author, 2017)

6.3 Results and Discussion

The properties of the yarn and jersey fabric are given in Table 6.1 and 6.2 respectively.

Table 6.1 Properties of chitosan/cotton blended yarn

Yarn Property	**C100-38**	**C70CS30-38-F**	**C50CS50-38-F**	**C30CS70-38-F**	**CS100-38**
Yarn Count (Ne) [CV%]	18.9 [0.46]	19.3 [1.56]	20.6 [2.04]	20.9 [2.04]	19.3 [0.88]
Yarn Diameter (µm) [CV%]	20.6 [0.08]	20.2 [0.06]	20.6 [0.10]	19.6 [0.12]	21 [0.09]
Yarn Twist (tpm) [CV%]	560 [5.54]	566 [5.54]	566 [5.16]	560 [6.71]	617 [7.51]
Tenacity (cN/tex) [CV%]	22.56 [6.2]	18.87[6.7]	13.26 [12.9]	12.08 [8.6]	8.48 [8.8]
Elongation (%) [CV%]	6.43 [4]	6.06 [5.9]	4.89 [9.3]	4.79 [10.8]	4.97 [21.3]
Yarn Initial Modulus (cN/tex) [CV%]	302.14 [5.49]	322.02 [6.8]	348.39 [10.16]	351.63 [5.55]	318.63 [4.84]
Evenness (CVm%) [CV%]	12.48 [1.53]	12.29 [1.09]	14.34 [1.22]	13.39 [3.99]	17.34 [6.26]

Thin Places (-50%) /km [CV%]	0 [0]	1 [0]	2 [149.1]	0 [0]	11 [109.7]
Thick Places (+50%) /km [CV%]	36 [14.4]	68 [26.9]	134 [19.6]	105 [21.4]	505 [20]
Neps (+280%)/km [CV%]	37 [32.9]	32 [36.6]	22 [44.1]	37 [19.9]	124 [40.8]
Hairiness (-) [CV%]	5.51 [3.04]	5.9 [1.99]	6.25 [0.78]	7.2 [0.77]	7. 24 [1.6]
Bending Rigidity ($x10^{-4}$ Nm/m/yarn)[CV%]	0.0051 [1E-02]	0.0047 [9E-02]	0.0008 [7E-01]	0.0024 [3E-02]	0.0075 [3E-01]

Table 6.2 Properties of jersey fabric made from chitosan/cotton blended yarn

Fabric Property	**C100-38**		**C70CS30-38-F**		**C50CS50-38-F**		**C30CS70-38-F**		**CS100-38**	
Weight (g/m^2)	299.44		263.14		229.76		209.58		203.74	
Stitch density (WPI x CPI)	236		199		189		185		168	
Peak voltage after friction test [CV%]	57 [11.26]		86 [0]		69 [2.05]		174 [1.22]		204 [6.93]	
Surface	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
BAR (warp) [CV%]	375.90 [0.20]	382.82 [0.24]	261.58 [0.22]	275.12 [0.26]	16029 [0.11]	160.31 [0.25]	129.83 [0.13]	124.20 [0.32]	139.46 [0.18]	145.69 [0.21]
BAR (weft) [CV%]	395.29 [0.42]	432.24 [0.47]	223.83 [0.13]	211.93 [0.28]	149.47 [0.47]	170.37 [0.31]	170.75 [0.20]	141.57 [0.06]	150.11 [0.41]	135.51 [0.10]
BW (warp) [CV%]	1082.39 [0.24]	1349.67 [0.14]	727.56 [0.11]	970.02 [0.11]	513.81 [0.06]	611.61 [0.07]	414.41 [0.07]	512.74 [0.11]	401.47 [0.14]	468.37 [0.17]
BW (weft) [CV%]	1155.28 [0.29]	903.67 [0.36]	850.47 [0.17]	610.79 [0.22]	536.26 [0.19]	433.58 [0.07]	465.36 [0.12]	383.92 [0.13]	481.98 [0.13]	414.19 [0.05]
T [CV%]	0.97 [0.08]	0.99 [0.05]	0.86 [0.04]	0.85 [0.03]	0.085 [0.07]	0.83 [0.04]	0.74 [0.06]	0.74 [0.06]	0.81 [0.21]	0.80 [0.12]
CW [CV%]	2597.25 [0.13]	2305.93 [0.10]	2180.96 [0.41]	1681.18 [0.25]	960.89 [0.13]	805.71 [0.16	976.70 [0.13]	818.49 [0.21]	787.19 [0.28]	550.71 [0.21]
CRR [CV%]	0.25 [0.17]	0.32 [0.11]	0.33 [0.16]	0.35 [0.20]	0.43 [0.05]	0.49 [0.09]	0.37 [0.09]	0.43 [0.06]	0.41 [0.14]	0.46 [0.14]
CAR [CV%]	1.04 [0.08]	1.28 [0.18]	1.54 [0.63]	1.81 [0.30]	3.03 [0.09]	3.33 [0.13]	3.01 [0.11]	3.40 [0.19]	3.60 [0.29]	5.54 [0.25]
RAR [CV%]	4.35 [0.16]	3.81 [0.14]	4.58 [0.37]	4.73 [0.25]	6.67 [0.10]	6.63 [0.13]	7.49 [0.12]	7.89 [0.08]	9.52 [0.13]	12.16 [0.26]
TCC [CV%]	0.05 [0.05]	0.05 [0.06]	0.05 [0.05]	0.05 [0.02]	0.05 [0.06]	0.05 [0.09]	0.04 [0.05]	0.04 [0.09]	0.04 [0]	0.04 [0.10]
TCR [CV%]	0.056[0.04]	0.06 [0.05]	0.05 [0.04]	0.05 [0.03]	0.05 [0.05]	0.05 [0.07]	0.04 [0.06]	0.04 [0.07]	0.04 [0]	0.04 [0.08]
Qmax[CV%]	399.99 [0.25]	359.42 [0.19]	477.54 [0.27]	482.99 [0.23]	624.19 [0.05]	632.13 [0.01]	622.52 [0.06]	630.76 [0.09]	592.10 [0.06]	619.20 [0.09]
SFC (warp) [CV%]	0.47 [0.03]	0.38 [0.15]	0.46 [0.06]	0.52 [0.11]	0.37 [0.18]	0.34 [0.15]	0.36 [0.18]	0.35 [0.12]	0.32 [0.26]	0.42 [0.18]
SFC (weft) [CV%]	0.43 [0.08]	0.51 [0.05]	0.48 [0.05]	0.52 [0.04]	0.42 [0.11]	0.45 [0.13]	0.36 [0.18]	0.42 [0.18]	0.37 [0.13]	0.29 [0.21]
SRA (warp) [CV%]	36.64 [0.24]	43.66 [0.30]	36.96 [0.31]	53.60 [0.27]	40.32 [0.17]	72.56 [0.14]	47.78 [0.33]	75.02 [0.26]	50.25 [0.25]	77.86 [0.21]
SRA (weft) [CV%]	67.74 [0.20]	34.55 [0.32]	56.48 [0.16]	61.08 [0.75]	51.68 [0.19]	32.89 [0.22]	46.28 [0.06]	37.76 [0.12]	37.51 [0.25]	40.87 [0.12]
SRW(warp) [CV%]	1.98 [0.17]	1.75 [0.36]	1.77 [0.46]	2.07 [0.24]	1.41 [0.10]	1.45 [0.22]	1.48 [0.04]	1.73 [0.13]	1.80 [0.26]	1.31 [0.21]
SRW (weft) [CV%]	1.68 [0.12]	2.60 [0.14]	2.37 [0.16]	3.52 [0.14]	2.08 [0.06]	2.84 [0.25]	2.17 [0.14]	2.59 [0.16]	2.07 [0.16]	2.26 [0.16]
Hand Value [CV%]	0.28 [0.04]	0.37 [0.06]	0.27 [0.07]	0.39 [0.02]	0.21 [0.03]	0.40 [0.01]	0.24 [0.04]	0.40 [0.02]	0.22 [0.01]	0.39 [0.01]

6.3.1 Statistical analysis

A one-way analysis of variance (ANOVA) at the 95% confidence limit (level of significance $\alpha_{0.05}$) was carried out by using SPSS Statistics 22 software to analyze the correlation between the different blend ratios and the different fabric properties. The analysis reflected that the relationships between all of the fabric properties and different blend ratios are significant except the hand value (Table 6.3).

Table 6.3 One-way ANOVA carried out between samples with different blend ratios and fabric properties

Source of variance	Sum of squares	df	Mean square	F	P value
Different blend ratios-BARa	458376.526	4	114594.131	46.338	0.000
Different blend ratios-BARe	511745.049	4	127936.262	16.542	0.000
Different blend ratios-BWa	4333016.634	4	1083254.158	52.508	0.000
Different blend ratios-BWe	2658110.808	4	664527.702	20.411	0.000
Different blend ratios-T	3.902	4	0.976	43.223	0.000
Different blend ratios-CW	24360869.32	4	6090217.329	44.561	0.000
Different blend ratios-CRR	0.202	4	0.050	17.882	0.000
Different blend ratios-CAR	73.800	4	18.450	27.175	0.000
Different blend ratios-RAR	291.161	4	72.790	34.678	0.000
Different blend ratios-TCC	0.001	4	0.000	36.311	0.000
Different blend ratios-TCR	0.001	4	0.000	44.813	0.000
Different blend ratios-Qmax	487667.961	4	121916.990	25.456	0.000
Different blend ratios-SFCa	0.052	4	0.013	3.089	0.025
Different blend ratios-SFCe	0.178	4	0.045	13.910	0.000
Different blend ratios -SRAa	4281.542	4	1070.385	3.365	0.017
Different blend ratios-SRAe	3624.549	4	906.137	2.786	0.039
Different blend ratios-SRWa	2.170	4	0.543	2.895	0.041
Different blend ratios-SRWe	4.202	4	1.050	3.389	0.017
Different blend ratios-Hand Value	0.007	4	0.002	0.216	0.928

6.3.2 Bending

As a reaction force from fabric deformation, bending reflects the stiffness of a fabric which is also received by human skin as a stimulus. The bending properties determine the handling performance of fabrics (Du & Yu, 2005; Koo, 2001; Leaf, 1995). The BAR and BW values in both the warp and weft directions and outer and inner surfaces of the prepared cotton/chitosan fabric samples were recorded, and are shown in Figure 6.2 and Table 6.2. The BAR and BW significantly decrease when the chitosan blend ratio is increased from 0% to 50% (Figure 6.2a, 6.2b). However, the BAR and BW have negligible variations when pure chitosan fabrics are examined. This result indicates that compared to 100% cotton, pure chitosan and cotton/chitosan blended fabrics have relatively little stiffness which implies a softer handle. In comparing the BAR of the fabrics with the bending rigidity of the yarn, it is worth noting that as the concentration of chitosan was increased from 0% to 50%, the yarn experienced a trend of reduction in the bending rigidity similar to the fabrics. Moreover, the fabrics with 70% and 100% chitosan have a much smaller bending rigidity which is different from the corresponding yarn samples (Figure 6.2c). This phenomenon is explained by young's modulus of cotton and chitosan fibers and bending rigidity of blended yarn samples.

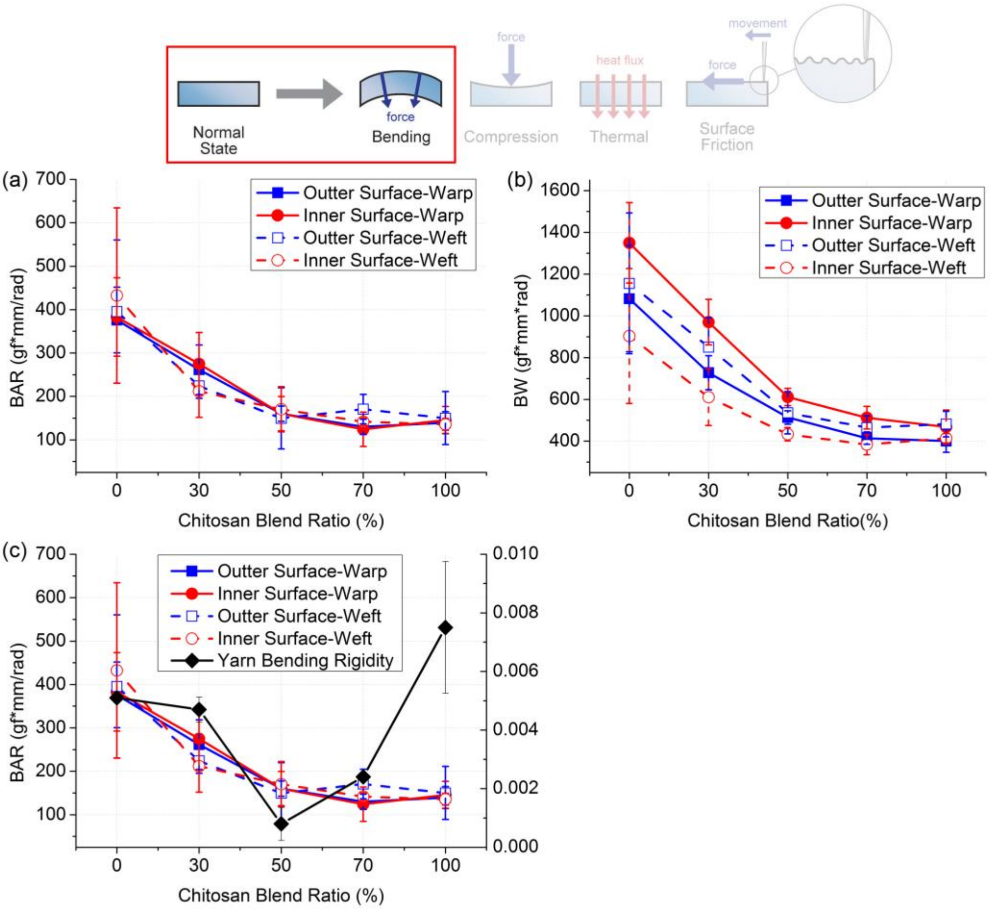


Figure 6.2 Bending properties of jersey fabric samples: warp and weft directions of (a) bending average rigidity (BAR) and (b) bending work (BW).(c) BAR and bending rigidity of yarn of chitosan/cotton blended yarn. (Author, 2017)

The initial modulus of the cotton/chitosan blended yarns was determined (Table 6.1). As the concentration of chitosan is increased from 0% to 70%, the initial modulus also increases due to the variation in chitosan from 302.14 to 351.63 as shown in Figure 6.3c. This phenomenon might be attributed to the fact that the chitosan fibers have a higher modulus than that of the cotton fibers as mentioned in the section on fiber properties. However, the initial modulus of pure chitosan is less than that of the 30%, 50% and 70% blended yarns. One possible explanation is that a higher ratio of chitosan fibers generates plastic deformation or fractures, and finally, the fibers break during the spinning process since they have a small area of elastic deformation (as shown in the plot and graph of Figures 6.3 and 6.4). A linear fitting algorithm was applied to the relationship between the tenacity/chitosan blend ratio and elongation/chitosan blend ratio (Table 6.4). The fiber length distribution of the pure chitosan yarn is shown in Figure 7a, which indicates that the original chitosan has a fiber length of 38 mm. It can be observed that at least 75% of the chitosan fibers have plastic deformation or break during the spinning progress. For the pure chitosan yarn, the defects and breaking of the fibers lead to a reduction in the modulus.

