A pilot intervention with chitosan/cotton knitted jersey fabric to provide comfort for epidermolysis bullosa patients

Ngan Yi Kitty Lam[a], Meng Zhang[b], Chenxiao Yang[c], Chu Po Ho[d] and Li Li[e]*

[a] *Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong*

[b] *Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong*

[c] *Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong*

[d] *Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong*

[e] *Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong*

*Corresponding author:
Li Li, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.
Email: li.lilly@polyu.edu.hk

Abstract

Epidermolysis bullosa (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 skin disease, patients suffer from the related physical and psychological pain during their lifetime. Therefore, it is important that skin-protective apparel with protective functions be 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 study investigated the fabric comfort properties of chitosan/cotton blend knitted jersey fabric in order to provide comprehensive knowledge to facilitate further medical textile development for EB patients. A proposed model determines the role of chitosan-based yarn in providing comfort to EB patients to determine scientifically the association between textile comfort and medical treatment, and establishes the relationship between percentage composition and comfort to facilitate further examination of medical textiles in both theoretical and practical aspects. The results show that increases in the concentration of chitosan (50% or above) in the blend ratio reduce the rigidity of the fabric and provide a softer handle for the inner surface of the fabric. The surface friction coefficient is reduced which means a smoother surface and the thermal maximum flux is also reduced, that intends a fabric with a cooler handle. It is concluded that fabric with a composition that incorporates chitosan fibers can provide better comfort, which in turn, facilitated the development of a skin-protective textile for EB patients, by the application of chitosan/cotton blend knitted jersey fabric.

Keywords
epidermolysis bullosa, chitosan/cotton yarn, skin comfort, wound healing

Epidermolysis bullosa (EB) is a rare hereditary skin disease that causes skin fragility and blistering (Figure 1). This skin disorder usually occurs at birth or soon afterwards. Due to the visibility of the symptoms of EB, patients not only suffer from physical pain but also psychological burden.[1–4] As for newborn infants with EB, it is difficult to reduce their body movement and prevent injuries; thus, the burden of care lies with their family and medical personnel. Since there is currently no available medical technology that can cure this ailment, patients suffer from the related physical and psychological pain during their lifetime.[5,6] Horn and Tidman reported that some patients with EB will experience some improvement as they become older, although many patients still continue suffer from the pain and inconvenience of EB.[7,8] The prevention of injury is a life issue.[9,10] There are large amounts of bandages covering the body surface of EB patients, which will cause body overheating.[11–13] Moreover, their body temperature increases if blister might form to secondary trauma. Therefore, it is important to determine and develop the skin protective functions of apparel for patients with EB that will help to reduce their chances of injury. Wound care is the most challenging task because changes of dressing are the most painful experience that EB patients have to face on a daily basis.

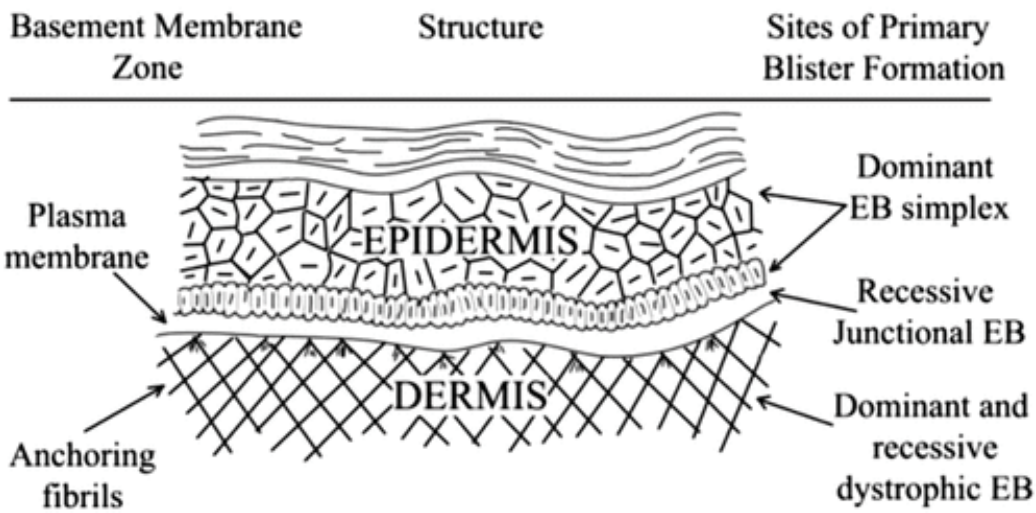

Figure 1. Skin structure diagram of EB.

Chitosan is a well-known medical fiber, which is retrieved from the shells of crustaceans, with excellent biocompatibility, biodegradability, non-toxicity, and adsorption properties.[14] It has been widely used in wound healing products through the use of nonwoven fabrication technologies.[15] However, there are some limitations with these dressings. The majority of the dressings cannot be used independently and the assistance of secondary bandages is required. Some of the dressings require frequent changes. Also, some dressings will become adhesive if they dry out. This behavior adds difficulty when removing the dressing and causes friction that increases the risk of trauma. Furthermore, the dressing may hinder the immediate curing of the wound. Therefore, this study focuses on how the “second skin” clothing and skin interact with each other to serve the wound healing functions for patients with EB that helps to reduce the chance of injury.

Chitosan is commonly seen in nonwoven wound dressing due to some limitations of further production for chitosan fibers, such as high electrostatic and poor mechanical properties. With reference to some of the previous research and preliminary experiments conducted by our research team, through the modification of chitosan spinning technology to solve the spinning problem caused by yarn spinning of a high percentage of chitosan fibers.[16]Besides, chitosan based yarn fabric is proven to have positive advantages over traditional medical gauze, especially during the first stage of healing, and there is a linear relationship between the percentage composition of chitosan and performance.[17] Undoubtedly, there are more benefits of chitosan-based yarn fabric than nonwoven fabric in terms of the structure and capacity of the layered system, sustainability, and potential comfort.