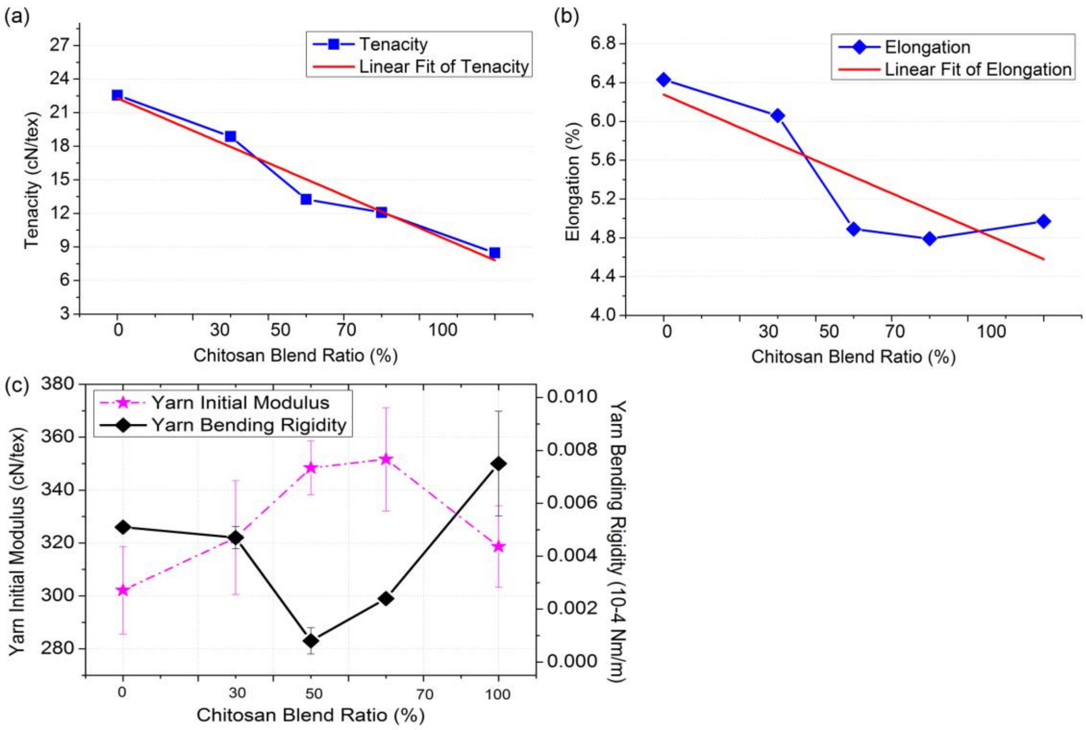


Figure 6.3 Linear regression of (a) tenacity and (b) elongation of chitosan/cotton blended yarn. (c) Initial modulus and bending rigidity of chitosan/cotton blended yarn. (Author, 2017)

Table 6.4 Linear fit and regression equations for yarn tenacity and elongation of chitosan/cotton blended yarn

	Unit	Fit model
Tenacity	cN/tex	y = -0.14479 + 22.28966 * x
Elongation	%	y = -0.01697 + 6.27628 * x

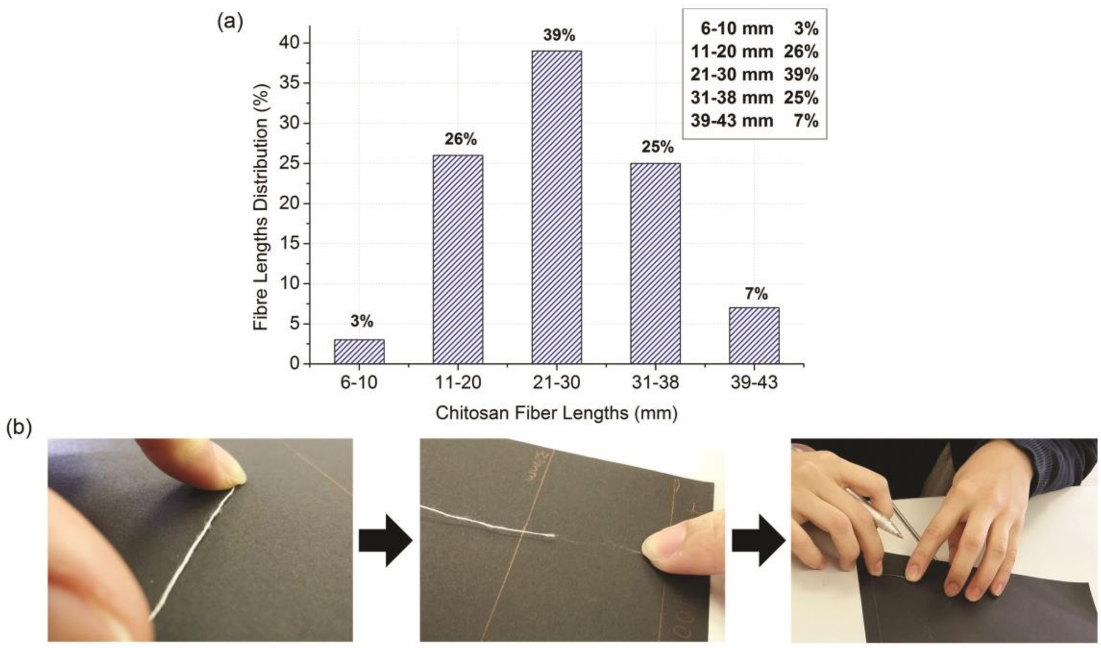


Figure 6. 4 (a) Fiber length distribution of 100% chitosan yarn determined by manual fiber counting of untwisted yarn. (b) Method of manual fiber counting of untwisted yarn. (Author, 2017)

The bending rigidity of the fiber is defined as (Meredith & Hsu, 1962a, 1962b)

$$R_i = EI \qquad (1)$$

E is the young's modulus of the fiber, with unit (cN/cm^2), *I* is the moment of inertia, considering the cross-section factor, the equation is transferred as

$$R_i = \frac{\pi}{64} E d^4 \cdot \eta \qquad (2)$$

d is the diameter of the fiber, with the unit cm,

$$d^2 = \frac{4}{\pi} \frac{N}{\rho} \times 10^{-5} \qquad (3)$$

N is the line density of the fiber, tex; ρ is the material density, g/cm^3. Take the equation 3 into equation 2:

$$R_i = \frac{1}{4\pi} E_i \eta \frac{N^2}{\rho^2} \times 10^{-10} \quad (4)$$

so that the relative bending rigidity is

$$R = \frac{1}{4\pi} \eta \frac{E}{\rho} \times 10^{-5} (\mathrm{cN} \bullet \mathrm{cm}^2 / \mathrm{tex}^2) \quad (5)$$

Taking all of the factors into consideration, the cotton fibers have softer handle than the chitosan fibers. And, it is deduced that 50% blended yarn has the least bending rigidity, but increases or reductions in the concentration of chitosan would lead to higher bending rigidity (Table 6.1 and Figure 6.3c). This might be resultant of the high stickiness of chitosan material. Figure 6.5 shows an experiment in which pure chitosan and cotton fibers are split. It is obvious that the chitosan fiber is more difficult to split than the cotton fiber, which implies a high stickiness of fiber. When the concentration of chitosan fibers is increased, the high stickiness would induce the bonding of multiple fibers into a compacted group of fibers, so that the blended yarn which has a compact structure will tend to have high bending rigidity.

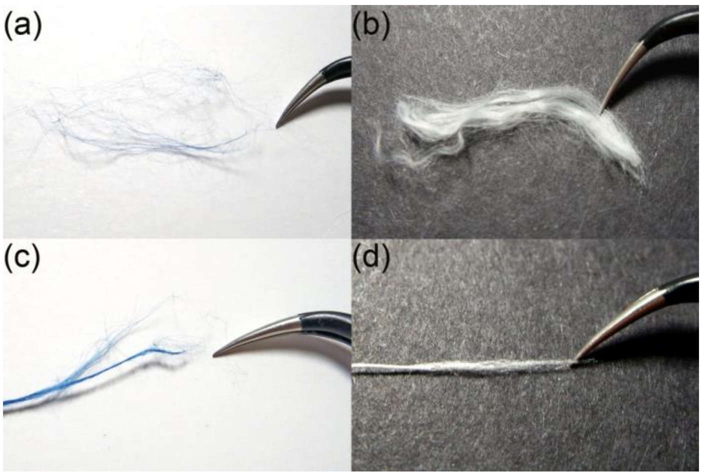


Figure 6.5 Experiment to demonstrate stickiness of (a) blue-dyed-cotton fiber (b) chitosan fiber. Fiber separation by manual untwisting of (c) 100% cotton yarn and (d) 100% chitosan yarn (Author, 2017)

6.3.3 Compression

The compression properties determine the fullness and elasticity of fabrics. They influence the touch/feel through the surface smoothness and as a proprioceptive stimulus (Liao et al., 2014). Thus, fabric compression values indicate the handle and comfort of a fabric (Giorgio Minazio, 1995; Shishoo, 1995; Yao, Yan, Hong, & Wang, 2013) . The thickness of the fabrics in this study has negligible variations as the blend ratio is increased (Figure 6.6a). The CW decreases due to increases in the chitosan blend ratio from 0% to 100% (Figure 6.6b). The CRR, CAR, and RAR of the fabrics increase in accordance with increases in the chitosan blend ratio. From the compression results, it could be easily observed that fabric with higher concentrations of chitosan fibers has a higher stiffness (Figures 6.6c-d). The compression rigidity of the fabrics is associated with the tensile modulus of the materials. The CAR of the fabrics is directly proportional to the chitosan concentration. When the concentration of chitosan is increased from 0% to 70%, both the CAR and initial modulus of the yarn samples have a similar trend. However, this changes with 100% chitosan (see Figure 6.6e), which is due to the compacted structure of the pure chitosan yarn (Figure 6.7) resultant of the high stickiness.

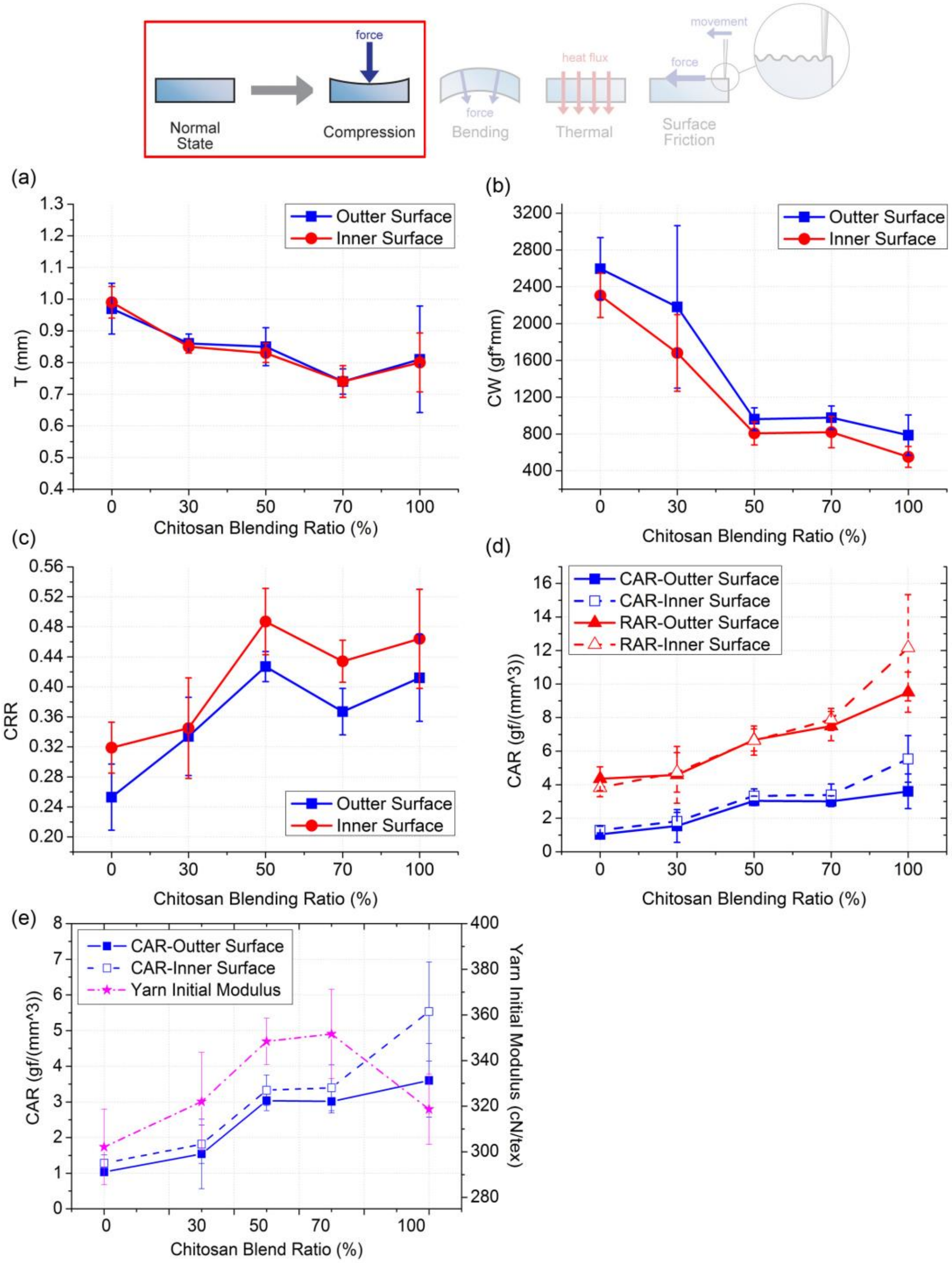


Figure 6.6 Compression properties of jersey fabric samples: (a) thickness; (b) CW; (c) CRR; (d) CAR; and RAR. (e) CAR and yarn initial modulus of chitosan/cotton blended yarn. (Author, 2017)

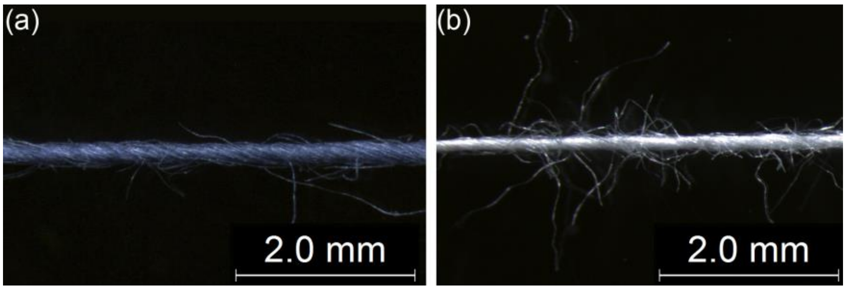


Figure 6.7 Microscope image of yarn surface of (a) 100% cotton and (b) 100% chitosan. (Author, 2017)

6.3.4 Thermal

Thermal properties refer to the heat transfer between fabric and human skin and the perception of coolness. Thermal properties also reflect the ability of a material to maintain heat and comfort during wear (Hu, Hes, Li, Yeung, & Yao, 2006; Y. Li, 2001; Özdil, Marmaralı, & Kretzschmar, 2007). For both the outer and inner surfaces of the jersey fabric made from the chitosan/cotton blended yarns, the TCC is reduced with increases in the chitosan blend ratio (Figure 6.8a). This is because the transfer of heat is easier between the fabric and human skin with a lower blend ratio of chitosan. More chitosan fibers result in a better maintenance of warmth. The Qmax is rapidly increased from 100% cotton (0% chitosan) to a 50% blend ratio of chitosan (Figure 6.8b). This explains why fabric with a higher blend ratio (50% or above) of chitosan would be perceived as being cooler when it is in contact with human skin. Fabric with cooler surface offers the comfort by releasing the heat from body surface of EB patient.

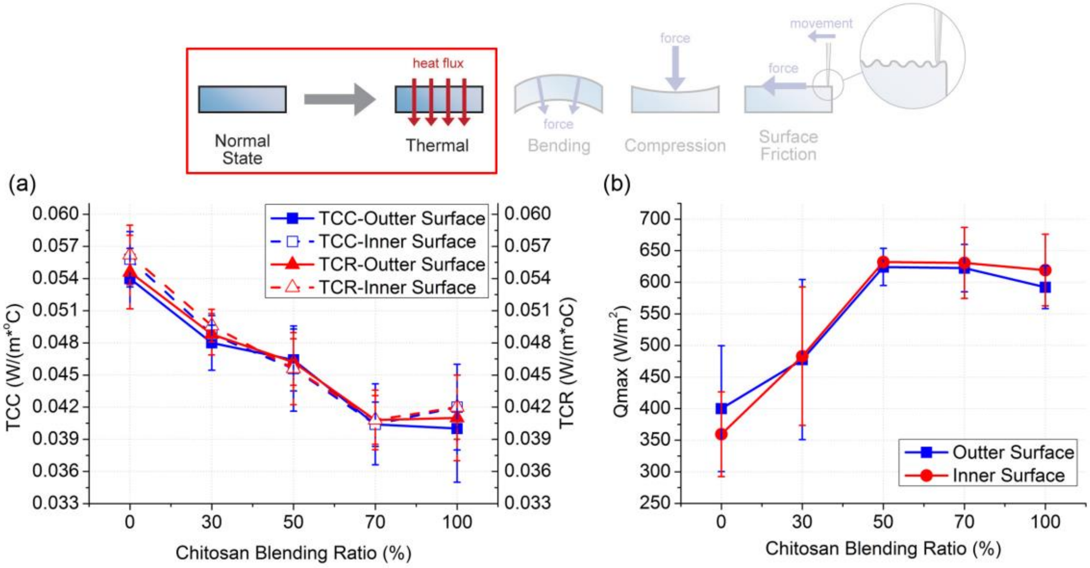


Figure 6.8 Thermal properties of jersey fabric samples: (a) TCC and TCR; (b) Qmax. (Author, 2017)

6.3.5 Surface Friction & Roughness

The surface friction and roughness are two critical factors that indicate the surface smoothness (Ajayi, 1992a, 1992b; Carr, Posey, & Tincher, 1988). In this study, the SFC, SRA and SRW were measured and recorded. The testing was carried out in both the warp and weft directions as well as on the outer and inner surfaces. All three indices showed no obvious changes due to changes in the blend ratio (Figure 6.9). In Figure 6.9a, fabric samples with 30:70 chitosan/cotton and 50:50 chitosan/cotton, show similar tendency of surface friction, inner surface of weft direction has the highest value, follow with outer surface of weft direction and outer surface of warp direction. Besides of the 100% chitosan fabric sample, other samples recorded the least value of inner surface of warp direction, follow with outer surface of warp direction. Compare with all samples, fabric samples with 30% chitosan in composition has the highest SRA value of inner surface of weft direction, while 100% cotton fabric has the highest value of outer surface of weft direction (Figure 6.9b). This could be explained that the higher stitch density of jersey fabric.

For surface roughness wavelength, it was obvious that the surface roughness in the weft direction is greater than that the warp direction, which is due to the textile structure (Figure 6.9c). It is suggested that warp direction of plain jersey fabric samples could offer least surface friction to handle if the fabric has less stitch density.

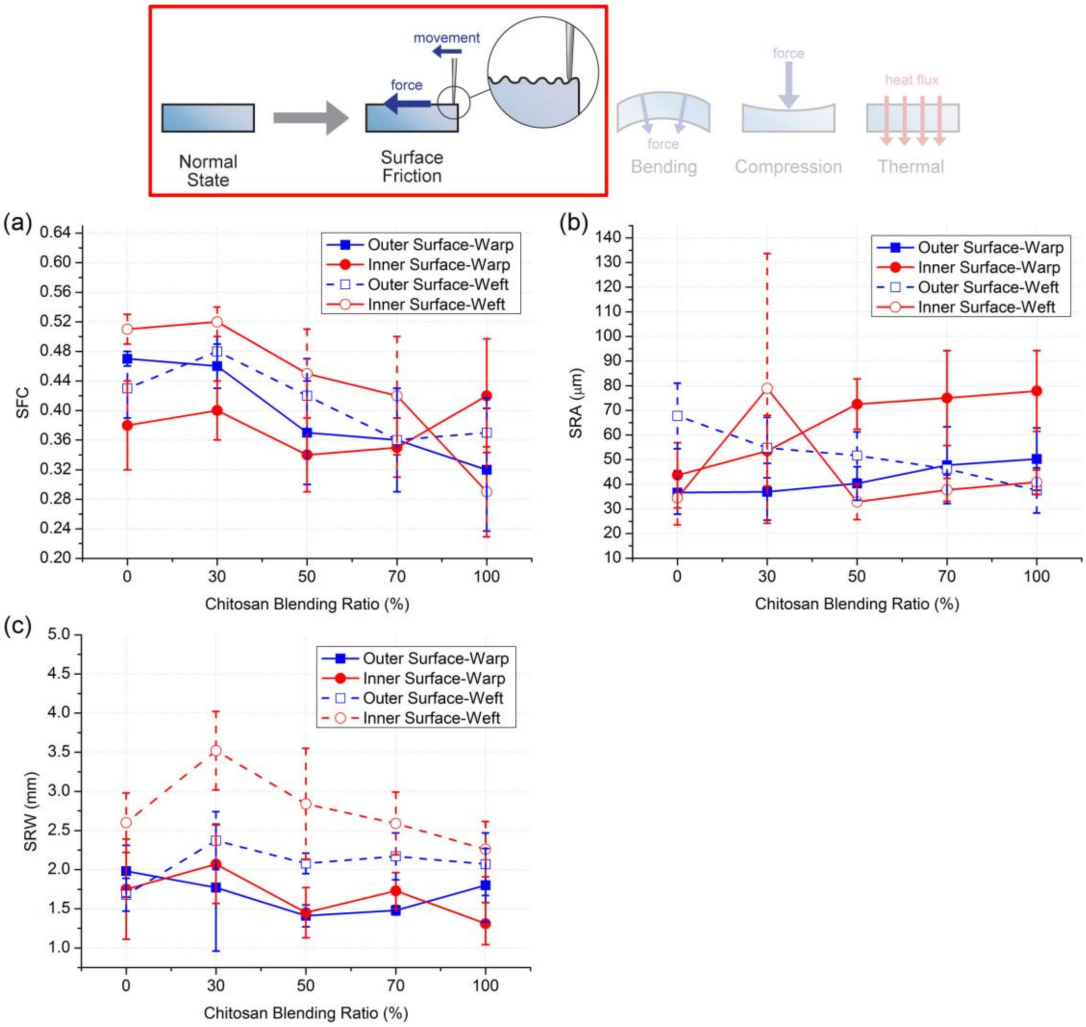


Figure 6.9 Surface friction and roughness properties of jersey fabric samples: (a) SFC; (b) SRA; and (c) SRW measured in warp and weft directions. (Author, 2017)

6.3.6 Fabric Touch/feel Performance of Knitted Jersey Fabric

By using the FTT, fabrics with different compositions of cotton/chitosan were tested to evaluate the comfort properties resultant of the mechanical properties, thermal conductivity, and smoothness. Data from 5 categories of physical properties (BW, CW, TCC, Qmax and SFC) were selected to present the overall evaluation of the three different blend ratios of chitosan fibers (0%, 50% and 100%). As 100% cotton (0% chitosan) jersey fabric served as the bench mark of the overall comfort rating (value is 1 for both outer and inner surfaces), 50% and 100% chitosan were used as to show the effect of a chitosan blend of 50:50 and pure chitosan in the composition of the fabric, and the values were presented as a ratio in comparison to 100% cotton (Figure 6.10). For Figure 6.11, in order to have a directly comparison of three fabric samples on both surfaces, value of 100% cotton is set as 1 for outer surface and 0.9 for inner surface, the values of 50% chitosan and 100% chitosan presented as a ratio in comparison to 100% cotton.

The cotton/chitosan blended fabric samples and pure chitosan sample have various advantages when used as a textile to provide comfort to EB patients. In terms of physical properties, fabrics with chitosan have better softness. The BW and CW of the samples have an obvious descending trend due to the usage of chitosan (Figure 6.10). Furthermore, these blends and pure chitosan samples seem to have optimal thermal properties. The reduction in the thermal conductivity implies better warmth while the Qmax value shows a cooler direct touch/feel which is important to EB patients so that they feel better. Besides, the decreasing SFC showed that the addition of chitosan as a component in fabric will help to improve the fabric smoothness (Figure 6.11). Overall, compared with the pure cotton fabric samples, it is very likely that fabrics can be optimized by adding chitosan as a component in fabric which would improve the comfort properties for EB patients due to the outstanding performance in softness, smoothness and thermal conductivity.

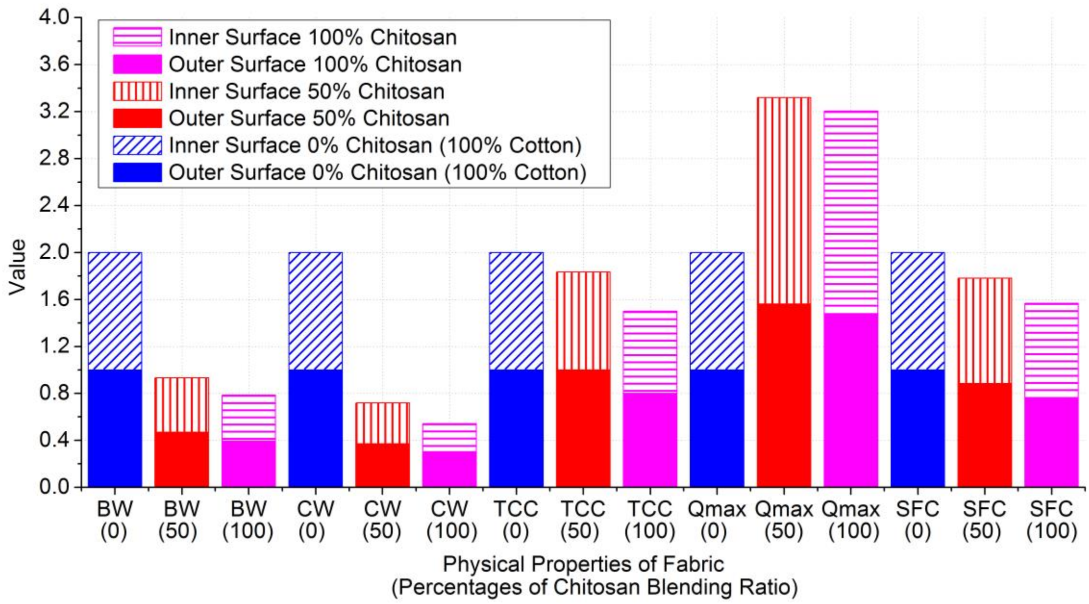


Figure 6.10 Overall evaluation of physical properties (BW: bending work; CW: compression work; TCC: thermal conductivity when compressed; Qmax: thermal maximum flux and SFC: surface friction coefficient) of 0:100, 50:50, and 100:0 chitosan/cotton jersey fabrics (Author, 2017)

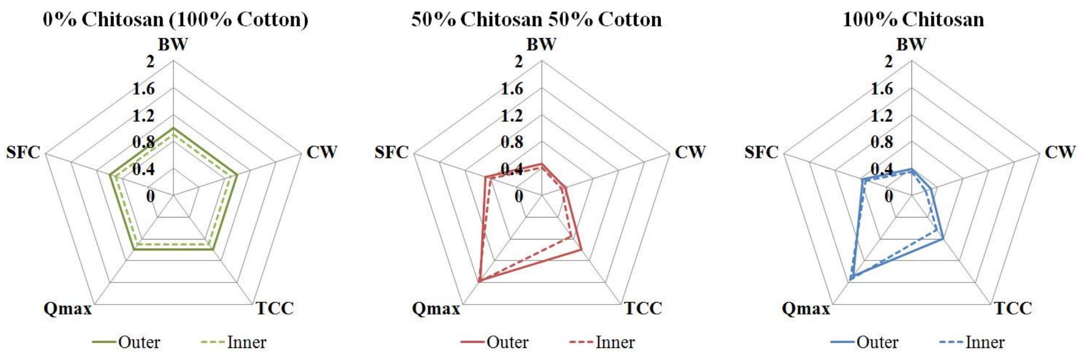


Figure 6.11 Physical properties of 0:100, 50:50, and 100:0 chitosan/cotton jersey fabrics (BW: bending work; CW: compression work; TCC: thermal conductivity when compressed; Qmax: thermal maximum flux and SFC: surface friction coefficient) (Author, 2017)

6.4 Conclusion

The relationship between the percentage of the composition of chitosan in plain jersey fabric and its comfort properties has been studied in this paper. An analysis of the physical properties including bending, compression, thermal conductivity, and surface friction are measured by using an FTT. The results show that chitosan fibers added to fabric has a good impact on handle and all of the physical properties of plain jersey fabric. With an increase in the blend ratio of chitosan fibers (50% or more), the rigidity of the fabric is reduced, and the inner surface has a softer handle. The SFC is also reduced, which provides a smoother surface. The Qmax is reduced which means a cooler handle, fabric with a higher blend ratio of chitosan fibers offer a cooler touch to human skin. EB patients who have large amounts of bandages covered on their body surface will cause overheating. Besides, blister might form to secondary trauma by increased body temperature. Fabric with 50% or above chitosan in composition would give higher Qmax value, and the fabric would be perceived as being cooler when it is in contact with human skin. It is suggested to apply with high Qmax value in order to lower the high body temperature of EB patients, so as to reduce the physical pain by chitosan/cotton blended fabric. It is concluded that fabric with chitosan fibers added as part of the fiber composition will provide better smoothness, softness and thermal conductivity, which have facilitated the development of a fabric with skin-protective function for EB patients to reduce the friction between clothing and their skin. Products that use this chitosan based yarn will have great potential in future applications that require a good hand feel and wound healing property.

Chapter 7

Investigation on Skin-Protective Clothing that Addresses Needs of Epidermolysis Bullosa Patients/Children with Epidermolysis Bullosa and their Parents

7.1 Introduction

The development of skin-protective clothing contribute to skin disease patients by providing information towards a more suitable apparel system that would enhance their quality of life by reducing their physical and psychological pain in daily life. This chapter introduced the application of chitosan/cotton blend yarn and fabric in functional apparel system for children, and then an investigation of proposed functional apparel system that addresses the needs of Epidermolysis Bullosa patients and children with Epidermolysis Bullosa and their parents was conducted through semi-structured interviews with 6 participants.