The aim of this study was to investigate the fabric comfort properties of chitosan/cotton blend knitted jersey fabric in order to provide comprehensive knowledge to facilitate further medical textile development for EB patients. Besides, a model that determines the role of chitosan based yarn in providing comfort to EB patients, so as to determine scientifically the association between textile comfort and medical treatment is proposed, 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. The chitosan materials in this study are selected based on previous trials that were carried out to explore the further application of chitosan fibers, which involved textile equipment modifications, spinning analysis, antimicrobial testing, and cell and animal testing. There is strong evidence that shows that our chitosan fabric can heal wounds at a faster rate and better in terms of the wound area, compared with the cotton fabric from the beginning through day 10. The experimental work also demonstrated differences in healing efficacy in the wound area with our experimentally developed chitosan fabric within first three days compared with commercially available chitosan fabrics.

Materials and methods

In this study, 20 Ne chitosan/cotton yarns were spun at five different blend ratios; 14 gauge plain jersey fabrics were then knitted with a computerized flat knitting machine. Afterwards, the comfort properties of the plain jersey fabric made from the chitosan/cotton blended yarn were examined with a fabric touch tester (FTT). The FTT is used to measure the physical properties of touch, including softness, thermal conductivity, and smoothness.

Materials

Cotton fibers with an upper half mean length (UHML) of 38 mm and chitosan fibers with a length of 38 mm were used. The cotton was pre-dyed with a navy blue color before the fibers were blended. Five yarn samples of 20 Ne (4 kg of each sample) with the same blend were produced at different blend ratios. The five samples comprised 30:70, 50:50, 70:30 of chitosan/cotton as well as 100% cotton and 100% chitosan, which were prepared by using a cotton ring spinning system at a traditional spinning mill with standard spinning procedures (Figure 2).[16] The fiber specifications are given in Table 1. Fourteen gauge plain jersey fabrics (2-ply yarn inserted) (Figure 2) were produced from these yarn samples with a dimension of 60 cm × 50 cm on a Stoll CMS 822 computerized flat knitting machine; the fabric density was 26.1–36.7 WPI × CPI.

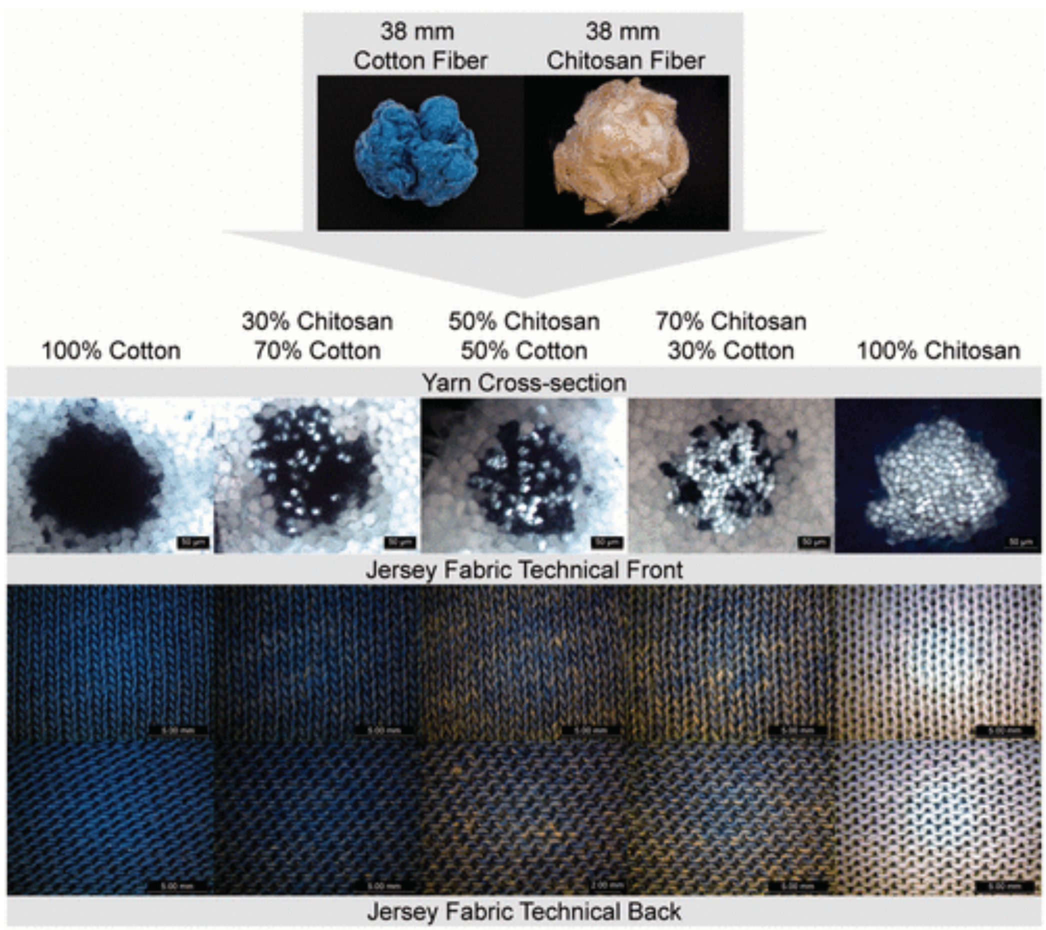

Figure 2. Yarn samples were made of 38 mm cotton fiber and 38 mm chitosan fiber. Cross-section of chitosan/cotton blend yarn samples and microscopy image of 14 gauge plain jersey fabric of chitosan/cotton yarn sample with five different blend ratios.

	Chitosan	Cotton
Fiber mean length (mm) [CV%]	38 [6]	38.04 [2.94][1]
Fiber fineness (denier) [CV%]	1.81 [14]	1.6, 3.96 (micronaire) [3.79]
Fiber strength (cN/tex) [CV%]	15.49 [29.45]	46.09 [3.62]
Fiber elongation (%) [CV%]	16.27 [46.06]	7.72 [33.25]
Modulus (%) [CV%]	521.24 [27.33]	344.22 [26.16]
Uniformity index (%)	–	87.0 [1.38]
Short fiber index	–	6.0 [8.33]

Table 1. Fiber specifications of chitosan and cotton fibers used in chitosan/cotton blend yarn

Methods

A series of yarn assessments was conducted.[16] The properties of the yarns are given in Table 2. Fourteen gauge knitted jersey fabrics samples of five different yarns were produced to test their physical properties for comfort. The yarn twist, linear density, diameter, yarn strength and elongation, evenness and hairiness, and yarn bending rigidity of all of the yarn samples were investigated.

Yarn property	CS/CO, 0:100%	CS/CO, 30:70%	CS/CO, 50:50%	CS/CO, 70:30%	CS/CO, 100:0%
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]
Hairiness (S3) [CV%]	572 [9.18]	878 [3.15]	863 [5.90]	713 [5.27]	672 [7.59]
Bending rigidity ($\times 10^{-4}$ 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 2. Properties of chitosan/cotton blended yarn

The electrostatic properties of the plain jersey fabric made from each yarn sample were tested on a YG402 fabrics friction-type electrostatic measuring instrument in accordance with Chinese Standard GB/T12703.5-2010. Four specimens of each jersey fabric (made by each blend) with dimensions of 4×8 cm^2 were directly cut from the plain jersey fabric. The technical front side of the knitted fabrics was rubbed on 100% nylon for 30 s, at the rotation speed of 400 r/min with the load weight of 500 g.

For each type of fabric, four different physical properties were measured by using a FTT.[18]The physical properties included bending, compression, thermal conductivity, surface friction, and roughness (see Figure 3(c)).

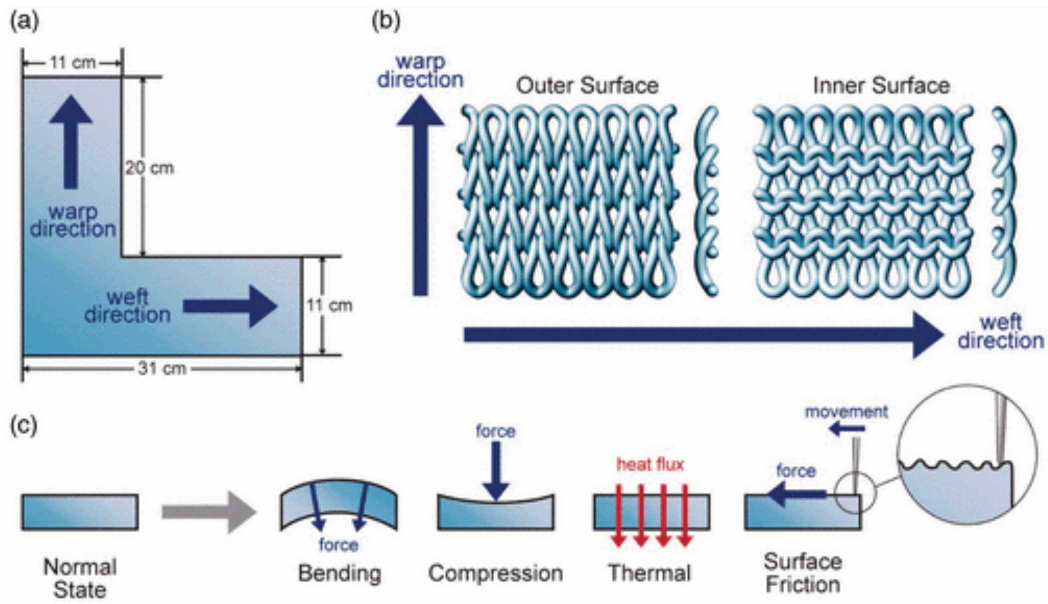

Figure 3. (a) Dimension and direction of fabric sample that is cut into L shape (vertical is warp direction and horizontal is weft direction). (b) Knit fabric structure of outer (knit stitch) and inner (purl stitch) surfaces. (c) Four different physical properties measured in each type of fabric.

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 center region of the plot. BW was calculated as an integral of the curve.

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 center region of the plot. These two indices used to present the changing rate of force during compression and recovery.

In the thermal module, three indices, including thermal conductivity when compressed (TCC), thermal conductivity during recovery (TCR), and thermal maximum flux (Q_{max}), were measured and the heat flux through fabrics recorded during the compression process. They were used to define the thermal properties by plotting the heat flux versus thickness and to provide a reference for the coolness of a fabric.

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 3.

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°C)
Thermal conductivity during recovery	TCR	W/(m°C)
Thermal maximum flux	Q_{max}	W/(m^2)
Surface friction coefficient	SFC	–
Surface roughness amplitude	SRA	µm
Surface roughness wavelength	SRW	mm

Table 3. Indices of physical properties defined by fabric touch tester (FTT)

Before the testing, the samples were cut into an "L" shape with specific dimensions and directions (Figure 3(a)). 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 3(b)) was tested. Five specimens of each blend were cut from each jersey fabric sample. All specimens were conditioned in standard atmosphere for 24 h before the testing.