7.2 Skin-Protective Garment Development

For the application of chitosan/cotton blend yarn in fashion design for EB patients, fabrics combining antibacterial properties and comfort were developed through jersey knitting technology. Jersey fabric comprised with 10% chitosan 90% cotton was examined by antibacterial test, and it showed >99% reduction of *Staphylococcus aureus* (ATCC 6538), and >90% reduction of *Klebsiella pneumoniae* (ATCC 4352) (Appendix 7.1). Fabric was washed for 20 washes before the testing. The fine and soft 20% chitosan 80% cotton jersey fabric was selected and applied for skin-protective garment prototypes, and the prototypes were donated to the Taiwan Epidermolysis Bullosa Association for evaluation, and a dinosaur print was created to bring happiness and positive imagery to the patients, in keeping with the goals of the association. The dinosaur print was designed by Venus Luo and our research team.

Figure 7.1 Dinosaur print used on skin-protective garment prototypes, designed by Venus Luo and our research team (Author, 2017)

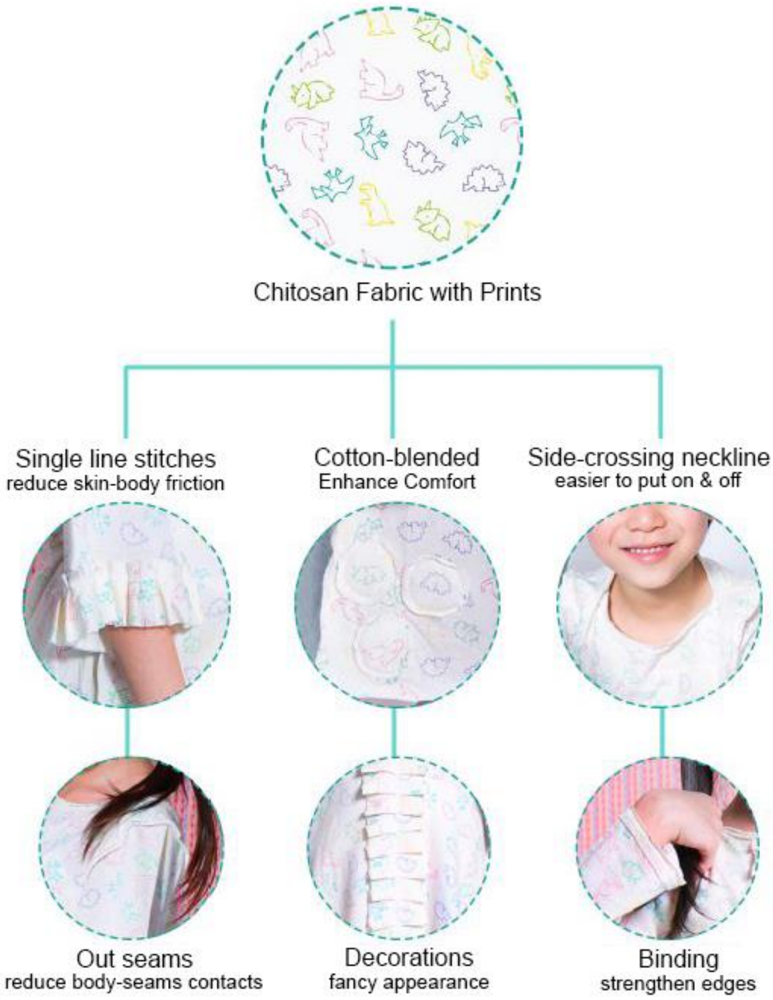


Figure 7.2 Clothing detailing for skin-protective garment prototypes, designed by Psyche Chiu and our research team (Author, 2017)

Skin protective garment prototypes were designed by Psyche Chiu and our research team. Prototypes were developed based on the results of the experiments of chitosan/cotton blend yarn tensile properties, fabric comfort and antibacterial test, and the balance of production cost. The clothing detailing was design which met the basic principles of easy wearing and less friction between fabric and skin. Figure 7.2 highlighted the details of prototype designs. The proposed single line stitches and out seams could reduce pain caused by skin-fabric friction. To enhance the wearability and functionality of the fabric, fabric made by 20% chitosan 80% cotton was utilised. To offer comfort to patients, a side-crossing neckline was used to create a wider neck opening. For garment finishing, a binding is suggested for strengthen the edges. The appearance is another requirement in the prototype design. Colourful dinosaurs were printed on the fabric (Figure 7.1), and decorations using the same fabric were occupied. The garment prototypes were designed initially to fulfil the clothing requirements of EB patients. Style photos of skin-protective garment prototypes for both girls and boys are shown in Figure 7.3 and 7.4 respectively. Figures 7.3a shows a one-piece dress design with a semi-loose fit that facilitates easy wearing. Figure 7.3b is a long sleeved one-piece dress designs with loose fit. To minimize the friction between the garment and patient's skin, the out-seamed sewing technique was used. Figures 7.43 shows a long raglan sleeved t-shirt with loose shorts. To provide comfort and easy wearing, a short sleeved t-shirt with side crossing neckline, matched with loose long pants (Figure 7.4a) and a long sleeved jacket with loose shorts was also designed (Figure 7.4b).

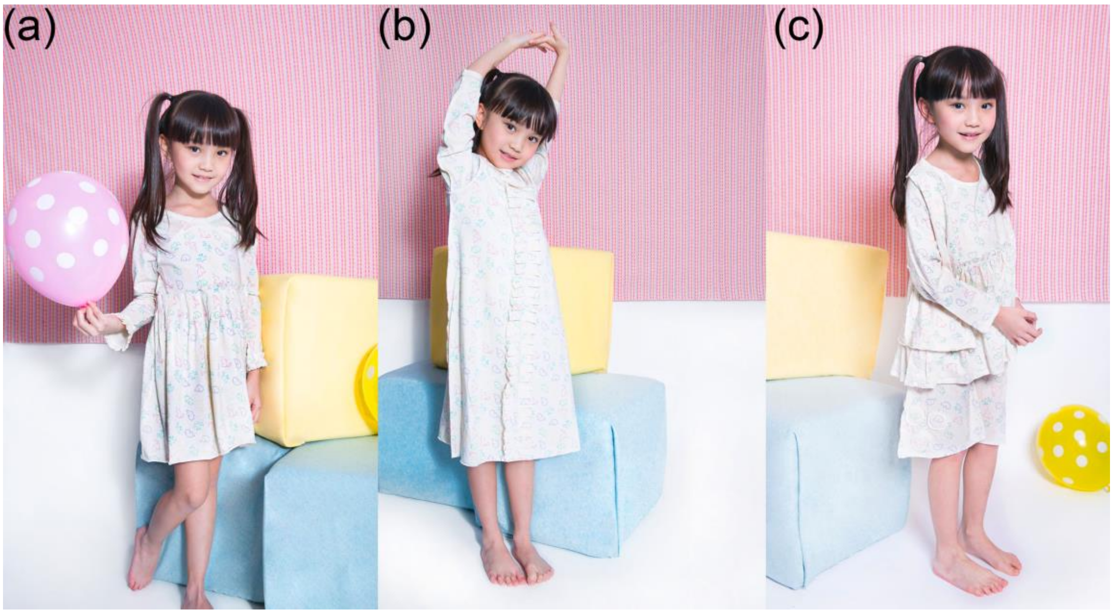


Figure 7.3 Skin-protective garment prototypes for girls: (a) a long sleeved one-piece dress designs with semi loose fit; (b) a long sleeved one-piece dress designs with loose fit; and (c) a long raglan sleeved t-shirt with loose shorts. (Author, 2017)

Figure 7.4 Skin-protective garment prototypes for boys: (a) a short sleeved t-shirt with side crossing neckline, matched with loose long pants; (b) a long sleeved jacket with loose shorts. (Author, 2017)

7.3 Methods

The semi-structured interviews were conducted to collect opinions and data to understanding the difficulties faced encountered by EB patients and the parents of children with EB. Two set of questions were designed for EB patients and parents, the interview questions were summarised in Appendix 3.1 and 3.2.

7.3.1 Participants

The six participants were recruited from the EB database of the Taiwan Epidermolysis Bullosa Association (Table 7.1). They are all Mandarin native speakers and willing and motivated to participate in this study with informed consent. The definitive sample consisted of 2 children with EB who are 9 and 11 years old (Participants 1 and 2) at the time of the study, 1 female adult with EB who is 33 years old (Participant 3) at the time of the study and 3 parents of EB patients who range from 33 to 50 years old. The parents are a father of a 5 month-old male baby with EB (Participant 4), the mother of the 11 year-old female participant with EB (Participant 5); and the mother of a 17 year-old male youth with EB (Participant 6). Participant 1 and the 5 month-old male infant of Participant 4 were not diagnosed with any particular type of EB, while Participant 2 was diagnosed with Köebner subtype of EB simplex (EBS-K), Participant 3 with epidermolysis bullosa simplex (EBS), and the 17 year-old male child of Participant 6 with junctional epidermolysis bullosa.

Table 7.1 Demographics of interviewees

Interviewee	Age (years)	Gender	Age of child (years)	Gender of child	EB type	Remarks
1	9	Male	-	-	Unknown*	
2	11	Female	-	-	EBS-K	
3	33	Female	-	-	EBS	
4	33	Male	5-month	Male	Unknown*	
5	40	Female	11	Female	EBS-K	Mother of interviewee 2
6	50	Female	17	Male	JEB	

* Unknown: not diagnosed.
EBS: epidermolysis bullosa simplex; EBS-K: Köebner subtype of epidermolysis bullosa simplex; JEB: junctional epidermolysis bullosa

7.3.2 Procedure

Ethical approval for this study was granted by the Departmental Research Committee at The Hong Kong Polytechnic University. The participants were informed about the purpose and contents of the study by means of an information sheet. Participation was voluntary and all of the participants were asked to sign a written consent form and informed that their personal details would be kept confidential. Each participant received a signed copy of the consent form. The interviews took place in a Chinese restaurant in Taipei after lunch with the participants, and the president and the secretary of Taiwan Epidermolysis Bullosa Association. This arrangement allowed familiarisation with the participants, or considered as an ice breaking opportunity, and also at the same time, reduced the time required to travel. The group interviews were conducted face to face in Mandarin which lasted 100 minutes. During the interviews, paraphrasing and reflective listening were used to obtain a better understanding of the conversation with the participants. At the end of the group interviews, each participant was given the opportunity to summarise the functions that s/he felt is most important and would address their own needs or the needs of their child.

7.4 Analysis

The analysis was conducted along the lines of the seven topics of the survey questionnaire.

7.4.1 Importance and satisfaction of clothing with current garments on market

The average ratings of importance and satisfaction with the features of garments that are currently available by the 6 participants are plotted in Figure 7.5a. The reference line is calculated by adding together the average ratings of importance and satisfaction (11 factors), which were first determined separately (see Figures 7.5b and 7.5c respectively). The fluctuations (differences) were then plotted in comparison with the reference line.

According to the average ratings of importance of issues related to clothing on the market, the participants show less concern with five factors: price (-9.94%), style (-6.73%), colour (-29.24%) type of fastener (-9.94%) and quality (-0.29%) (Figure 4a). However, they indicated that function (+2.92%), size (+12.57%), material (+15.79%), stretchability (+9.36%), comfort (+9.36%), and method of donning and doffing (+6.14%) are comparatively important which could affect their motivation to purchase. The stretchability of clothing is related to the material (fabric), while method of donning and doffing and stretchability are directly in response to the comfort performance of the clothing. These 5 factors all indicate the intended function of clothing and that EB patients or their parents have specific needs and requirements in terms of clothing features (Figure 7.5a).

In terms of the previous clothing purchase experiences of the participants (Figure 7.5a, average rating of satisfaction), it was found that they are not satisfied with the price (-6.44%), size (-7.86%), and style (-7.86%). However, they are moderately satisfied with the quality (+2.77%), colour (-0.77%), function (-0.77%), comfort (+2.77%), type of fastener (+2.77%) and method of donning and doffing (-0.77%). On the other hand, they are relatively satisfied with the material (+6.31%) and stretchability (+9.86%) (Figure 7.5a).

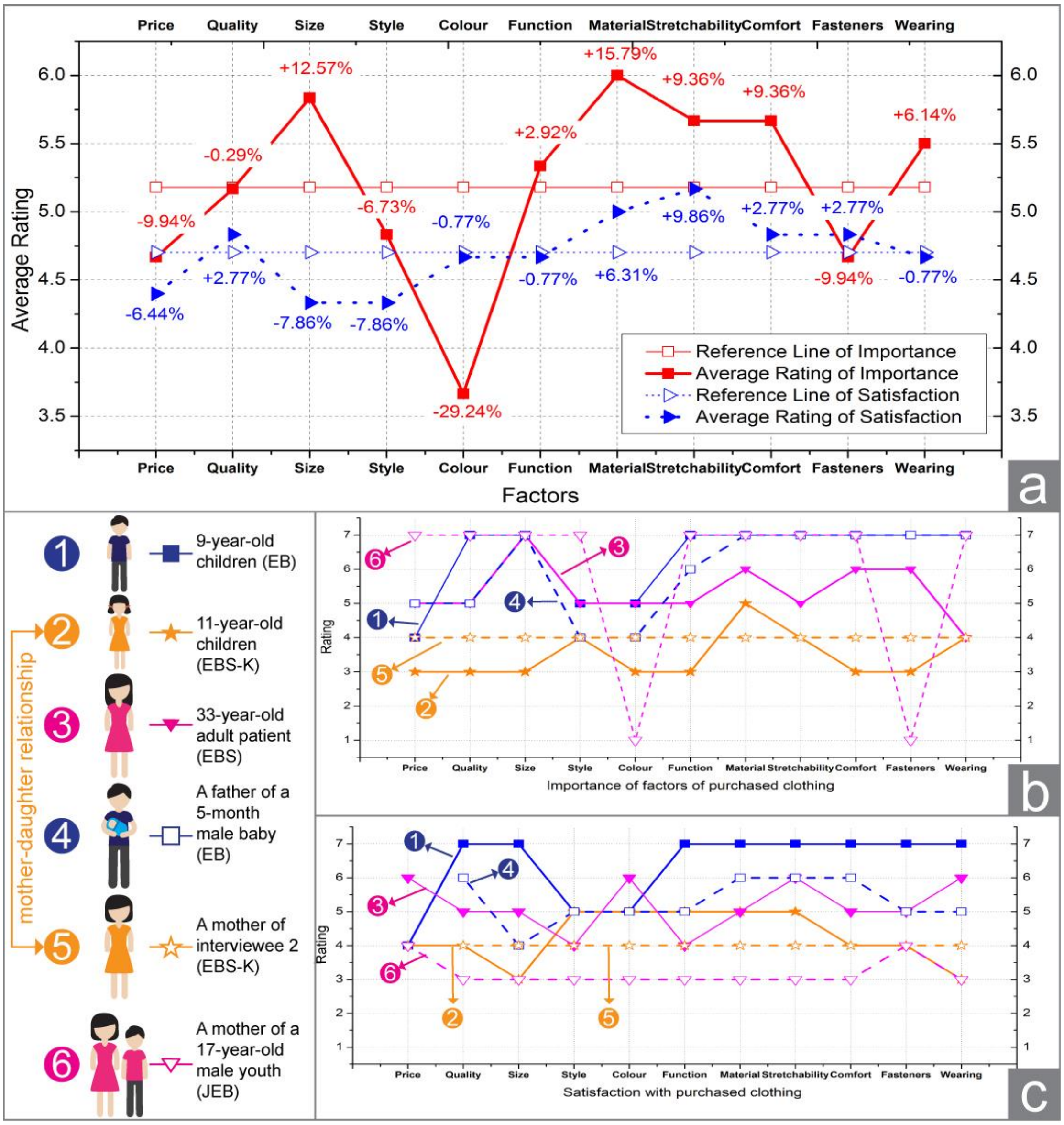


Figure 7.5 Plotting of (a) average rated importance of issues related to clothing; satisfaction of factors of purchased clothing, (b) rating of importance of factors of purchased clothing and (c) satisfaction with purchased clothing. (Author, 2017)

In Figures 7.5b and 7.5c, it can be observed that Participant 6 does not have any preference about the clothing colour and the edging of garments, but is greatly concerned about some of the aspects of clothing that she had already bought, such as price, quality, size, etc. This result is not consistent with the consumption patterns of female consumers in general because colour is a key element that could affect the purchase decision of a normal consumer, but in this case, the mother places no importance on colour. Therefore, the results could subconsciously reflect the concerns of a mother with a child who has EB about the functionality of clothing. From the data that we collected, there is no obvious relationship between the parameters from Participant 5. Participant 4 is very concerned about the features of infant clothing, such as quality, size, functionality, material, comfort, stretchability, type of fastener and method of donning and doffing, but his ratings for colour and style are slightly under the mean, which indicates that he is more concerned about the functionality of clothing than colour and style, and requires infant clothing to be functional. The response of Participant 1 reflected the needs of a normal child, as he has least concerned about the price of clothing nor does he mind the style and colour. Participant 2 provided slightly higher ratings for style, material, and method of donning, which shows that she is also very concerned about the functionality of clothing. Participant 3 provided higher ratings for size, material, comfort, and type of fastener, which indicate that she is very concerned about the functionality of clothing and has a need for clothing to be functional.