Results and discussion

A theoretical model is proposed for determining the association between the function of chitosan-based textile and medical treatment, 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 (Figure 4).[16] The model shows how the features of materials and properties which directly affect the relationship of comfort and medical treatment for EB patients during their lifetime.

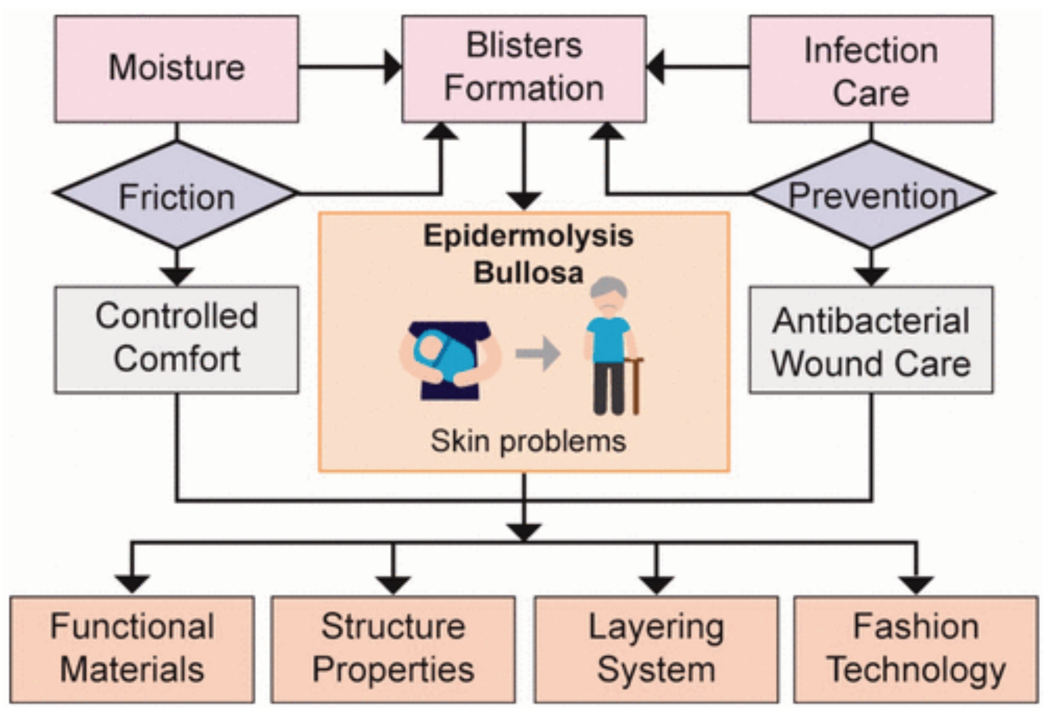

Figure 4. The association between the function of chitosan-based textile and medical treatment.

Textile touch/feel is a critical factor that influences the comfort of clothing to EB patients in term of smoothness, softness and stiffness. In this study, jersey fabrics are fabricated by using different ratios of chitosan/cotton blended yarns (0%, 30%, 50%, 70%, and 100%), in which the physical properties such as blend, compression, thermal conductivity and surface roughness have been measured and analyzed to determine the comfort of the investigated cotton/chitosan fabrics. The properties of jersey fabric are given in Table 4.

Fabric property	CS/CO, 0:100%		CS/CO, 30:70%		CS/CO, 50:50%		CS/CO, 70:30%		CS/CO, 100:0%	
Weight (g/m^2)	299.44		263.14		229.76		209.58		203.74	
Stitch density (WPI × 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]
Q_{max} [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]

Table 4. Properties of jersey fabric made from chitosan/cotton blended yarn

A one-way analysis of variance (ANOVA) at the 95% confidence limit (level of significance $\alpha_{0.05}$) and Pearson correlation were carried out by using SPSS Statistics 22 software to analyze the influence and the correlation coefficient 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 (Table 5). The correlation coefficient between samples with different blend ratios and fabric properties was listed in Table 6.

Source of variance	Sum of squares	df	Mean square	F	*p* value
Different blend ratios-BARa	458,376.526	4	114,594.131	46.338	0.000
Different blend ratios-BARe	511,745.049	4	127,936.262	16.542	0.000
Different blend ratios-BWa	4,333,016.634	4	1,083,254.158	52.508	0.000
Different blend ratios-BWe	2,658,110.808	4	664,527.702	20.411	0.000
Different blend ratios-T	3.902	4	0.976	43.223	0.000
Different blend ratios-CW	24,360,869.32	4	6,090,217.329	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-Q_{max}	487,667.961	4	121,916.990	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

Table 5. One-way ANOVA carried out between samples with different blend ratios and fabric properties

		Chitosan blend ratio
BARa	Pearson correlation	−.815**
	Sig. (2-tailed)	.000
BARe	Pearson correlation	−.651**
	Sig. (2-tailed)	.000
BWa	Pearson correlation	−.849**
	Sig. (2-tailed)	.000
BWe	Pearson correlation	−.723**
	Sig. (2-tailed)	.000
T	Pearson correlation	−.800**
	Sig. (2-tailed)	.000
CW	Pearson correlation	−.833**
	Sig. (2-tailed)	.000
CRR	Pearson correlation	.637**
	Sig. (2-tailed)	.000
CAR	Pearson correlation	.817**
	Sig. (2-tailed)	.000
RAR	Pearson correlation	.843**
	Sig. (2-tailed)	.000
TCC	Pearson correlation	−.109
	Sig. (2-tailed)	.449
TCR	Pearson correlation	−.288*
	Sig. (2-tailed)	.043
Q_{max}	Pearson correlation	−.713**
	Sig. (2-tailed)	.000
SFCa	Pearson correlation	−.370**
	Sig. (2-tailed)	.008
SFCe	Pearson correlation	−.679**
	Sig. (2-tailed)	.000
SRAa	Pearson correlation	.469**
	Sig. (2-tailed)	.001
SRAe	Pearson correlation	−.320*
	Sig. (2-tailed)	.030
SRWa	Pearson correlation	−.352*
	Sig. (2-tailed)	.048
SRWe	Pearson correlation	−.122
	Sig. (2-tailed)	.398

Table 6. Correlation carried out between samples with different blend ratios and fabric properties

Bending

As a reaction force from fabric deformation, bending reflects the stiffness of a fabric, which is also received by the human skin as a stimulus. The bending properties determine the handling performance of fabrics.[19–21] 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 5 and Table 4.

There were strong negative correlations between BAR and chitosan blend ratio (BARa, $r = -.815$, $p < 0.01$; BARe, $r = -.651$, $p < 0.01$), and BW and chitosan blend ratio (BWa, $r = -.849$, $p < 0.01$; BWe, $r = -.723$, $p < 0.01$) (Table 6). The BAR and BW significantly decrease when the chitosan blend ratio is increased from 0% to 50% (Figure 5(a) and (b)). However, the BAR and BW have negligible variations when pure chitosan fabrics are examined. This result indicates that compared with 100% cotton, pure chitosan, and cotton/chitosan blended fabrics have a 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 5(c)). This phenomenon is explained by young's modulus of cotton and chitosan fibers and bending rigidity of blended yarn samples.[22,23]

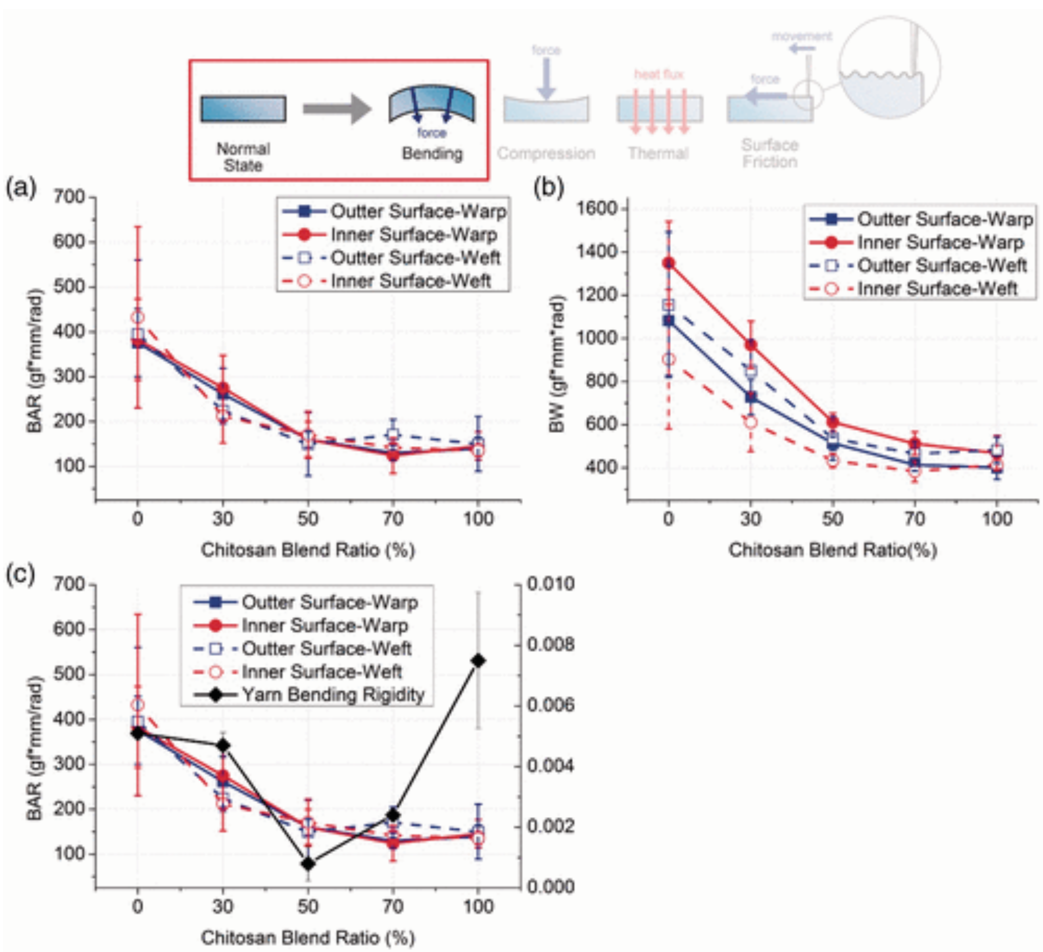

Figure 5. Bending properties of jersey fabric samples: warp and weft directions of (a) bending average rigidity (BAR) and (b) bending work (BW). (c) BAR and bending rigidity of chitosan/cotton blended yarn.

The concentration of chitosan is increased from 0% to 70%, this phenomenon might be attributed to the fact that the chitosan fibers have a higher modulus than that of the cotton fibers. 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. Taking all of the factors into consideration, 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 2). This might be resultant of the high stickiness of chitosan material.

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.[18] Thus, fabric compression values indicate the handle and comfort of a fabric.[24–26] There were strong negative correlation between CW and chitosan blend ratio, $r = -.833$, $p < 0.01$; T and chitosan blend ratio, $r = -.800$, $p < 0.01$. Moreover, there were strong positive correlation between CRR and chitosan blend ratio, $r = .637$, $p < 0.01$; CAR and chitosan blend ratio, r = .817, $p < 0.01$; RAR and chitosan blend ratio, $r = .843$, p < 0.01 (Table 6). The thickness of the fabrics in this study has negligible variations as the blend ratio is increased (Figure 6(a)). The CW decreases due to increases in the chitosan blend ratio from 0% to 100% (Figure 6(b)). The CRR, CAR, and RAR of the fabrics increased 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 (Figure 6(c) and (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(e)), which is due to the compacted structure of the pure chitosan yarn.