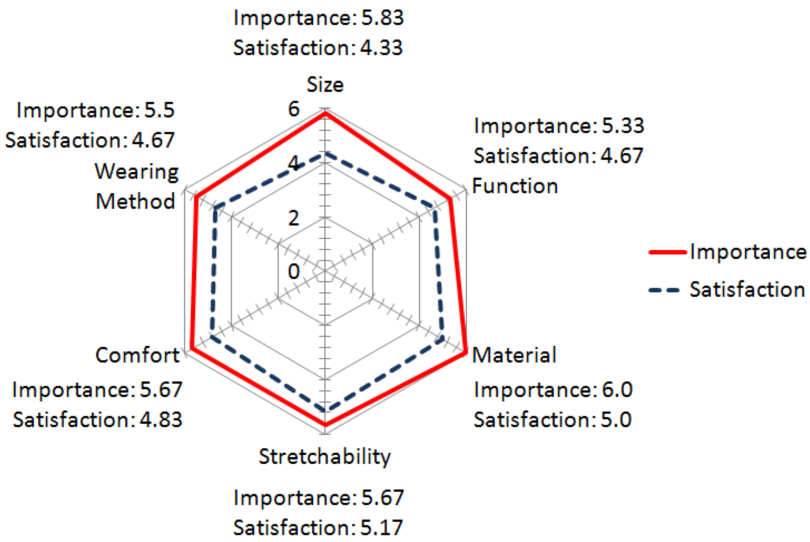


Figure 7.6 Rating of importance of six factors that affect clothing purchase and satisfaction with purchased clothing. (Author, 2017)

Overall, the patients and the caregivers of the children patients are very concerned about size and material of clothing. They are also concerned about the stretchability, comfort, function, and method of donning and doffing (Figure 7.6). Therefore, it is obvious that there is the need to reduce friction between the skin and clothing surface for EB patients. However, the friction between skin and clothing is more concerning as this could contribute to the formation of blisters, so materials that offer sufficient stretchability and cause less friction between two layers would be appreciated. The method of donning and doffing and size of clothing are two factors that were considered important because they could affect the wear comfort.

7.4.2 Proposed garment detailing for comfort and aesthetics

The average ratings given to comfort and clothing aesthetics by the 6 participants are presented in Figure 7.8a. The garment detailing include the design of the collar and shoulders, seam design, edge finishing, and type of fastener (Figure 7.7) which are used as the variables. The reference line was calculated by adding together the average ratings of comfort and aesthetics which were first determined separately (Figures 7.8b and 7.8c). The fluctuations (differences) were then plotted in comparison with the reference line.

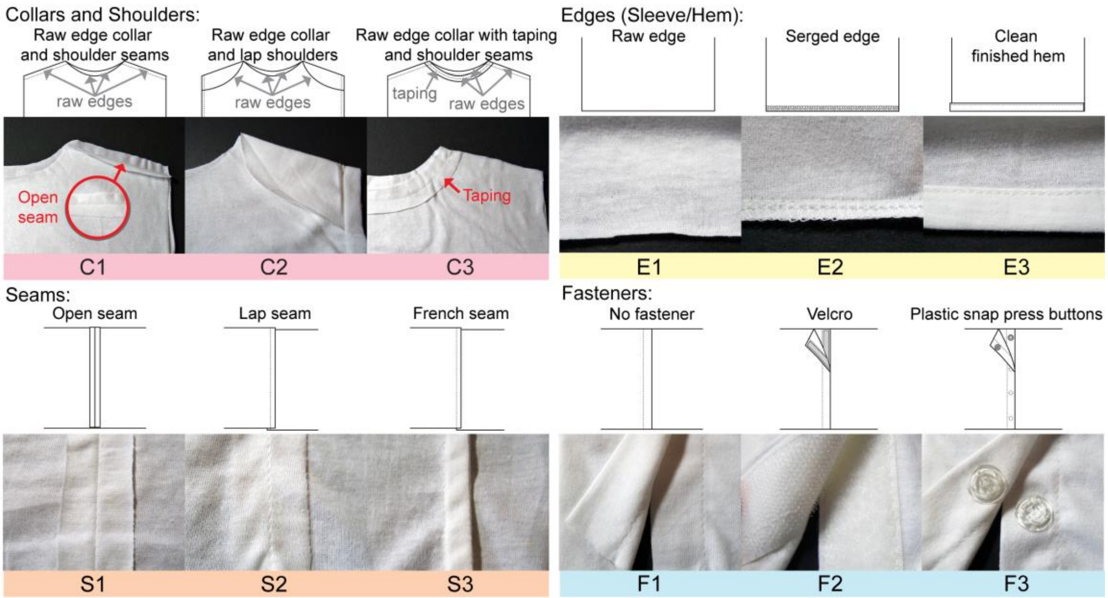


Figure 7.7 Diagram and photos of clothing details. (Author, 2017)

Figure 7.8a shows that the participants gave three types of garment details the lowest rating, including S3 or French seams (-16.14%), F2 or velcro (-24.52%) and F3 or plastic snap press buttons (-24.52%). French seams, Velcro and plastic snap press buttons might induce higher friction on the body of the patients, and may lead to painful blister formation. In this case, they gave higher ratings to E1 or raw edge (+17.41%), and F1 or no fastener (+22.3%). In terms of the seam design, the respondents indicated that they prefer S1 or open seams (+4.83%) and S2 or lap seams (+4.83%).

According to Figure 7.8b, Participant 6 gave high ratings for comfort to most of the clothing details, except for Velcro and plastic snap press buttons as clothing fasteners. She explained that Velcro and snap press button on clothing are not a good choice for her son because they put pressure onto his body. Participant 4 preferred C2 or raw edge collar and lap shoulder seams, S2 or a lap seam, E1 or a raw edge and F1 or no fastener. Participant 3 similarly gave higher ratings to C2, S2 (lap seam), E1 and F1 for comfort, and C2, S3 (French seams) and E1 for aesthetics. Aesthetically pleasing clothing are important to consumers, but from the data acquired, comfort from garment detailing is a greater concern for EB patients (Figures 7.8b and 7.8c).

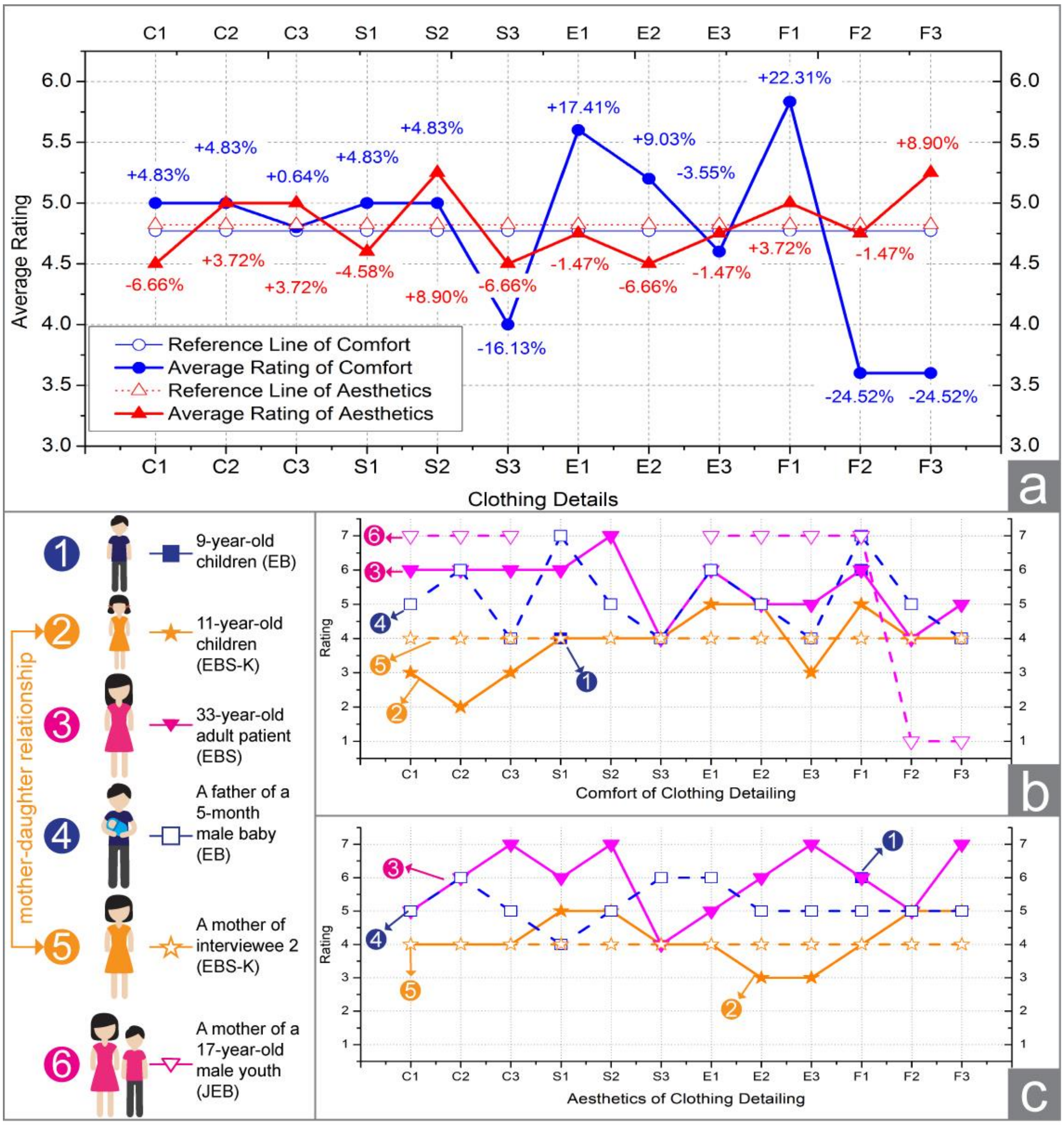


Figure 7.8 (a) Average rating of comfort and aesthetics of clothing detailing. (b) Rating of comfort of clothing detailing. (c) Rating of aesthetics of clothing detailing. (Author, 2017)

There is no doubt that the participants are concerned about the aesthetics of their clothing. However, they also understand that they face restrictions in choosing clothing because of their skin ailment. Some clothing detailing will provide a better appearance, but may increase the chances of skin-to-fabric friction and cause discomfort during wear at the same time, such as F3 or plastic snap press buttons (comfort: -24.52%; aesthetics: +8.90%). Nevertheless, based on the data obtained, there are some compromise between comfort and aesthetics, such as C2 or raw edge collar and shoulder seams, S2 or lap seam, E1 or raw edge and F1 or no fastener (Figure 7.9).

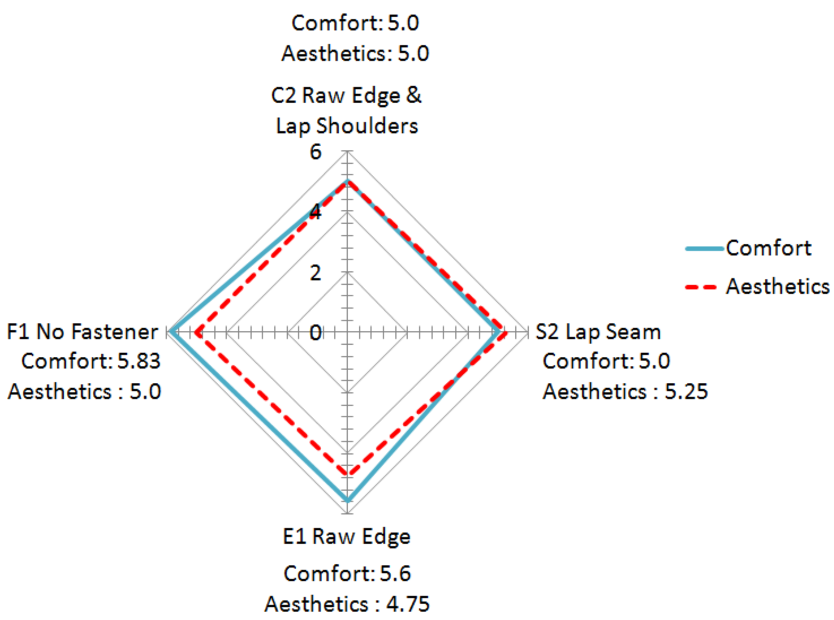


Figure 7.9 Rating of comfort and aesthetics of clothing detailing with raw edge collar and shoulder seams, lap seams, raw edges and no fasteners. (Author, 2017)

7.4.3 Functions of garments for EB patients

Participants 4 and 6 believed protection of the skin of EB patients can be possible through the use of clothing (Figure 7.10a), while Participants 1 and 3 felt that it is somewhat possible, and Participants 2 and 5 neither agreed nor disagreed. In Figure 7.10b, it is obvious that all of the participants agree on the importance of 5 different functions of clothing for EB patients, including providing antibacterial property, moistening and deodorising, promoting healing process, assisting immunity and protecting by adsorption. Besides, they indicated that they are more likely to purchase clothing with these functions (Figure 7.10b). Four out of the 6 participants indicated that these functions are extremely important and are very likely to purchase clothing with such functions. The other 2 may not have truly understood the functions and do not agree that they are important (Figures 7.10c and 7.10d). With regard to the response of Participants 2 and 5 (daughter and mother) to the clothing functions, they both gave a rating slightly under the average rating of the rest of the participants, which could be explained by a negative psychological tendency.