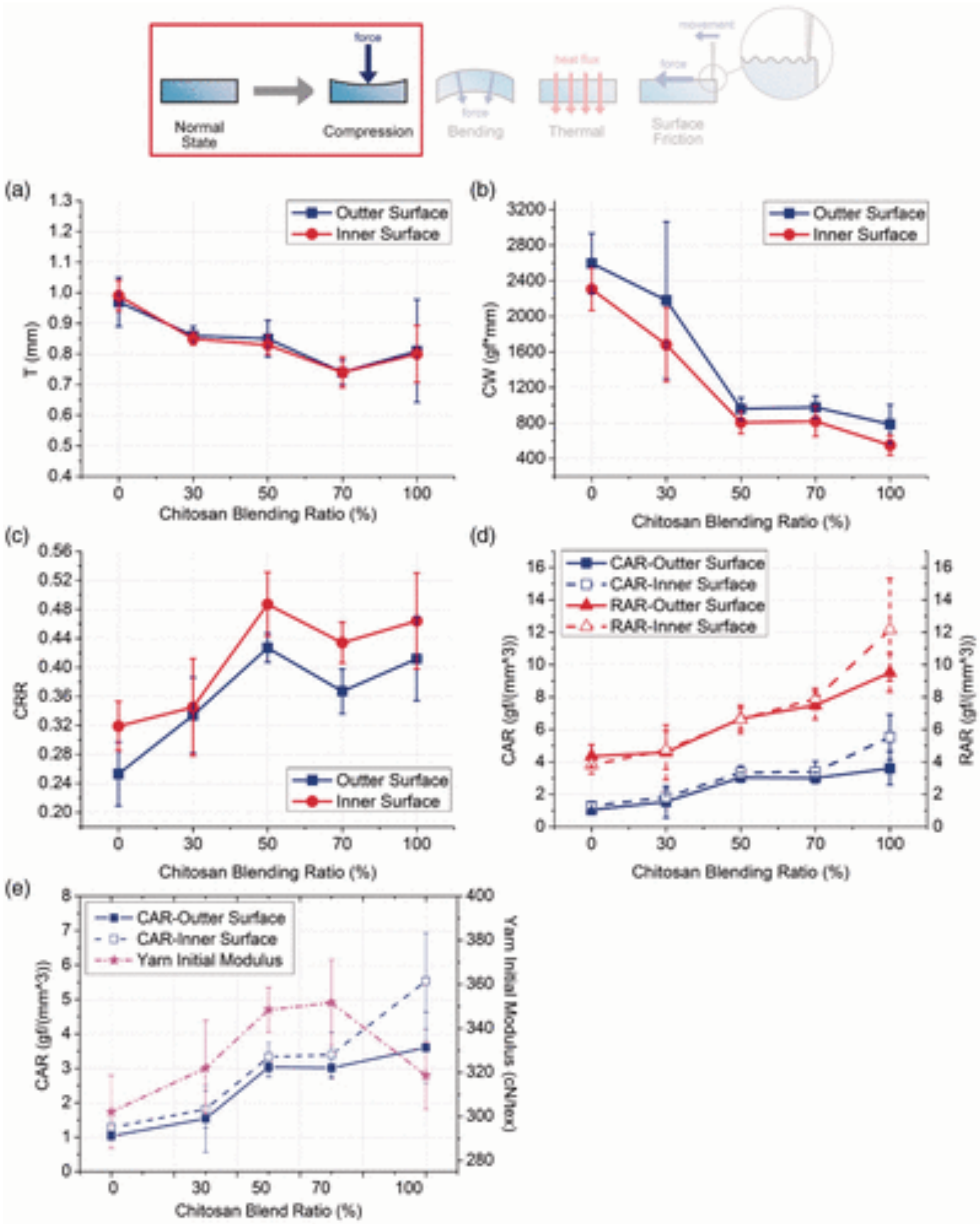

Figure 6. Compression properties of jersey fabric samples: (a) thickness; (b) CW; (c) CRR; (d) CAR and RAR. (e) CAR and yarn initial modulus of chitosan/cotton blended yarn.

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.[27–29] There was weak negative correlation between TCR and chitosan blend ratio, $r = -.288$, $p < 0.05$. However, There was a strong negative correlation between Q_{max} and chitosan blend ratio, $r = -.713$, $p < 0.01$

(Table 6). 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 7(a)). 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 Q_{max} is rapidly increased from 100% cotton (0% chitosan) to a 50% blend ratio of chitosan (Figure 7(b)). 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.

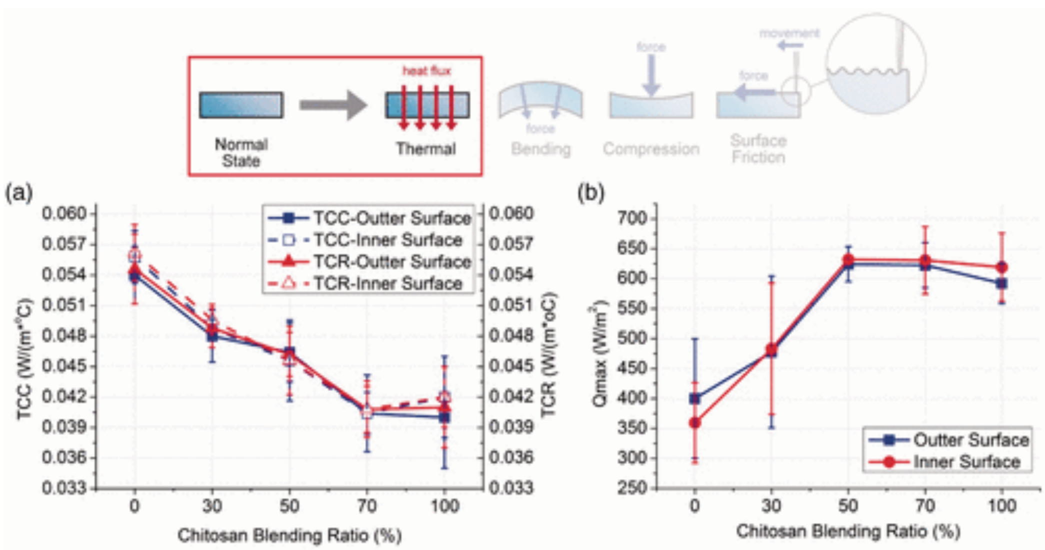

Figure 7. Thermal properties of jersey fabric samples: (a) TCC and TCR; (b) Q_{max}.

Surface friction and roughness

The surface friction and roughness are two critical factors that indicate the surface smoothness.[30–32] 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. There was a strong negative correlation between SFCe and chitosan blend ratio, $r = -.679$, $p < 0.01$. Meanwhile, there were moderate negative correlation between SFCa and chitosan blend ratio, $r = -.370$, $p < 0.01$; SRAe and chitosan blend ratio, $r = -.320$, $p < 0.05$; SRWa and chitosan blend ratio, $r = -.352$, $p < 0.05$. However, there was a moderate positive correlation between SRAa and chitosan blend ratio, $r = .469$, $p < 0.01$ (Table 6). In Figure 8, fabric samples with 30:70 chitosan/cotton and 50:50 chitosan/cotton show similar tendency of surface friction; the inner surface of weft direction has the highest value, followed by the outer surface of weft direction and the outer surface of warp direction. Besides, except for the 100% chitosan fabric sample, other samples recorded the least value of the inner surface of warp direction, follow with the outer surface of warp direction.

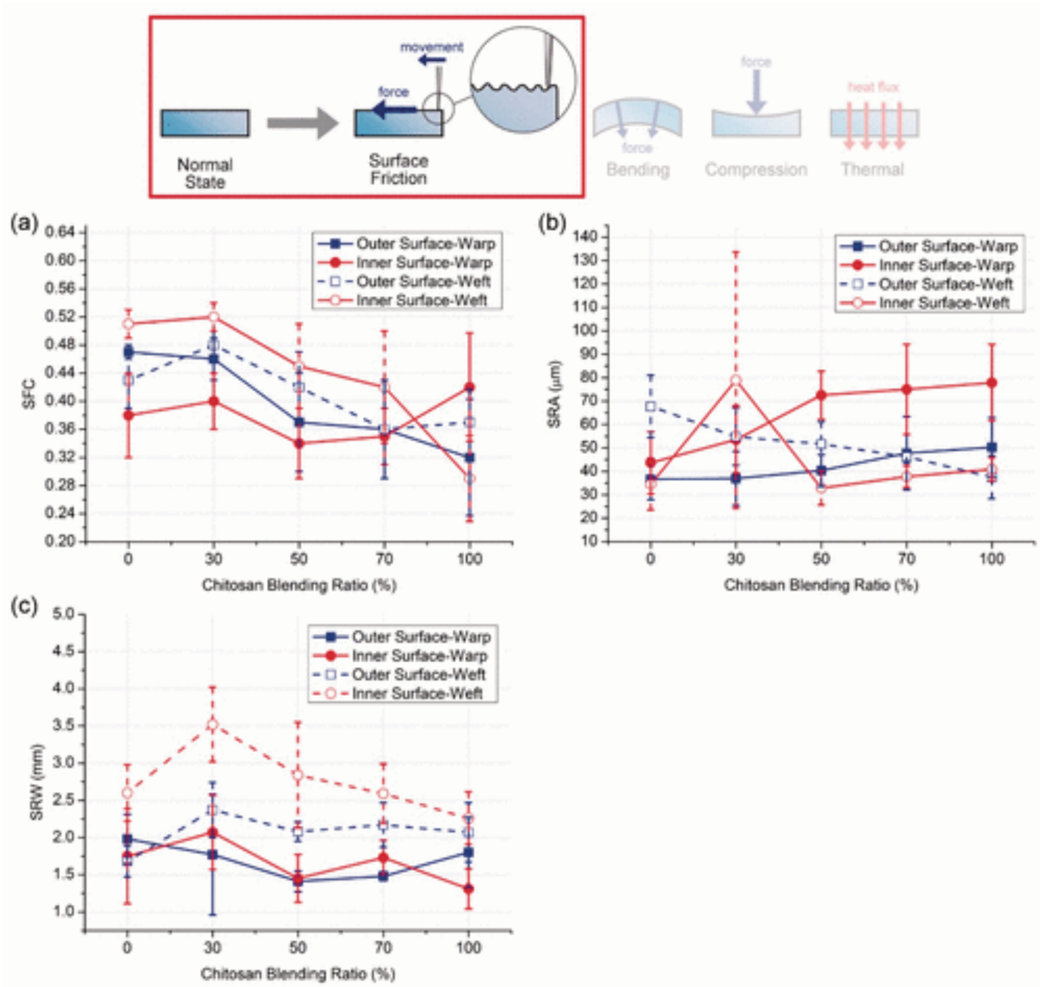

Figure 8. Surface friction and roughness properties of jersey fabric samples: (a) SFC; (b) SRA; and (c) SRW measured in warp and weft directions.