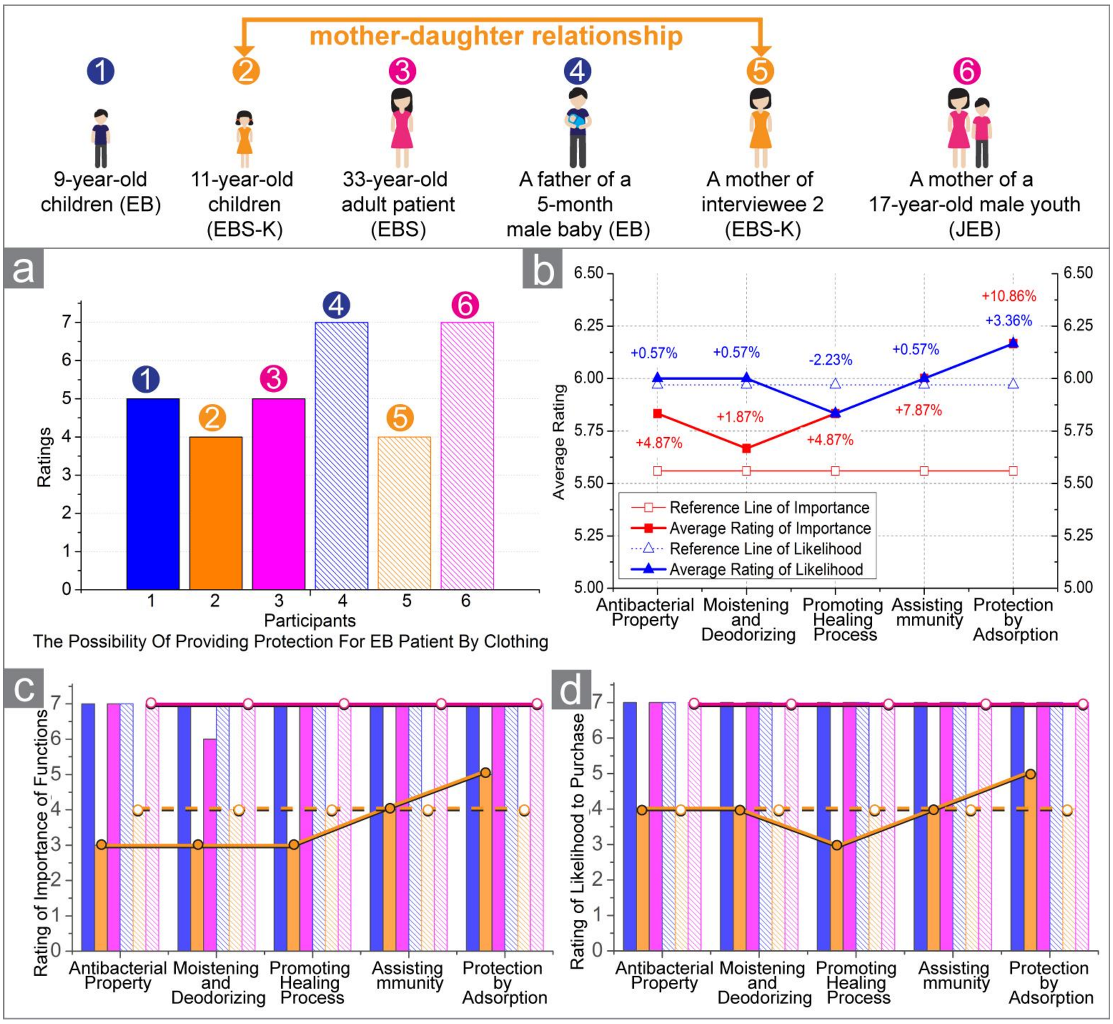


Figure 7.10 (a) Rating of possibility of using clothing protect EB patient skin. (b) Average rating of importance of different functions of clothing for EB patients and

likelihood of purchasing clothing with said functions. (c) Rating of importance of different functions of clothing for EB patients. (d) Rating of likelihood to purchase clothing with said functions (Author, 2017)

From the interviews, it can be found that there is a significant demand for clothing features that would help the conditions and symptoms of EB, such as the right type of material and style. In terms of the expressive considerations of clothing, we found that the normal consumer theory (clothing value added) could also be applied to these patients. The desire for functional clothing that would help EB patients is greatly reflected in the responses of the interviewees.

7.5 Discussion

7.5.1 Materials used in clothing for EB patients

In terms of materials, Participant 3 indicated her preference for natural fibers which is directly related to wear comfort. The three EB patients, Participants 1, 2 and 3, felt that the fabric for clothing could either protect or injure. This is because the fabric could stick to their wound(s), which causes secondary abrasion, and is painful both emotionally and physically. Most put their wound dressing on at home and use soft fabric, since rough fabric can easily scratch their skin. Breathable fabric that will not stick to their skin and wounds are preferred. Therefore, their quality of life could be improved through the use of apparel technology, such as cooling fabric that allows rapid drying of perspiration and provides deodorising effects. Ease of washing is also preferred since it is difficult to wash out blood stains after a period of time.

7.5.2 Garment detailing and design for EB patients

The participants expressed their special requirements in terms of the clothing detailing. They prefer long-sleeved tops and long pants to cover their wound scars and protect their skin; primarily covering the hands and arms, legs and feet, chest, abdomen and back. Garments should not have buttons and zippers as the opening and on the collar. A loose cut is preferred. Seamless elastic tubular compression bandages (probably because tape will cause secondary abrasion) are also preferred for wound dressing. An aesthetically pleasing design that combines clothing and tubular bandages (since the bandage cannot be worn alone and after a skin injury, the use of wound dressings, tubular bandages and then outer clothing result in increased amount of thermal heat which is unpleasant) is favoured, so that the patients can address their skin ailment with only one item. There were requests for sweat shirts and men's underwear for EB patients.

7.5.3 Special wound dressings for EB patients

Participants 4, 5 and 6 indicated that traditional bandages cannot meet the requirements of EB patients for wound dressings, and they use seamless elastic tubular compression bandages for better coverage. In this study, the parents of the children with EB mainly used stockings and wrapped them with gauze on the four limbs of their child, but this is inconvenient for everyone.

7.5.4 Subjective and aesthetic concerns of garments for EB patients

Without a doubt, the patients and their family members have repeatedly stressed that the importance that clothing can address their needs and symptoms. The most vulnerable parts of the body to injury are the limbs and back. They also repeatedly stressed that long-sleeved tops and long pants that could cover and protect their body parts at the same time are important. In terms of garment appearance, cartoons and fun graphics will fulfil the aesthetics expectations of children patients. The feedback from these patients and their parents therefore reflect the need for functionality yet also aesthetics in apparel for EB patients.

7.6 Conclusion

This is the first study that has obtained an in-depth understanding of EB patients and their parents on their needs in functional apparel, with expressive and aesthetic considerations. In the interview with EB patients and their parents, they prefer long-sleeved tops and long pants to cover the body parts and protect the skin of EB patients, while fabric with cooling and deodorising effects improve on both parents and patients' quality of life by the use of apparel technology. They use compression bandages for better coverage of EB patients wound. Children patients prefer cartoons and fun graphics which fulfil their aesthetics expectations. The feedback from these patients and their parents therefore reflect the need for functionality yet also aesthetics in apparel for EB patients.

The results of this study contribute to skin disease patients by providing information towards a more suitable apparel system that would reduce their physical and psychological pain in daily life, so as to enhance their quality of life. The proposed prototypes in this study for an appropriate apparel system do not only apply to EB patients, but also to other patients with skin diseases who need to improve wound healing and require greater skin protection, such as burn victims or patients with pressure ulcers. Technological advancements in materials studies promote developments in the medical industry and thus human welfare. As for textile technology, improvements in materials and mechanical technologies innovate product variety which benefit human beings. From the perspective of functional apparel design, the results in this study better show the current situation of EB patients and their parents as well as their needs, by analysing the potential problems and providing details that could contribute to future apparel based materials development and research in the medical field. This is also interdisciplinary research work in the hopes of reducing human pain and suffering.

Chapter 8

Conclusion and Suggestions for Future Research

8.1 Introduction

In this research work, the aim is to develop a functional apparel system for EB patients by systematically producing chitosan-based fibres through yarn spinning and fabric knitting. The objectives are to meet the goals of this research, including: (1) studying the characteristics and symptoms of EB to understand the special wound care needs and existing medical garments for EB patients; (2) studying the functionality and applications of chitosan materials, and the fibre migration theory; (3) establishing a functional apparel design framework to facilitate the development of a functional garment prototype which meets the needs of EB patients; (4) developing chitosan/cotton blend yarn prototypes and examining their mechanical properties through a series of assessments; (5) developing a functional apparel system for EB patients by applying the developed chitosan/cotton blend yarn; (6) evaluating the apparel system with EB patients and their parents to determine if the system addresses their functional and aesthetic needs in garments.

8.2 Conclusion

The relationships among the length, strength, and elongation of the chitosan fibres and fibre migration behaviours have been studied by producing yarn samples of four different fibre lengths of chitosan blended with cotton at a blended ratio of 50:50 with a ring spinning system. It is found that the yarn tenacity deteriorates with increases in the length of the chitosan fibre. Chitosan fibres that are shorter in length (22 mm) or excessively long (46 mm) will bring about difficulties in yarn spinning. Chitosan fibres that are 30 and 38 mm in length are compatible for blending with long cotton fibres. The results contribute to the selection of a yarn sample for developing a textile for the functional apparel system.

Furthermore, this study has determined the role of chitosan based yarn in providing comfort to EB patients that scientifically demonstrates the correlation between textile comfort and medical treatment by investigating five different blend ratios, and establishing a relationship between percentage composition and comfort to facilitate further investigations in medical textiles both theoretically and practically. The results of fabric touch test show that chitosan fibers added to fabric has a good impact on handle and all of the physical properties of plain jersey fabric. With an increase in the blend ratio of chitosan fibers (50% or more), the rigidity of the fabric is reduced, and the inner surface has a softer handle.

The functional apparel system developed in this study combines functional, expressive and aesthetic considerations to provide antibacterial properties and enhance the rate of wound healing with chitosan/cotton blend yarn. In-depth research work has been carried out with a functional apparel design framework to examine the use of chitosan/cotton yarn and textile to meet the needs and concerns of the end users (EB patients). In the interview with EB patients and their parents, they prefer long-sleeved tops and long pants to cover the body parts and protect the skin of EB patients, while fabric with cooling and deodorising effects improve on both parents and patients' quality of life by the use of apparel technology. They use compression bandages for better coverage of EB patients wound. Children patients prefer cartoons and fun graphics which fulfil their aesthetics expectations. The feedback from these patients and their parents therefore reflect the need for functionality yet also aesthetics in apparel for EB patients.

8.3 Contributions

A functional apparel design framework for the application and development of chitosan/cotton yarn and textile is developed based on related apparel design frameworks in previous studies and takes into account functional, expressive and aesthetic considerations. Nine steps are used in the process: (1) identifying the problem; that is, to discover and seek a solution to a problem; (2) generating preliminary ideas; that is, to generate ideas to solve the stated problem; (3) refining the design by eliminating and modifying the previous ideas based on a functional, expressive, and aesthetic (FEA) model; (4) developing prototype of chitosan/cotton yarn to initiate yarn prototyping; (5) evaluation of chitosan/cotton yarn to assess the prototype according to the criteria; (6) prototype development of chitosan/cotton textile; that is, to initiate textile prototyping; (7) evaluating the chitosan/cotton textile; that is, to assess the prototype according to the criteria; (8) developing prototype of functional apparel system made of chitosan/cotton textile to initiate apparel prototype; and (9) evaluating the functional apparel system made of chitosan/cotton textile by interviewing EB patients. This functional apparel design framework has generated new ideas and knowledge for the systematic development of functional apparel, especially for medical garments that take into account the functional, expressive and aesthetic considerations of the end users. This framework could also contribute to educating students on the development of functional apparel for specific medical issues or with newly developed materials combined with the utilization of the FEA model which addresses the actual needs of the end users, by acting as a reference so that they can determine an appropriate solution to a particular problem. The value of the research is particularly reflected by the price-performance ratio of antibacterial functionality and cost control by studying the effects of fibre distribution and the length of the chitosan fibres in the chitosan/cotton blend yarn. The proposed formula in Chapter 5 could serve as guidance for yarn manufacturers and producers in the textile industry in terms of the effects of the length of the chitosan fibres on the fibre distribution in yarn. The relationship between the percentage of the composition of chitosan in plain jersey fabric and its comfort properties is established in Chapter 6. This has facilitated the development of a fabric with a skin-protective function for EB patients to reduce the friction between clothing and their skin. This chitosan based yarn will have great potential in future applications that require a good hand feel and wound healing property.

8.4 Limitations of Study

Although this study has made significant contributions to the development of a functional apparel system with chitosan/cotton to provide wear comfort to EB patients, in terms of the design framework development both theoretically and practically, there are still limitations. There are first, limitations of the sample during the evaluation of functional apparel system, such as the number of participants who were interviewed, their age, gender, area of residence, and skin conditions of the EB patients. The lack of an examination on the textile structure of the chitosan/cotton yarn prototype is another limitation in this study. There are various structures of knitted textiles that can be used for intimate medical garments, but the jersey stitch on the surface could minimize the friction between the skin and fabric of EB patients, and reduce secondary trauma which would result in blistering and pain. The wear comfort properties are exemplified by the smoothness, softness and stiffness of the material used for the apparel.

8.5 Implications for Future Research

In this research, a new apparel design framework for functional medical garments is produced and verified by integrating the apparel design frameworks from previous work and FEA model from Lamb and Kallal (1992) to meet the functional needs of EB patients by applying chitosan/cotton yarn and textile. The significance of the research has been demonstrated by published refereed journal papers and conference presentations that attest to the credibility of the research findings. Therefore, recommended future research should focus on the following.

(1) The management and care of wounds, and garment requirements for different symptoms in EB patients across different regions should be explored through qualitative research with larger number of participants, so as to understand the physical and psychological feelings of EB patients towards existing medical treatment in different countries and their garment needs, which could have greater impacts and provide EB patients with a more advanced functional medical apparel system that enhances wound healing and wear comfort with chitosan/cotton yarn and textile, and allows the reduction of human pain and suffering.

(2) The possibility of blending material with chitosan to enhance yarn properties and functional performances should be examined, such as natural fibres: wool, silk, or hemp; or synthetic fibres: nylon, polyester, or viscose.

(3) The textile prototype should be further investigated with the use of different fabrication techniques to increase product variety, such as fine knitting or weaving. Except for the 14 gauge of jersey fabric used to investigate the relationship between the chitosan blend ratio and comfort, the utilization of different knit gauges with suitable knit stitches, and different weaving

structures could be explored to further examine the effects between wear comfort and fabric structure.

(4) Apparel prototypes for different people and needs should be further explored, such as those that are gender specific or for different ages of patients, including underwear for females and males; designs for children and adults, to study their concerns and needs in functional apparel.

(5) The developed functional apparel system should be further evaluated with extensive wear trials to examine the fabric structure, materials utilization and apparel category.

(6) Fabric properties related to wear comfort such as thermal resistance and moisture management are suggested in order to facilitate to variety functional apparel development.

APPENDICES

Appendix 3.1 Interview and survey questions for EB patients

This survey aims to determine the consumer behaviour of purchasing clothing for EB patients for themselves and their satisfaction with current clothing designs. Based on your shopping and wear trial experiences, please answer the following questions.