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 five categories of physical properties (BW, CW, TCC, Q_{max}, 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 benchmark 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 are presented as a ratio in comparison to 100% cotton (Figure 9).

For Figure 10, in order to have a direct comparison of three fabric samples on both surfaces, the 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.

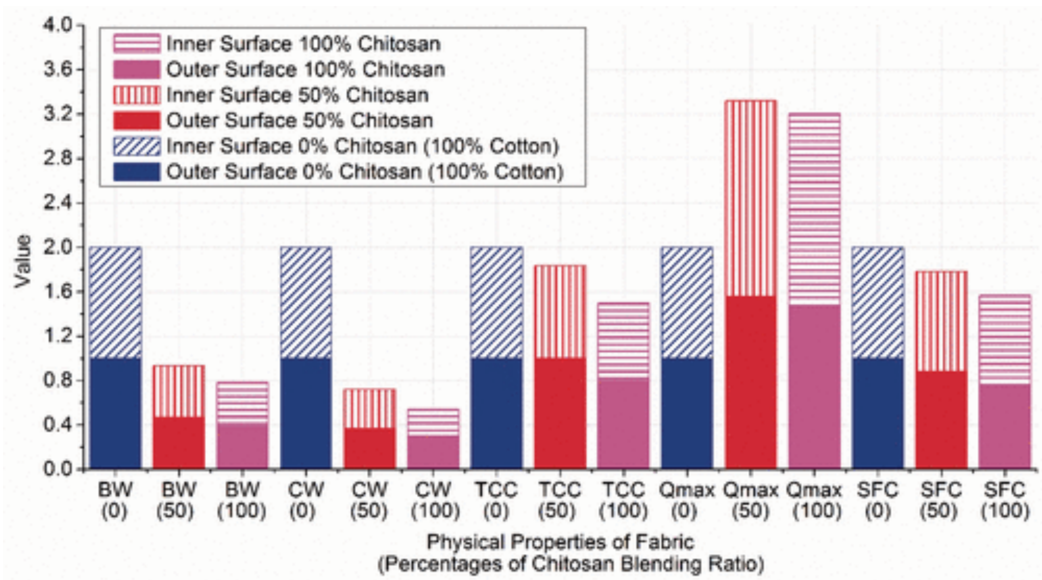

Figure 9. Overall evaluation of physical properties (BW: bending work; CW: compression work; TCC: thermal conductivity when compressed; Q_{max}: thermal maximum flux; and SFC: surface friction coefficient) of 0:100, 50:50, and 100:0 chitosan/cotton jersey fabrics.

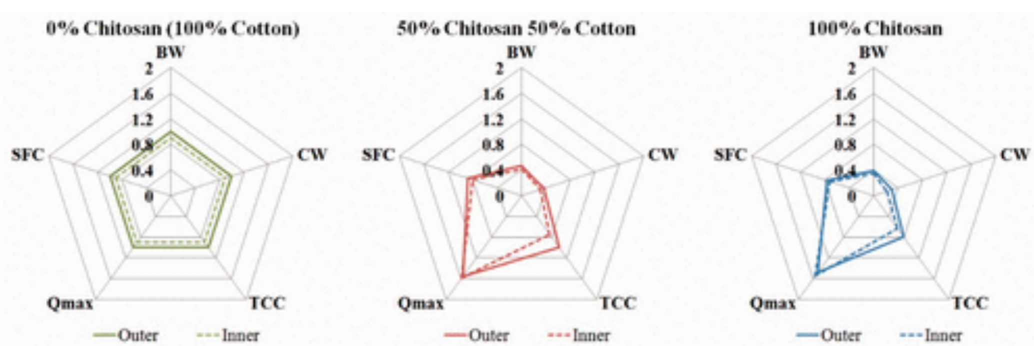

Figure 10. Physical properties of 0:100, 50:50, and 100:0 chitosan/cotton jersey fabrics (BW: bending work; CW: compression work; TCC: thermal conductivity when compressed; Q_{max}: thermal maximum flux; and SFC: surface friction coefficient)

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. Furthermore, these blends and pure chitosan samples seem to have optimal thermal properties. The reduction in the thermal conductivity implies better warmth while the Q_{max} 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 the fabric will help to improve the fabric smoothness (Figure 10). Overall, compared with the pure cotton fabric samples, it is very likely that fabrics can be optimized by adding chitosan as a component in the fabric, which would improve the comfort properties for EB patients due to the outstanding performance in softness, smoothness, and thermal conductivity.

Conclusion

A model has been proposed that determines the association between textile comfort and medical treatment, and to establish the relationship between percentage composition of chitosan and comfort, which could facilitate further examination of medical textiles in both theoretical and practical aspects. 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 the composition of chitosan fibers added to fabric has a good impact on the 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 and SFC of the fabric are reduced, which provides a softer handle and a smoother surface. 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 Q_{max} value, and the fabric would be perceived as being cooler when it is in contact with human skin. It is suggested to apply higher blend ratio of chitosan to the fabric so as to offer cooler surface in order to lower the high body temperature of EB patients, which could contribute to reducing 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 a skin-protective function for EB patients to reduce the friction between clothing and their skin. This could contribute to reducing the physical and psychological pain of EB patients that they suffer during their lifetime by offering the medical textile composited with chitosan. Products that applied with this chitosan-based yarn will have great potential for future applications that require a good hand feel, wound healing, and antibacterial property.

Acknowledgement

We would like to thank Taiwan Epidermolysis Bullosa Association for contributing to this study.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: We would like to acknowledge funding support from RGC General Research Fund PolyU 5420/13H.

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