此問卷調查旨在研究泡泡龍病友對服裝購買的行為及對其設計的滿意程度的關係。請根據您的購物和樣衣試穿的經驗，回答以下問題。

A. Patient Personal Information & Preferences
泡泡龍病友的個人資料及偏好

1. Name 姓名: ______________________
2. Age 年齡: ______________________
3. Sex 性別: ☐ Male 男 ☐ Female 女
4. Type of EB類型

☐ EBS表淺性單純性大皰性表皮松解症	☐ Hands and feet Weber-Cockayne氏侷限於手腳型 ☐ Anodontia/hypodontia Kallin綜合征 牙發育不全 ☐ Koebner variant Koebner氏 全身型 ☐ Herpetiformis Dowling-Meara氏 皰疹樣水皰性表皮鬆解症 ☐ with or without associated neuromuscular disease單純性水皰性表皮鬆解症併有肌肉失養症 ☐ Superficialis表淺性單純性水皰性表皮鬆解症 ☐ Mottled pigmentation with/without keratoderma單純性水皰性表皮鬆解症併有色素斑點 ☐ Lethal autosomal recessive致死性自體隱性遺傳單純性水皰性表皮鬆解症 ☐ Ogna variant Ogna氏(Gedde-Dahl氏)單純性水皰性表皮鬆解症
☐ JEB 交界性水皰性表皮鬆解症	☐ Gravis Herlitz型(致死性)交界性水皰性表皮鬆解症 ☐ Atrophic benign良性交界性水皰性表皮鬆解症 ☐ Pyloric atresia交界性水皰性表皮鬆解症併有幽門萎縮 ☐Non-Herlitz type臨床表現介於此3種之間，難以界定

☐ DEB 失養性水皰性表皮鬆解症

☐ Mitis隱性遺傳失養性水皰性表皮鬆解症
☐ Albopapuloidea白色丘疹樣水皰性表皮鬆解症
☐ Pruriginosa癢疹性水皰性表皮鬆解症
☐ Pretibial脛骨前失養性水皰性表皮鬆解症
☐ Transient bullous dermolysis短暫性水皰性表皮鬆解症
☐ Cockayne-Touraine氏失養性水皰性表皮鬆解症
☐ Hallopeau-Siemens氏失養性水皰性表皮鬆解症
☐ Autosomal dominant顯性遺傳失養性水皰性表皮鬆解症

5. How would you rate the importance of the following factors that affect your clothing purchase? Please circle a number on the scale below to indicate importance with 1 = Extremely Unimportant and 7 = Extremely Important. 您認為為自己選購服裝的影響因素的重要性是? 請圈出您認為的重要性, 1 =非常不重要; 7 =非常重要.

	Extremely unimportant 非常不重要						Extremely important 非常重要	Don’t know 不知道
Price 價格	1	2	3	4	5	6	7	
Quality 品質	1	2	3	4	5	6	7	
Size 尺碼	1	2	3	4	5	6	7	
Style 樣式	1	2	3	4	5	6	7	
Colour 顏色	1	2	3	4	5	6	7	
Function 功能	1	2	3	4	5	6	7	
Material 材質	1	2	3	4	5	6	7	
Stretchability 彈性	1	2	3	4	5	6	7	
Comfort 舒適度	1	2	3	4	5	6	7	
Type of fasteners 緊固件 (Buttons, etc 鈕扣, 等)	1	2	3	4	5	6	7	
Method of donning and doffing 穿/脫衣方法	1	2	3	4	5	6	7	

6. How would you rate your satisfaction with the purchased clothing for yourself? Please circle a number on the scale below to indicate your satisfaction, with 1 = Extremely Dissatisfied and 7=Extremely Satisfied. 您對於已為自己購買的服裝產品的滿意程度是? 請圈出您認為的滿意程度, 1 =非常不滿意; 7 =非常滿意.

	Extremely dissatisfied	Extremely satisfied	Don’t know

	非常不滿意						非常滿意	不知道
Price 價格	1	2	3	4	5	6	7	
Quality 品質	1	2	3	4	5	6	7	
Size 尺碼	1	2	3	4	5	6	7	
Style 樣式	1	2	3	4	5	6	7	
Colour 顏色	1	2	3	4	5	6	7	
Function 功能	1	2	3	4	5	6	7	
Material 材質	1	2	3	4	5	6	7	
Stretchability 彈性	1	2	3	4	5	6	7	
Comfort 舒適度	1	2	3	4	5	6	7	
Type of fasteners 緊固件 (Buttons, etc 鈕扣, 等)	1	2	3	4	5	6	7	
Method of donning and doffing 穿/脫衣方法	1	2	3	4	5	6	7	

7. What kind of fabric material would you choose when purchasing clothing for yourself? 您平常會為自己選購那種的服裝材質?

---

8. Which part of your body is the most vulnerable? 身體哪一個部分最容易受傷?

---

9. How do you bandage the wound(s) on your body? 你一般是怎樣進行身體傷口的包紮?

---

10. Which part of your body requires special ways of dressing to increase protection? 身體哪一個部分需要特別的包紮方法去加強保護?

---

11. Do you use any other ways to dress your wounds that you have tailored to increase the protection of the dressing? If yes, what kind of fabric/ material did you use? 有沒有一些自創的包紮方法去加強保護? 用什麼布/材料?

☐ Yes有 ☐ No 沒有 Fabric/ Material 布/材料: ________________________________

12. Is the tailored method of dressing your wound effective? 自創的方法有用嗎?

☐ Yes有 ☐ No沒有 ☐ Don’t know不知道

13. What do you usually do if your wound increases in severity? Do you treat it at home by yourself, or seek help from the hospital? 如果傷口情況變更嚴重了, 通常會在家裡處理, 還是到醫院?

☐ Home 家裡 ☐ Hospital 醫院

14. Do you want to enhance the protection of the vulnerable parts of your body with garments? 希望利用衣服去加強保護容易受傷的身體部分嗎?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

15. Is there the possibility that the fabric of your clothing comes into contact with your skin? 衣服的面料會有任何可能與皮膚接觸？

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

16. Does the fabric of your clothing/clothing of the EB patient stick to your skin? 衣服布料有沒有貼住了病友的傷口?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

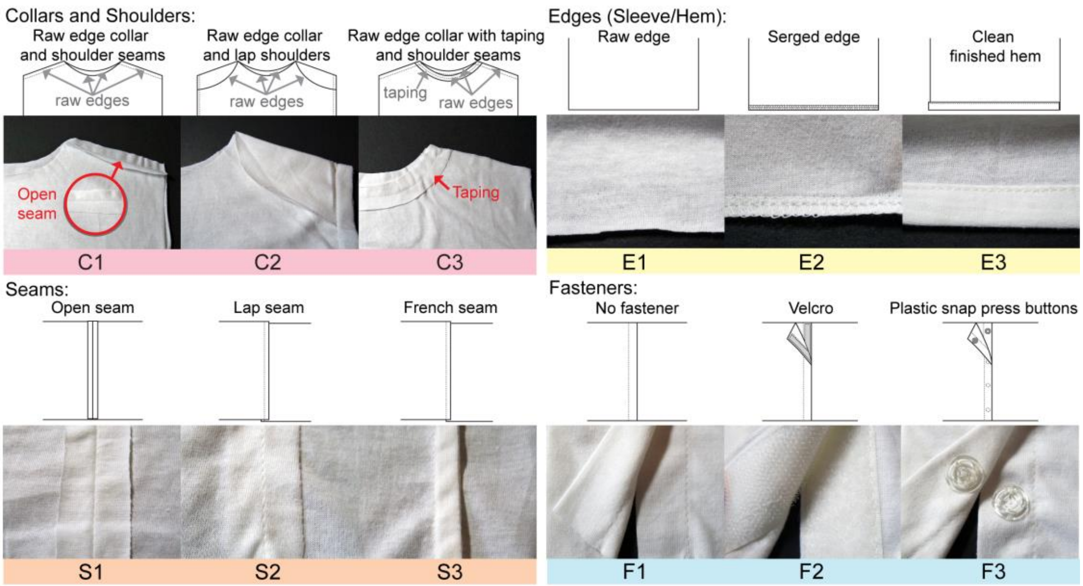
17. Do you need to remove all of the brand / care information labels on the garment or collar before the clothing item is worn? 穿著之前, 會否自行拆下頸後/領子上的品牌/洗滌標籤?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

18. Do you need to turn the clothing inside out before wearing? 穿著之前, 會否需要把衣服反過來才可以穿著?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

19. How would you rate the comfort of the following clothing detailing? Please circle a number on the scale below to indicate comfort, with 1 = Extremely Uncomfortable and 7= Extremely Comfortable. 您認為以下的服裝細節有多舒適? 請圈出您認為的舒適程度, , 1 =非常不舒適; 7 =非常舒適.



	Extremely Uncomfortable 非常不舒適						Extremely Comfortable 非常舒適	Don’t know 不知道
Collar 領子								
(C1) Raw Edge 原邊	1	2	3	4	5	6	7	
(C2) Raw edge collar & lap Shoulders 肩膀重疊式	1	2	3	4	5	6	7	
(C3) Taping 縫上帶子	1	2	3	4	5	6	7	
Seam 接縫								
(S1) General Seam 合縫	1	2	3	4	5	6	7	
(S2) Lap Seam 搭接縫	1	2	3	4	5	6	7	
(S3) French Seam 來回縫	1	2	3	4	5	6	7	
Edges/Hem 邊緣/底邊								
(E1) Raw Edge 原邊	1	2	3	4	5	6	7	
(E2) Serged 包邊	1	2	3	4	5	6	7	
(E3) Clean Finish Hem 原身包邊	1	2	3	4	5	6	7	
Type of Fastener 緊固件								
(F1) No Fasteners 沒有緊固件	1	2	3	4	5	6	7	
(F2) Velcro 黏扣帶	1	2	3	4	5	6	7	
(F3) Plastic Snap Press Button 塑膠按扣	1	2	3	4	5	6	7	

20. How would you rate the aesthetics of the following clothing detailing? Please circle a number on the scale below to indicate the aesthetics, with 1 = Extremely Unaesthetically Pleasing and 7 = Extremely Aesthetically Pleasing. 您認為以下的服裝細節的美觀度是? 請圈出您認為的美觀程度, 1=非常不美觀; 7 =非常美觀.

	Extremely Unaesthetically Pleasing 非常不美觀						Extremely Aesthetically Pleasing 非常美觀	Don’t know 不知道
Collar 領子								
(C1) Raw Edge 原邊	1	2	3	4	5	6	7	
(C2) Raw edge collar & lap Shoulders	1	2	3	4	5	6	7	

肩膀重疊式								
(C3) Taping 縫上帶子	1	2	3	4	5	6	7	
Seam 接縫								
(S1) General Seam 合縫	1	2	3	4	5	6	7	
(S2) Lap Seam 搭接縫	1	2	3	4	5	6	7	
(S3) French Seam 來回縫	1	2	3	4	5	6	7	
Edges/Hem 邊緣/底邊								
(E1) Raw Edge 原邊	1	2	3	4	5	6	7	
(E2) Serged 包邊	1	2	3	4	5	6	7	
(E3) Clean Finish Hem 原身包邊	1	2	3	4	5	6	7	
Type of Fastener 緊固件								
(F1) No Fasteners 沒有緊固件	1	2	3	4	5	6	7	
(F2) Velcro 黏扣帶	1	2	3	4	5	6	7	
(F3) Plastic Snap Press Button 塑膠按扣	1	2	3	4	5	6	7	

21. **How would you rate the possibility that clothing can provide protection to EB patients? Please circle a number on the scale below to indicate the possibility, with with 1 = Extremely Unlikely and 7 – Extremely Likely. 您認為衣服有多大可能會為泡泡龍病友提供保護作用? 請圈出您認為的可能性， 1=非常不可能; 7 =非常可能.**

Extremely unlikely 非常不太可能					Extremely likely 非常可能		Don't know 不知道
1	2	3	4	5	6	7	

22. **How would you rate the importance of the following functions for clothing for EB patients? Please circle a number on the scale below to indicate the importance, with 1 = Extremely Unimportant and 7 - Extremely Important. 您認為具備以下功能的泡泡龍病友服裝有多重要? 請圈出您認為的重要性， 1=非常不重要; 7 =非常重要.**

	Extremely unimportant 非常不重要				Extremely important 非常重要			Don't know 不知道
Antibacterial Property 抑菌性能	1	2	3	4	5	6	7	

Moistening and Deodorizing 保濕防臭	1	2	3	4	5	6	7	
Promoting Healing Process 促進再生	1	2	3	4	5	6	7	
Assisting Immunity 強化免疫	1	2	3	4	5	6	7	
Protection by Adsorption 吸附防護	1	2	3	4	5	6	7	

23. How likely are you to purchase clothing for yourself or an EB patient with the following functions? Please circle a number on the scale below to indicate your likelihood, with 1 = Extremely Unlikely and 7 – Extremely Likely. 您有多大可能會選購具備以下功能的泡泡龍病友服裝? 請圈出您認為的可能性, 1=非常不可能; 7 =非常可能.

	Extremely unlikely 非常不太可能						Extremely likely 非常可能	Don't know 不知道
Antibacterial Property 抑菌性能	1	2	3	4	5	6	7	
Moistening and Deodorizing 保濕防臭	1	2	3	4	5	6	7	
Promoting Healing Process 促進再生	1	2	3	4	5	6	7	
Assisting Immunity 強化免疫	1	2	3	4	5	6	7	
Protection by Adsorption 吸附防護	1	2	3	4	5	6	7	

24. Please provide other comments. 請提出其他的意見.

Appendix 3.2 Interview and survey questions for children with Epidermolysis Bullosa and their parents (caregiver)

This survey aims to determine the consumer behaviour of purchasing clothing for EB patients by their primary caregiver and their satisfaction with the current clothing designs. Based on your shopping and patient wear trial experiences, please answer the following questions.

此問卷調查旨在研究主要照顧者對為泡泡龍病友的服裝購買的行為及對其設計的滿意程度的關係。請根據您的購物和病友樣衣試穿經驗，回答以下問題。

B. Primary Caregiver and Patient Personal Information & Preferences
主要照顧者及泡泡龍病友的個人資料及偏好

1. Name 姓名: ______________________________
2. Age 年齡: ______________________________
3. Sex 性別: ☐ Male 男 ☐ Female 女
4. Relationship with patient與病友關係 ☐ Father 父親 ☐ Mother 母親

   ☐ Other, please specify 其他，請注明 ______________________________
5. Patient's Name 病友姓名: ______________________________
6. Patient's Age 病友年齡: ______________________________
7. Patient's Sex 病友性別: ☐ Male 男 ☐ Female 女
8. Type of EB類型

☐ EBS表淺性單純性大皰性表皮松解症	☐ Hands and feet Weber-Cockayne氏侷限於手腳型 ☐ Anodontia/hypodontia Kallin綜合征 牙發育不全 ☐ Koebner variant Koebner氏 全身型 ☐ Herpetiformis Dowling-Meara氏 皰疹樣水皰性表皮鬆解症 ☐ with or without associated neuromuscular disease單純性水皰性表皮鬆解症併有肌肉失養症 ☐ Superficialis表淺性單純性水皰性表皮鬆解症 ☐ Mottled pigmentation with/without keratoderma單純性水皰性表皮鬆解症併有色素斑點 ☐ Lethal autosomal recessive致死性自體隱性遺傳單純性水皰性表皮鬆解症 ☐ Ogna variant Ogna氏(Gedde-Dahl氏)單純性水皰性表皮鬆解症
☐ JEB 交界性水皰性表皮鬆解症	☐ Gravis Herlitz型(致死性)交界性水皰性表皮鬆解症 ☐ Atrophic benign良性交界性水皰性表皮鬆解症 ☐ Pyloric atresia交界性水皰性表皮鬆解症併有幽門萎縮 ☐Non-Herlitz type臨床表現介於此3種之間，難以界定
☐ DEB 失養性水皰性表皮鬆解症	☐ Mitis隱性遺傳失養性水皰性表皮鬆解症 ☐ Albopapuloidea白色丘疹樣水皰性表皮鬆解症 ☐ Pruriginosa癢疹性水皰性表皮鬆解症 ☐ Pretibial脛骨前失養性水皰性表皮鬆解症 ☐ Transient bullous dermolysis短暫性水皰性表皮鬆解症 ☐ Cockayne-Touraine氏失養性水皰性表皮鬆解症 ☐ Hallopeau-Siemens氏失養性水皰性表皮鬆解症 ☐ Autosomal dominant顯性遺傳失養性水皰性表皮鬆解症

9. How would you rate the importance of the following factors that affect clothing purchase for EB patient? Please circle a number on the scale below to indicate importance with 1 = Extremely Unimportant and 7 = Extremely Important. 您認為選購泡泡龍病友服裝的影響因素的重要性是? 請圈出您認為的重要性, 1 =非常不重要; 7 =非常重要.

	Extremely unimportant 非常不重要						Extremely important 非常重要	Don’t know 不知道
Price 價格	1	2	3	4	5	6	7	
Quality 品質	1	2	3	4	5	6	7	
Size 尺碼	1	2	3	4	5	6	7	
Style 樣式	1	2	3	4	5	6	7	
Colour 顏色	1	2	3	4	5	6	7	
Function 功能	1	2	3	4	5	6	7	

Material 材質	1	2	3	4	5	6	7	
Stretchability 彈性	1	2	3	4	5	6	7	
Comfort 舒適度	1	2	3	4	5	6	7	
Type of fasteners 緊固件 (Buttons, etc 鈕扣, 等)	1	2	3	4	5	6	7	
Method of donning and doffing 穿/脫衣方法	1	2	3	4	5	6	7	

10. How would you rate your satisfaction with the purchased clothing for the EB patient? Please circle a number on the scale below to indicate your satisfaction, with 1 = Extremely Dissatisfied and 7=Extremely Satisfied. 您對於已購買的泡泡龍病友服裝產品的滿意程度是? 請圈出您認為的滿意程度, 1 =非常不滿意; 7 =非常滿意.

	Extremely dissatisfied 非常不滿意						Extremely satisfied 非常滿意	Don't know 不知道
Price 價格	1	2	3	4	5	6	7	
Quality 品質	1	2	3	4	5	6	7	
Size 尺碼	1	2	3	4	5	6	7	
Style 樣式	1	2	3	4	5	6	7	
Colour 顏色	1	2	3	4	5	6	7	
Function 功能	1	2	3	4	5	6	7	
Material 材質	1	2	3	4	5	6	7	
Stretchability 彈性	1	2	3	4	5	6	7	
Comfort 舒適度	1	2	3	4	5	6	7	
Type of fasteners 緊固件 (Buttons, etc 鈕扣, 等)	1	2	3	4	5	6	7	
Method of donning and doffing 穿/脫衣方法	1	2	3	4	5	6	7	

11. What kind of fabric material would you choose when purchasing clothing for the EB patient? 您平常會為病友選購那種的服裝材質?

12. Which part of the patient's body is the most vulnerable? 病友身體哪一個部分最容易受傷?

13. How do you bandage the wound(s) on the patient's body? 一般是怎樣為病友進行身體傷口的包紮?

---

14. Which part of the patient's body requires special ways of dressing to increase protection? 病友身體哪一個部分需要特別的包紮方法去加強保護?

---

15. Do you use any other ways to dress wounds of the EB patient that you have tailored to increase the protection of the dressing? If yes, what kind of fabric/ material did you use? 有沒有一些自創的包紮方法去加強保護? 用什麼布/材料?

☐ Yes有 ☐ No 沒有 Fabric/ Material 布/材料: ________________________________

16. Is the tailored method of dressing wound of the EB patient effective? 自創的方法有用嗎?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

17. What do you usually do if the EB patient's wound increases in severity? Do you treat it at home by yourself, or seek help from the hospital? 如果病友的傷口情況變更嚴重了, 通常會在家裡處理, 還是到醫院?

☐ Home 家裡 ☐ Hospital 醫院

18. Do you want to enhance the protection of the vulnerable parts of EB patient's body with garments? 希望利用衣服去加強保護病友容易受傷的身體部分嗎?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

19. Is there the possibility that the fabric of EB patient clothing comes into contact with his/her skin? 衣服的面料會有任何可能與病友的皮膚接觸？

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

20. Does the fabric of your clothing/clothing of the EB patient stick to EB patient's skin? 衣服布料有沒有貼住了病友的傷口?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

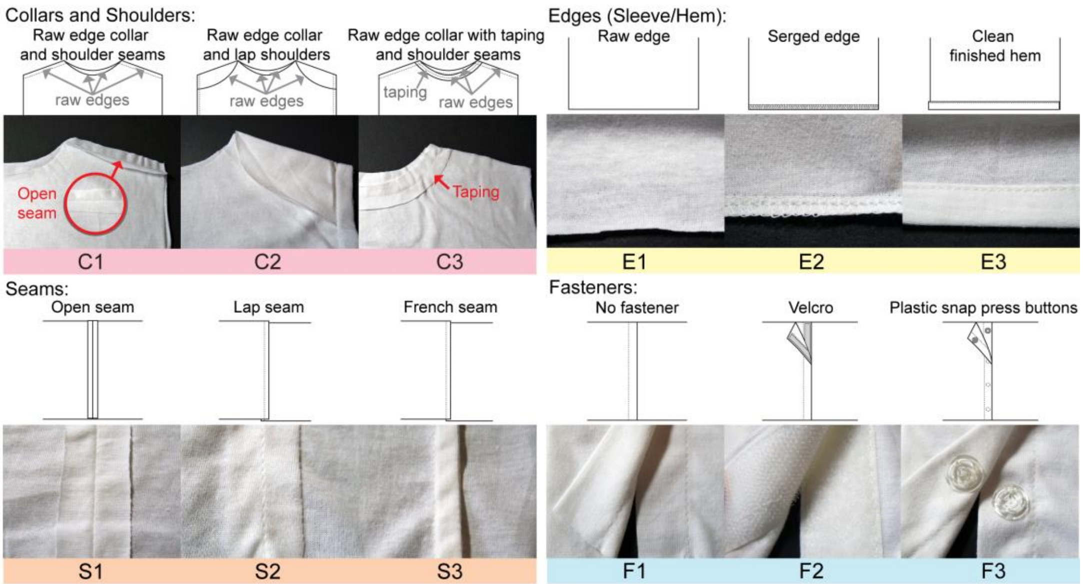
21. Do you need to remove all of the brand / care information labels on the garment or collar before the clothing item is worn? 病友穿著之前, 會否自行拆下頸後/領子上的品牌/洗滌標籤?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

22. Do you need to turn the clothing inside out before wearing for the EB patient? 在病友穿著之前, 會否需要把衣服反過來才可以穿著?

☐ Yes有 ☐ No沒有 ☐ Don't know不知道

23. How would you rate the comfort of the following clothing detailing for the EB patient? Please circle a number on the scale below to indicate comfort, with 1 = Extremely Uncomfortable and 7= Extremely Comfortable. 您認為以下的服裝細節有多舒適? 請圈出您認為的舒適程度, , 1 =非常不舒適; 7 =非常舒適.



	Extremely Uncomfortable 非常不舒適						Extremely Comfortable 非常舒適	Don't know 不知道
				Collar 領子				
(C1) Raw Edge 原邊	1	2	3	4	5	6	7	
(C2) Raw edge collar & lap Shoulders 肩膀重疊式	1	2	3	4	5	6	7	
(C3) Taping 縫上帶子	1	2	3	4	5	6	7	
				Seam 接縫				
(S1) General Seam 合縫	1	2	3	4	5	6	7	
(S2) Lap Seam 搭接縫	1	2	3	4	5	6	7	
(S3) French Seam 來回縫	1	2	3	4	5	6	7	
				Edges/Hem 邊緣/底邊				
(E1) Raw Edge 原邊	1	2	3	4	5	6	7	
(E2) Serged 包邊	1	2	3	4	5	6	7	
(E3) Clean Finish Hem 原身包邊	1	2	3	4	5	6	7	
				Type of Fastener 緊固件				
(F1) No Fasteners 沒有緊固件	1	2	3	4	5	6	7	
(F2) Velcro 黏扣帶	1	2	3	4	5	6	7	
(F3) Plastic Snap Press Button 塑膠按扣	1	2	3	4	5	6	7	

24. How would you rate the aesthetics of the following clothing detailing for the EB patient? Please circle a number on the scale below to indicate the aesthetics, with 1 = Extremely Unaesthetically Pleasing and 7 = Extremely Aesthetically Pleasing. 您認為以下的服裝細節的美觀度是? 請圈出您認為的美觀程度, 1=非常不美觀; 7 =非常美觀.

	Extremely Unaesthetically Pleasing 非常不美觀						Extremely Aesthetically Pleasing 非常美觀	Don't know 不知道
Collar 領子								
(C1) Raw Edge 原邊	1	2	3	4	5	6	7	
(C2) Raw edge collar & lap Shoulders 肩膀重疊式	1	2	3	4	5	6	7	
(C3) Taping 縫上帶子	1	2	3	4	5	6	7	
Seam 接縫								
(S1) General Seam 合縫	1	2	3	4	5	6	7	
(S2) Lap Seam 搭接縫	1	2	3	4	5	6	7	
(S3) French Seam 來回縫	1	2	3	4	5	6	7	
Edges/Hem 邊緣/底邊								
(E1) Raw Edge 原邊	1	2	3	4	5	6	7	
(E2) Serged 包邊	1	2	3	4	5	6	7	
(E3) Clean Finish Hem 原身包邊	1	2	3	4	5	6	7	
Type of Fastener 緊固件								
(F1) No Fasteners 沒有緊固件	1	2	3	4	5	6	7	
(F2) Velcro 黏扣帶	1	2	3	4	5	6	7	
(F3) Plastic Snap Press Button 塑膠按扣	1	2	3	4	5	6	7	

25. How would you rate the possibility that clothing can provide protection to EB patients? Please circle a number on the scale below to indicate the possibility, with with 1 = Extremely Unlikely and 7 – Extremely Likely. 您認為衣服有多大可能會為泡泡龍病友提供保護作用? 請圈出您認為的可能性, 1=非常不可能; 7 =非常可能.

Extremely unlikely 非常不太可能					Extremely likely 非常可能		Don’t know 不知道
1	2	3	4	5	6	7	

26. How would you rate the importance of the following functions for clothing for EB patients? Please circle a number on the scale below to indicate the importance, with 1 = Extremely Unimportant and 7 - Extremely Important. 您認為具備以下功能的泡泡龍病友服裝有多重要? 請圈出您認為的重要性， 1=非常不重要; 7 =非常重要.

	Extremely unimportant 非常不重要					Extremely important 非常重要		Don’t know 不知道
Antibacterial Property 抑菌性能	1	2	3	4	5	6	7	
Moistening and Deodorizing 保濕防臭	1	2	3	4	5	6	7	
Promoting Healing Process 促進再生	1	2	3	4	5	6	7	
Assisting Immunity 強化免疫	1	2	3	4	5	6	7	
Protection by Adsorption 吸附防護	1	2	3	4	5	6	7	

27. How likely are you to purchase clothing for yourself or an EB patient with the following functions? Please circle a number on the scale below to indicate your likelihood, with 1 = Extremely Unlikely and 7 – Extremely Likely. 您有多大可能會選購具備以下功能的泡泡龍病友服裝? 請圈出您認為的可能性， 1=非常不可能; 7 =非常可能.

	Extremely unlikely 非常不太可能					Extremely likely 非常可能		Don’t know 不知道
Antibacterial Property 抑菌性能	1	2	3	4	5	6	7	
Moistening and Deodorizing 保濕防臭	1	2	3	4	5	6	7	
Promoting Healing Process 促進再生	1	2	3	4	5	6	7	
Assisting Immunity 強化免疫	1	2	3	4	5	6	7	
Protection by Adsorption 吸附防護	1	2	3	4	5	6	7	

28. Please provide other comments. 請提出其他的意見.

Appendix 7.1 Antibacterial Activity Test Report of 10% chitosan 90% cotton jersey fabric

Intertek

Valued Quality. Delivered.

Hong Kong Government Recognized Service Supplier
Approved Laboratory of The Woolmark Company

Members of :
American National Standards Institute
American Society for Testing and Materials
British Standards Institute
Hong Kong Association for Testing, Inspection and Certification Limited
Hong Kong Toys Council

Test Report Number: HKGH01657756

Applicant: THE HONG KONG POLYTECHNIC UNIVERSITY
QT715 INSTITUTE OF TEXTILES & CLOTHING
THE HONG KONG POLYTECHNIC UNIVERSITY
HUNG HOM KLN HK
Attn: MISS VENUS LUO

Date: Jun 19, 2014

Submitted sample said to be :
Item Name : **10% CTS/ Cotton Fabric from Zhong Sheng**
Reference No. : SC02

Conclusion:
The submitted sample was tested under the following requirements requested by the applicant, subject to the information stated in the remark and attached page(s) for details :

Requirement	Result
(1) Antibacterial activity (AATCC-100)	See details enclosed

For and on behalf of :
Intertek Testing Services HK Ltd.

Angel Y.F. Cheung
Vice President

Page 1 of 2

Intertek Testing Services Hong Kong Ltd.
2/F., Garment Centre, 576 Castle Peak Road, Kowloon, Hong Kong
Tel: (852) 2173 8888 Fax: (852) 2786 1903 Website: www.intertek.com

Test Report Number: HKGH01657756

Tests Conducted

(1) Antibacterial Activity Test (Quantitative)

Test Method : *American Association of Textile Chemists and Colorists* (AATCC) Technical Manual, Test Method 100-2012.

Ultraviolet sterilization of sample before test.

Neutralizing solution:	Letheen Broth
Contact time:	24 hours
Incubation temperature:	37°C
Incubation period:	48 hours
Agar medium:	Nutrient agar
Test culture:	*Staphylococcus aureus* (ATCC 6538)
	Klebsiella pneumoniae (ATCC 4352)
No. of test specimen:	5 pieces / circular / @ 4.8 cm in diameter with 1 mL inoculum per trial

Result:

Test Microorganism	Percent Reduction of Bacteria (%)
Staphylococcus aureus	99.9
Klebsiella pneumoniae	90.5

Reference Rating*:	% Reduction	Anti-bacterial activity
	0%	Not acceptable
	<50%	Insignificant
	≥50%	Acceptable
	>95%	Acceptable & significant

Sample received condition: sample in closed plastic bag.

Date sample received : Jun 03, 2014
Testing period : Jun 04, 2014 to Jun 13, 2014

****

End of report

Intertek Testing Services Hong Kong Ltd.
2/F., Garment Centre, 576 Castle Peak Road, Kowloon, Hong Kong.
Tel: (852) 2173 8888 Fax: (852) 2786 1903 Website: www.intertek.com

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